



Faculty of Cognitive Sciences and Human Development

**Mobile Game-Based Learning Application Integrating Playability to
Address Challenges in Learning Cell Division Among Secondary School
Biology Students**

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Mobile Game-Based Learning Application Integrating Playability to Address
Challenges in Learning Cell Division Among Secondary School Biology
Students

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

A handwritten signature in blue ink, consisting of stylized cursive letters, positioned above a dotted line.

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ABSTRACT

STEM education is a key agenda for transforming the education system to produce students equipped with 21st-century skills to tackle the challenges of the modern world. Among STEM subjects, Biology is recognized as one of the most challenging to learn and teach. Within Biology, Cell Division is considered one of the most difficult topics, according to previous studies. Therefore, it is essential to develop innovations that help students to overcome the difficulties of learning Cell Division and enhance their learning process. Given the widespread ownership of mobile phones among students and the flexibility of mobile learning, mobile game-based learning (mGBL) presents a promising solution to address these challenges. In this study, a design-based research (DBR) approach was adopted, which consisted of two main phases. The first phase was a preliminary study to diagnose learning difficulties and identify design requirements, and the second phase involved the design, development, and testing of an mGBL application in collaboration with Biology teachers. A preliminary study was conducted, involving online interviews with three Biology teachers and self-administered questionnaires with thirty-one Form 4 students, to identify the challenges in learning Cell Division topic from both students' and teachers' views. The results revealed that students struggled with the topic due to cognitive, motivational, affective, social, and other challenges. Cognitive challenges were the most dominant, with students having difficulty memorizing content, distinguishing between similar terms, and understanding abstract concepts. The preliminary study also identified strategies suggested by both students and teachers to improve learning, including the use of games, visual aids, memory tools, and collaborative learning methods. Based on the findings from the preliminary study, an online mGBL application called Cell% was developed using the Flow Framework for Educational Games as the design framework and the mGBL Engineering

Model as the development methodology. After development, Cell% was implemented in Biology classes for approximately two weeks to assist teachers in teaching Cell Division. Data collection involved questionnaires with three Biology teachers and forty-two Form 4 students to evaluate the playability of Cell% and its effectiveness in addressing the learning challenges identified in the preliminary study. The findings showed that Cell% had high playability and effectively addressed all learning challenges, with overall ratings ranging from 3.67 to 4.45 out of 5, especially in cognitive and affective aspects. However, its effectiveness in addressing social challenges was lower, indicating room for improvement in enhancing Cell% in this area. Additionally, feedback from students and teachers revealed general satisfaction with Cell%, though some suggested technical improvements, particularly in bug fixes, gameplay enhancements, and additional features. This study exemplifies the use of multi-perspective, problem-based game design in game-based learning, introducing a novel approach in game-based learning studies for Cell Division learning.

Keywords: Mobile game-based learning, game-based learning, cell division, biology

Aplikasi Pembelajaran Berasaskan Permainan Mudah Alih dengan Integrasi Kebolehmmainan bagi Menangani Cabaran dalam Pembelajaran Pembahagian Sel dalam Kalangan Pelajar Biologi Sekolah Menengah

ABSTRAK

Pendidikan STEM adalah agenda utama untuk mentransformasi sistem pendidikan bagi melahirkan pelajar yang dilengkapi dengan kemahiran abad ke-21 untuk menghadapi cabaran dunia moden. Antara subjek STEM, Biologi diiktiraf sebagai salah satu subjek yang paling mencabar untuk dipelajari dan diajar. Dalam Biologi, topik Pembahagian Sel dianggap sebagai salah satu topik paling sukar, menurut kajian terdahulu. Oleh itu, adalah penting untuk membangunkan inovasi yang membantu pelajar mengatasi kesukaran dalam mempelajari topik Pembahagian Sel dan meningkatkan proses pembelajaran mereka. Memandangkan penggunaan telefon bimbit yang meluas dalam kalangan pelajar dan fleksibiliti pembelajaran mudah alih, pembelajaran berasaskan permainan mudah alih (mGBL) dilihat sebagai penyelesaian yang menjanjikan untuk menangani cabaran-cabaran ini. Kajian ini menggunakan pendekatan reka bentuk berasaskan penyelidikan (DBR) yang merangkumi dua fasa utama, iaitu kajian awal untuk mendiagnosis kesukaran pembelajaran dan mengenal pasti keperluan reka bentuk, serta fasa reka bentuk, pembangunan dan pengujian aplikasi mGBL bersama guru Biologi. Kajian awal telah dijalankan, melibatkan temu bual dalam talian dengan tiga orang guru Biologi dan soal selidik yang diisi sendiri oleh tiga puluh satu orang pelajar Tingkatan 4, untuk mengenal pasti cabaran dalam pembelajaran topik Pembahagian Sel dari sudut pandang pelajar dan guru. Hasil kajian menunjukkan bahawa pelajar menghadapi kesukaran dengan topik ini disebabkan oleh cabaran kognitif, motivasi, afektif, sosial, dan lain-lain. Cabaran kognitif adalah yang paling dominan, di mana pelajar menghadapi kesukaran untuk menghafal kandungan, memahami konsep abstrak, dan membezakan istilah yang serupa. Kajian awal juga

mengenal pasti strategi-strategi yang dicadangkan oleh pelajar dan guru untuk memperbaiki pembelajaran, termasuk penggunaan permainan, bahan pembelajaran visual, alat bantu ingatan, dan kaedah pembelajaran kolaboratif. Berdasarkan penemuan daripada kajian awal, sebuah aplikasi mGBL dalam talian yang dinamakan Cell% telah dibangunkan dengan menggunakan Rangka Kerja Aliran untuk Permainan Pendidikan sebagai kerangka reka bentuk dan Model Kejuruteraan mGBL sebagai metodologi pembangunan. Selepas pembangunan, Cell% telah dilaksanakan dalam kelas Biologi selama lebih kurang dua minggu untuk membantu guru mengajar topik Pembahagian Sel. Pengumpulan data melibatkan soal selidik dengan tiga guru Biologi dan empat puluh dua orang pelajar Tingkatan 4 untuk menilai kebolehmainan Cell% dan keberkesanannya dalam menangani cabaran pembelajaran yang dikenal pasti dalam kajian awal. Hasil kajian menunjukkan bahawa Cell% mempunyai kebolehmainan yang tinggi dan berjaya menangani semua cabaran pembelajaran, dengan penilaian keseluruhan antara 3.67 hingga 4.45 daripada 5, terutamanya dalam aspek kognitif dan afektif. Walau bagaimanapun, keberkesanannya dalam menangani cabaran sosial adalah lebih rendah, menunjukkan terdapat ruang untuk penambahbaikan dalam aspek sosial aplikasi ini. Di samping itu, maklum balas daripada pelajar dan guru mendedahkan kepuasan umum terhadap Cell%, namun ada yang mencadangkan penambahbaikan teknikal, terutamanya dalam membetulkan pepijat, penambahbaikan permainan, dan ciri-ciri tambahan. Kajian ini menggambarkan penggunaan reka bentuk permainan berasaskan masalah dan pelbagai perspektif dalam pembelajaran berasaskan permainan, yang memperkenalkan pendekatan baru dalam kajian pembelajaran berasaskan permainan berkaitan pembelajaran Pembahagian Sel.

Kata kunci: *Pembelajaran berasaskan permainan mudah alih, pembelajaran berasaskan permainan, pembahagian sel, biologi*

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LIST OF ABBREVIATIONS

CLT	Cognitive Load Theory
CTML	Cognitive Theory of Multimedia Learning
GBL	Game-Based Learning
ICT	Information and Communications Technology
mGBL	Mobile Game-Based Learning
MOE	Ministry of Education
PBL	Problem-Based Learning
RPG	Role-Playing Game
STEM	Science, Technology, Engineering, and Mathematics

CHAPTER 1

INTRODUCTION

1.1 Study Background

1.1.1 21st Century Learning

Today, we live in a digital era, where everything is increasingly digitalized due to the rapid development of information and communication technology. However, many graduates still lack essential digital skills needed in the workplace (Tee et al., 2024), leading to a shortage of qualified workers (Rahmat et al., 2022). As technology transforms traditional roles, jobs are becoming more complex (Tsiligiris & Bowyer, 2021), and the skills required to thrive in the 21st century are constantly evolving (Nursetyo et al., 2024). In today's 21st century educational era, the education system must be flexible and responsive to current needs and changes (Mohamad & Mustapha, 2022). Therefore, our education system should promote 21st century teaching and learning to equip learners with the skills needed to face future challenges.

21st century learning is a student-centred approach that aims to develop essential skills known as the 4Cs, such as critical thinking and problem-solving, communication, collaboration, and creativity and innovation (Wulandari, 2021). Equipping students with these 21st century skills is crucial to help them succeed as global citizens (Tran, 2023) and remain competitive in the future (Chun & Abdullah, 2022). Therefore, fostering students' 21st century skills was one of the main objectives of the education transformation (Indah & Rohmah, 2020).

Students born in the 21st century are digital natives familiar with technology (Ahmad et al., 2020). Accordingly, 21st century education emphasizes technology's role in fostering essential skills (Mohamad et al., 2023). For instance, Chen and Swan (2020) found that tech-supported teaching enhances active learning, critical thinking, collaboration, and engagement, while Azhar et al. (2020) highlighted Frog VLE's support for self-directed, student-centred learning. As traditional models struggle to meet modern demands, technology continues to drive innovation in education (Breech, 2022), making it essential for educators to keep pace with rapid technological advancements.

Realizing the importance of learning in the 21st century learning, the Ministry of Education (MOE) launched the Malaysia Education Blueprint 2015 to 2025 (MEB) to ensure our education system is up-to-date and to produce students with skills that can meet the challenges of the 21st century, such as communication skills, critical thinking, and collaboration or Higher Order Thinking Skills (HOTS) (Ismail et al., 2018). To achieve this objective, MOE introduced several transformations in the education system in Malaysia, including efforts to strengthen Science, Technology, Engineering, and Mathematics (STEM) in schools (Idris et al., 2023). This focus stems from the fact that STEM has long been a key driver of job opportunities (Black et al., 2021), many high school and university students still struggle to achieve proficiency in the field (Lavi et al., 2021).

1.1.2 STEM

STEM refers to science-related fields including technology, engineering, and mathematics (Bell, 2016). STEM education is essential for developing STEM-literate citizens who can solve real-world problems (Storksdieck, 2016).

In Malaysia, STEM is seen as vital for national development and economic growth (Aspin et al., 2022). To address this, the Malaysian Higher Education Planning Committee introduced the 60:40 policy in 1967, aiming for 60% of upper secondary students in science and 40% in arts (Saleh, 2014). However, this target has never been achieved (Ismail et al., 2019). In the recent year of 2024, only 50.8% of upper secondary students enrolled in STEM subjects, which still has not met the 60% goal set over fifty years ago (Azahar, 2024). Juhari and colleagues (2020) also reported a decline in students' interest in STEM, while Idris and colleagues (2023) noted persistently inconsistent enrolment that continues to fall short of targeted goals.

This trend raises concerns about the future STEM workforce. For example, Malaysia needed 500,000 engineers and scientists by 2020 but had only 70,000 registered engineers, which is just 17% of the target (Vijaindren, 2018). From 2010 to 2021, fewer graduates entered STEM fields than other sectors (Khazanah Research Institute, 2024). Multiple factors contribute to the shortfall, including low student motivation, limited interest in STEM, instructional challenges due to insufficient resources and language shifts (Azahar, 2024), as well as gaps between rural and city areas, teacher competency gaps, inadequate STEM understanding, insufficient facilities, and negative attitudes or weak foundations among educators (Idris et al., 2023)

Given these concerns, Malaysia must take steps to strengthen and improve STEM education. If these problems are not addressed, they could hinder the nation's progress in science and technology. Therefore, effective and innovative strategies are needed to enhance STEM education and help Malaysia remain competitive in the global landscape (Juhari et al., 2020).

1.1.3 Biology

Biology is one of the most challenging subjects to learn and teach among the STEM disciplines. According to Rozaidi and Ismail (2018), Biology is a science subject that focuses on life and living organisms in nature. It is a key requirement for admission into professional courses such as medicine, pharmacy, nursing, and various life science fields, including biotechnology, genetics, and ecology (Salleh et al., 2021).

However, various studies have reported that students face difficulties in learning Biology. These challenges are largely due to the subject's abstract nature (Cimer, 2012; Ozcan et al., 2014), complex terminology (Cimer, 2012; Ozcan et al., 2014), and heavy reliance on memorization (Cimer, 2012; Ozcan et al., 2014; Hadiprayitno, 2019). Additional factors include traditional teacher-centred instructional methods (Cimer, 2012; Etobro & Fabinu, 2017; Hadiprayitno, 2019), poor student study habits (Agboghroma & Oyovwi, 2015; Cimer, 2012; Etobro & Fabinu, 2017), and limited educational resources (Agboghroma & Oyovwi, 2015; Cimer, 2012; Etobro & Fabinu, 2017; Hadiprayitno, 2019). Salleh and colleagues (2021) also conducted a study on the challenges of learning Biology in the Malaysian context and reported similar findings, such as the concepts are too abstract, difficult to understand, and involve numerous complex terms that are hard to explain. Across these studies, one topic consistently identified as particularly challenging is genetics, especially the Cell Division (Agboghroma & Oyovwi, 2015; Cimer, 2012; Doğru & Özsevgeç, 2018; Fauzi & Mitalistiaini, 2018; Hadiprayitno et al., 2019; Salleh et al., 2021).

1.1.4 Cell Division

Cell division is the process by which a single parent cell divides into two or more daughter cells. It is a crucial process in biology as it gives rise to all cells, which are the basic

unit of life and constitute every living organism (Shelden et al., 2019). However, understanding the cell division processes of mitosis and meiosis can be difficult for students at all educational levels, from elementary school to higher education (Murtonen et al., 2020).

Numerous studies have highlighted that students often struggle to grasp the concept of cell division. These difficulties stem primarily from the abstract nature of the subject (Dikmenli, 2010; Kılıç et al., 2016; Nasharuddin et al., 2021; Özbudak & Özkan, 2014), misconceptions (Arslan & Arı, 2023; Dikmenli, 2010; Murtonen et al., 2020; Özbudak & Özkan, 2014; Rafat & Ali, 2023), and the use of complex terminology (Kılıç et al., 2016; Özbudak & Özkan, 2014; Salleh et al., 2021). Additional challenges include difficulties with memorization (Dikmenli, 2010; Murtonen et al., 2020; Salleh et al., 2021; Shelden et al., 2019) and other factors (Frederick-Jonah & Tobi, 2022; Imboy et al., 2025). Collectively, these issues contribute to the overall challenge students face when trying to master this topic.

1.2 Problem Statement

Existing studies on learning difficulties in the topic of Cell Division (Basri & Abdullah, 2020; Chattopadhyay, 2012; Dikmenli, 2010; Kılıç et al., 2016; Murtonen et al., 2020; Özbudak & Özkan, 2014) have primarily focused on the cognitive perspective, particularly misconceptions among learners (Chattopadhyay, 2012; Dikmenli, 2010; Murtonen et al., 2020; Özbudak & Özkan, 2014). However, these studies have not taken a comprehensive perspective that includes aspects beyond cognitive aspect of learning. This trend aligns with Quílez-Robres and colleagues' (2021) claim, where the recent studies emphasize on the impact of cognitive factors on learning performance, often overlooking motivational, emotional, and social influences. Therefore, it is important to diagnose learning challenges from multiple dimensions, including cognitive, motivational, affective,

and social perspectives, to provide a more comprehensive understanding of the learning challenges students face in the Cell Division topic. Furthermore, incorporating both students' and teachers' views is crucial, as teachers play a key role in shaping the learning environment. A dual perspective can offer deeper insights into the learning difficulties and inform the development of more effective teaching strategies.

Moreover, most of the related previous studies are from other countries, such as Turkey (Dikmenli, 2010; Kılıç et al., 2016; Özbudak & Özkan, 2014), India (Chattopadhyay, 2012), and Finland (Murtonen et al., 2020), with only one study (Basri & Abdullah, 2020) is from the local context of Malaysia. While the learning challenges highlighted in these previous studies may be similar in Malaysia, there is limited research specifically conducted within the local context. Therefore, it is essential to investigate whether the learning challenges identified in existing studies are applicable to Malaysia.

Once these learning challenges are identified, it is important to find effective ways to overcome them. Exploring suitable learning design interventions is therefore essential. Salleh and colleagues (2021) suggest using student-centred strategies and providing adequate resources to make Biology learning more engaging and effective.

One potential solution is the use of digital games, which have emerged as promising tools to support modern learners, especially students of the 21st century who are digital natives familiar with technology (Ahmad et al., 2020). Building on this, game-based learning (GBL) has shown strong potential to enhance students' learning experiences. A growing body of research highlights its positive impact on students' conceptual understanding (Corredor, 2011; Kanyapasit & Srisawasdi, 2014; Shamsudin et al., 2020; Wilson et al., 2018), academic performance (Nasharuddin et al., 2021), social interaction (Corredor, 2011),

and motivation (Shamsudin et al., 2020; Sumandal, 2023), particularly in genetics or Cell Division topic.

Despite these benefits, the implementation of digital games in education is often constrained by unequal access to technology. According to the findings from MOE's survey that involved 900,000 students in 2020, there are 46% of students have mobile phones, 5.67% of students have a tablet, 6% of students own a personal computer and 9% of students have a laptop (Teo, 2021). Additionally, according to the ICT Use by Individuals Survey in 2023, 80.4% of individuals own a computer and 99.4% have access to a mobile phone (DOSM, 2024). Based on the findings from both MOE and DOSM surveys mentioned above, mobile phones appear to be a more appropriate choice for digital learning, given the lower ownership rates of computers and laptops among students.

Therefore, as mobile phones are the most widely owned devices among students (Ni et al., 2021), mGBL could be a promising innovation to facilitate students' learning. As Lin and colleagues (2014) mentioned, if students can use their mobile phones for learning instead of killing time when free, their learning efficiency may be enhanced. mGBL has become a new trend in education due to the convenience of running user-friendly applications on mobile devices (Cahyana et al., 2017). However, despite its potential, there is still limited research on how effective mGBL is in addressing specific learning challenges in Cell Division while also providing a highly playable experience.

1.3 Research Questions

Based on the problem statements mentioned above, this study aims to address the following research questions:

- i. What are the underlying problems of learning Cell Division topic among secondary school students in Malaysia from both students' and teachers' views?
- ii. How can an mGBL application be designed and developed to ensure high playability while addressing challenges in learning Cell Division?

1.4 Purpose of Study

Based on Giannakas and colleagues (2017), the research on mGBL in STEM education is still “at a rather building stage”. Therefore, the present study focused on developing an mGBL application for secondary school students to learn Cell Division topic. However, before development, it was important to identify the challenges students face in learning Cell Division, as this would guide the design framework for the mGBL application. Both students' and teachers' views should be considered to provide comprehensive insights from multiple viewpoints. Thus, the present study sought to identify learning challenges in Cell Division topic from both students' and teachers' views. Based on the identified learning challenges, an mGBL application was developed as a learning intervention to address these challenges. Additionally, assessing the playability of the mGBL application was crucial to ensure its user-friendliness. Overall, the research objectives of the study are as listed below:

- i. To explore the learning difficulties in the Cell Division topic from both students' and teachers' perspectives.
- ii. To design and develop an mGBL application with high playability that would address challenges identified in the learning of Cell Division.

1.5 Study Scope

The present study focuses on designing and developing an mGBL application to assist students in learning the Cell Division topic, which is Chapter 6 of the Form 4 Biology textbook (Gan et al., 2019), based on the Malaysian National Secondary School Standard Curriculum (KSSM). The mGBL application was developed for the Android operating system, as it is currently the most widely used mobile operating system globally (Subscribed.fyi, 2024). The language of the content in the mGBL application is based on the language used by the Biology teachers in their teaching.

The target participants of this study include Form 4 students who are currently enrolled in the Biology subject and have just completed learning the Cell Division chapter. This ensures that students have prior exposure to the topic and are able to reflect on the specific learning difficulties they encountered. The study also involves experienced Biology teachers who teach the Form 4 syllabus, as their insights provide a deeper understanding of students' learning challenges in the Cell Division topic.

In terms of digital literacy, both students and teachers involved in the study are required to own or have access to an Android mobile phone and be familiar with using it. This is to ensure smooth interaction with the mGBL application during the intervention. However, prior experience with mobile gaming is not required, as one of the objectives of the study is to evaluate the application's playability and user-friendliness, even among users who are not regular mobile gamers.

1.6 Rationale of Study

The present study is significant because it aims to address the learning challenges students face in the Cell Division topic, which is part of the Form 4 Biology curriculum in

Malaysia. By exploring the difficulties from both students' and teachers' perspectives, the study offers a more complete understanding of the problem. It also goes beyond the usual focus on students' understanding by considering motivational, emotional, and social factors that affect learning.

To support students' learning, this study introduces an mGBL application designed specifically for the Cell Division topic. As many students today are familiar with mobile devices, this application offers a flexible and engaging way to support both classroom teaching and self-learning.

In addition, this study contributes to the field of educational technology by showing how mGBL can be designed based on real learning challenges and multiple learning needs. It can serve as a practical reference for educators, researchers, and developers interested in using mobile games to improve science education.

1.7 Definition of Terms

The present study utilises several terms that require explanations to facilitate understanding of the study. The terms operationalized in this study are game, gamification, game-based learning, and mobile game-based learning.

1.7.1 Game

There are many definitions for the term "game". Based on Salen and Zimmerman (2004), the definition of game is "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome". In simple words, a game is a system that provides a boundary between the virtual game environment and the real world, where a player interacts with the game environment by following a set of defined game rules to

achieve a certain quantifiable goal. Game is also referring to “structured activities carried out for pleasure, according to certain written or unwritten rules” (Chatfield, 2010). Games can be represented in various forms, either in no tech, such as hide and seek, or in high tech like digital games.

The present study adopts Salen and Zimmerman’s (2004) definition of game because it is one of the most frequently cited definitions in game-related studies (Stenros, 2022).

1.7.2 Game-Based Learning (GBL)

GBL refers to the use of games in educational contexts to achieve educational objectives, such as learning and behavioural change (Connolly et al., 2012). GBL is also defined as the use of actual games to impart knowledge and skills (Mohamad et al., 2017). According to Shaffer and colleagues (2005), the definitions of GBL typically highlight that it involves gameplay designed to achieve specific learning outcomes. GBL is often discussed in the same context as serious games (Boyle et al., 2016). While gamification involves using game mechanics in a non-game context, GBL emphasizes learning through the gaming experience itself.

In this study, Connolly and colleagues’ (2012) definition of GBL was adopted because it highlights the role of games in achieving learning and behavioural change, rather than just teaching knowledge and skills to learners (Mohamad et al., 2017), which aligns with the present study’s goal of addressing learners’ challenges.

1.7.3 Mobile Game-Based Learning (mGBL)

mGBL refers to a game that includes a summary of the lesson topic, is structured across various educational levels, aligns with the current curriculum, and is designed to

function on mobile devices (Cahyana et al., 2017). Based on Shiratuddin and Zaibon (2011), mGBL also refers to a game specifically designed for educational purposes that can be played on mobile phones, smartphones, PDAs, or other handheld devices.

In this study, mGBL refers to a game designed for learning purposes and played by mobile devices, because it is more straightforward and clearer, making it easy to understand. It highlights key aspects such as the game's focus on learning goals, and its compatibility with mobile devices, as stated in Shiratuddin and Zaibon's (2011) definition.

1.7.4 Cell Division

Cell division refers to the process by which a eukaryotic cell undergoes structural and functional splitting, resulting in the formation of two daughter cells (Baluška et al., 2006). According to Martin and Hine (2015), cell division is defined as the process by which a single parent cell divides into two or more daughter cells. Ferry and colleagues (2018) provide a similar definition, describing cell division as the fundamental process by which a parent cell divides, producing two identical daughter cells.

In this study, Martin and Hine's (2015) definition of cell division was adopted because it is straightforward and aligns with the study context.

1.7.5 Cognitive Challenge

Cognitive challenge is defined as a characteristic or aspect of mental processing that can affect the success or failure of learning (Chew & Cerbin, 2021). According to Arthur and Akwetey (2021), these cognitive challenges involve students' mindsets, issues with metacognition and self-regulation, fear and mistrust, insufficient prior knowledge,

misconceptions, ineffective learning strategies, difficulties in transferring learning, and limitations due to selective attention, mental effort, and working memory.

In this study, Chew and Cerbin's (2021) definition of cognitive challenge was adopted, as it aligns with the study's focus on learning difficulties.

1.7.6 Social Challenge

Social challenge refers to conditions or behaviours that negatively affect an individual's personal, academic, or social life, and may also impact the well-being of communities (Thelma, 2023). According to Thelma (2023), these challenges often involve social issues such as interpersonal conflicts, social exclusion, peer pressure, or communication barriers, which can hinder learning and participation. Social challenges are typically complex, with differing public views on their causes and solutions, and are commonly encountered in modern society.

However, Thelma's definition of social challenge is based on a broader social science context and does not fully match the focus of this study, which is on learning difficulties. Therefore, in this study, social challenge is defined as social factors in the learning environment, such as lack of peer support and poor interaction with peers or teachers, that make it difficult for students to engage, participate, and learn effectively.

1.7.7 Playability

Playability is an ambiguous term that is often used but seldom defined (Paavilainen, 2020). According to Sánchez and colleagues (2012), playability refers to the extent to which users can achieve their intended goals with effectiveness, efficiency, and especially a sense of satisfaction and enjoyment within the context of using the game. It is also defined as the

design quality of a game, shaped by its functionality, usability, and gameplay (Paavilainen, 2020). Korhonen and Koivisto (2006) used the term playability as a set of heuristics to evaluate a mobile game's usability, mobility, and gameplay. According to Korhonen (2016), a game has good playability when its user interface is easy to understand and the gaming platform does not distract the player, allowing full focus on the game itself. The gameplay becomes enjoyable and challenging when it is clear, appropriately difficult, and engaging. Shiratuddin and Zaibon (2011) expanded on Korhonen and Koivisto's (2006) concept of playability by including learning content as an additional dimension.

In this study, the definition of playability by Shiratuddin and Zaibon (2011) was adopted. Playability is measured as the average of four dimensions, which are game usability, mobility, gameplay, and learning content. This definition was chosen because this study used Shiratuddin and Zaibon's (2011) heuristic evaluation strategy to assess the mGBL application, and it aligns well with the study context in the development of an mGBL.

1.7.8 Problem-Based Game Design

In this study, the term "problem-based game design" is defined as an approach where gameplay is structured to address real-world learning challenges through active game engagement. This term was coined by the researcher, as no existing literature was found to use this specific phrase. It was introduced to highlight a novel approach to game design that is specifically based on actual learning challenges, with those challenges being directly addressed and resolved through gameplay.

1.8 Chapter Summary

In summary, this chapter discussed the study background, starting with the importance of 21st-century learning and STEM education. Within the context of STEM education, the subject of Biology has been a focus of the present study, as various studies have reported difficulties in learning Biology (Agboghroma & Oyovwi, 2015; Cimer, 2012; Etobro & Fabinu, 2017; Hadiprayitno, 2019; Ozcan et al., 2014). To narrow the study's scope, the topic of Cell Division was chosen, as it is one of the most challenging topics in Biology studies (Agboghroma & Oyovwi, 2015; Cimer, 2012; Doğru & Özsevgeç, 2018; Fauzi & Mitalistiaini, 2018; Hadiprayitno et al., 2019; Salleh et al., 2021). Therefore, the present study aims to identify learning challenges in the Cell Division topic from both student and teacher perspectives and proposes mGBL as a solution to address these identified challenges.

CHAPTER 2

LITERATURE REVIEW

The present study focuses on designing and developing an mGBL application for Cell Division learning. Accordingly, this literature review first examines the general difficulties students face in learning Biology, followed by a review of the most challenging topics identified in the Biology curriculum, with a particular focus on the Cell Division topic. It then explores key concepts related to play in learning, the use of games in education, GBL, mGBL, relevant game design models, development methodologies, and learning theories that inform the creation of the mGBL application.

2.1 The Difficulties in Learning Biology

Several studies reported difficulties in learning Biology (Agboghoroma & Oyovwi, 2015; Cimer, 2012; Etobro & Fabinu, 2017; Hadiprayitno, 2019; Ozcan et al., 2014), and the factors that cause difficulties in learning Biology can be categorized into four main factors, which are the nature of the Biology subject, teacher's teaching style, students' attitude and study habit, and environment and resources factor. Table 2.1 below shows the review of research about the reasons behind the difficulties of learning Biology.

Table 2.1: The Difficulties of Learning Biology Reported in Studies

Authors	The Difficulties in Learning Biology			
	The Nature of the Biology Subject	Teacher's Teaching style	Student's Attitudes and Study Habits	Environment and Resources Factor
Cimer (2012)	Based on memorization Abstract topics	Non-professional Biology teacher	Poor study habits	Unavailable instructional materials

Table 2.1 continued

	Including foreign words Complex topics Too detailed knowledge Vast syllabus	Not taught as associated with daily life	Negative attitudes towards Biology	Lack of laboratory for practical Insufficient lesson time
Ozcan et al. (2014)	Too detailed knowledge Complex topics Based on memorization Connection to daily life is difficult Including foreign words Abstract topics			
Agboghoroma & Oyovwi (2015)	Vast syllabus Abstract topics	Non-professional Biology teacher	Poor study habits	Lack of laboratory for practical
Etobro & Fabinu (2017)	Abstract topics Complex topics Misconception of topics	Poor attitude of teachers	Poor study habits	Unavailable instructional materials Lack of practical classes
Hadiprayitno (2019)	Based on memorization Connection to daily life is difficult	Monotonous teaching style Incomplete delivery of material Shallow discussion of material		Learning environment that is not conducive

First, the learning challenges stem from the nature of Biology itself. Unlike Chemistry and Physics, which rely heavily on logic and calculations, Biology always stands on its own as a separate subject (Wahid & Talib, 2017), which relies largely in memorization (Cimer, 2012; Ozcan et al., 2014; Hadiprayitno, 2019). Cimer (2012) noted that Biology includes numerous abstract concepts, making it difficult for students to visualize complex biological processes invisible to the naked eye. This abstractness and complexity can lead to misconceptions that negatively affect students' learning. Microscopic topics, such as Cell Division, are particularly challenging unless their content is visually represented and connected to daily life (Ozcan et al., 2014). Moreover, the overloaded curriculum with detailed content, and inclusion of unfamiliar Latin terms in Biology textbooks further contribute to learning difficulties (Cimer, 2012; Ozcan et al., 2014). Additionally, genetically related topics, including mitosis, meiosis, genes, and chromosomes, are often cited as the most difficult to understand (Matawali et al., 2019). Such struggles can significantly impact students' motivation and academic achievement in Biology (Hadiprayitno, 2019).

Second, teacher-centred teaching styles negatively affect students' learning in Biology. According to Hadiprayitno (2019), many teachers rely on theoretical and monotonous teaching style with little practical work or student-centred approaches, failing to connect lessons to daily life. This approach makes students perceive Biology as merely a subject requiring memorization, diminishing their interest and motivation to learn (Hadiprayitno, 2019). Additionally, the huge gaps between abstract concepts and reality make it harder for students to grasp complex topics. Teacher-centred methods also neglect student needs, because students just learn passively in the classroom (Etobro & Fabinu, 2017) and depends largely on the textbook that just required students to read and learn important

things only (Hadiprayitno, 2019). Moreover, Kelly's (2012) learning pyramid suggests that students only acquire 5%-30% of knowledge through reading or writing, but 75%-90% through hands-on activities. Consequently, a lack of engaging and practical teaching deepens student boredom and reduces motivation. This problem gets worse when students are taught by unqualified Biology teachers. Their lack of knowledge or poor attitude can make students lose trust in them and develop negative feelings toward both the subject and the teachers (Cimer, 2012).

Third, the difficulties in learning Biology arise from the students themselves. As reported by Cimer (2012), Agboghroma and Oyovwi (2015), and Etobro and Fabinu (2017), poor learning habits cause the students to face difficulties when learning Biology. For example, not every student will do exercise and revise Biology regularly, and some students even may do not complete tasks and questions in Biology class. Furthermore, some students are not interested in what teachers were saying in class, so they just simply ignore and do not listen to the teacher (Cimer, 2012; Hadiprayitno, 2019). Hence, students will face difficulties in learning Biology because they do not study Biology well. The reason behind the poor study habits of students might be due to the nature of Biology subject, the teachers' teaching style, or lack of interest in Biology also.

The last factor contributing to difficulties in learning Biology is the environment and resources. According to findings by Cimer (2012), Agboghroma and Oyovwi (2015), Etobro and Fabinu (2017), and Hadiprayitno (2019), these challenges arise due to limited facilities and infrastructure. Cimer (2012) emphasized that students need to do experiments and practical work to connect abstract knowledge from class to real-life applications. Without access to school laboratories, students miss the opportunity to engage in hands-on

activities, which negatively impacts their learning. Moreover, insufficient lesson time often forces teachers to rush through content, resulting in a less conducive learning environment for students (Hadiprayitno, 2019).

In sum, if students had trouble in learning Biology as mentioned above, there will be a great negative impact on the students' learning in Biology.

2.2 The Most Challenging Topic in Biology Curriculum

While the studies highlight students' difficulties in learning Biology, most focus on the subject as a whole rather than specific topics. Therefore, identifying challenging areas within Biology is essential for providing targeted support. Global research has identified various difficult topics. For example, Cimer (2012) found that material cycles, endocrine systems, aerobic respiration, cell division, and genes and chromosomes were among the most challenging topics for students in Turkey. Similarly, Agboghroma and Oyovwi (2015) identified heredity, genetics, and ecology as the toughest topics for Nigerian students. Doğru and Özsevgeç (2018) reported that Turkish teacher candidates struggled with cell division, controller and regulatory systems, chromosomes, and genes, while Fauzi and Mitalistiaini (2018) highlighted genetics, immune systems, and metabolism as the most difficult areas for Indonesian undergraduate students. Additionally, Hadiprayitno and colleagues (2019) found that bacteria and viruses, endocrine systems, cell structure, genetics, and the nervous system particularly challenging in Indonesia. For local context in Malaysia, Salleh and colleagues (2021) identified cell division, cell structure and organization, and chemical composition within the cell as difficult topics for students and teachers. Overall, these findings (Agboghroma & Oyovwi, 2015; Cimer, 2012; Doğru & Özsevgeç, 2018; Fauzi & Mitalistiaini, 2018; Hadiprayitno et al., 2019; Salleh et al., 2021) consistently show that

genetics-related topics, particularly Cell Division, are among the most challenging in the Biology curriculum.

2.3 The Difficulties in Learning Cell Division Topic

There have been many studies that have focused on identifying the learning issues of students in genetics or the topic of Cell Division. For instance, Dikmenli (2010) found that Biology student teachers in Turkey often confused the stages of cell division, especially meiosis, leading to misconceptions. Similarly, Chattopadhyay (2012) revealed that Indian secondary students struggled to differentiate between mitosis and meiosis. Additionally, Kılıç and colleagues (2016) compared genetics comprehension in English and Turkish students, highlighting how educational contexts shape understanding. For the local context in Malaysia, Basri and Abdullah (2020) reported that Form 4 students in Sabah had limited knowledge of genetic concepts, particularly genes and chromosomes.

Overall, the difficulties in learning Cell Division topic can be attributed to the abstract nature of the topic, misconceptions, complex terminologies, memorization problems, and the others. Firstly, the abstract nature of the Cell Division topic presents a challenge for students to learn. According to Dikmenli (2010), abstract concepts such as chromatin, chromatid, centriole, centromere, chromosomes, and spindle fibres are challenging for students to understand due to the changes they undergo during each phase of cell division. Additionally, the invisibility of genetic phenomena requires higher levels of abstract thinking (Kılıç et al., 2016). Students must visualise and conceptualise the processes and cell structures to grasp the topic effectively (Nasharuddin et al., 2021). This is supported by Mussard and Reiss (2022), who mentioned that students found it difficult to visualize the abstract, molecular-level concepts in the topic. Furthermore, Özbudak and Özkan (2014)

noted that the complexity of these concepts often exceeds students' cognitive abilities, making it difficult for them to apply the knowledge to real-life contexts.

Misconceptions are common among students when learning about the topic of Cell Division. According to Özbudak and Özkan (2014), teachers observed that students often misunderstand concepts such as genes, DNA, chromosomes, phenotypes, genotypes, and the processes of mitosis and meiosis. Rafat and Ali (2023) also observed that although students may recall factual information about cell division, they frequently struggle to comprehend the underlying principles, resulting in misconceptions. In particular, students often struggle to distinguish and make connections between mitosis and meiosis. For instance, Dikmenli (2010) found that students struggled with the relationships between these processes, often confusing concepts like the cell cycle and haploid and diploid cells. Similarly, Murtonen and colleagues (2020) reported misconceptions about bivalents and diploidy/haploidy, indicating a lack of understanding of the fundamental differences between mitosis and meiosis. Additionally, Arslan and Arı (2023) found that students frequently mix up the stages of meiosis and mitosis because they involve similar events in nuclear and cytoplasmic division. Their study also revealed that students tend to hold the misconception that meiosis produces two cells, likely because meiosis occurs in two stages, and students observe the formation of two cells after the first stage, leading to this misunderstanding.

Cell Division is a complex topic that poses a challenge for students due to the multitude of biological and complex terms they need to learn, which can lead to confusion (Salleh et al., 2021). Kılıç and colleagues (2016) noted that genetics includes visually and phonetically similar terms, making comprehension difficult. Moreover, Özbudak and Özkan (2014) identified terms like modification, adaptation, gene, nucleotide, chromosome,

organic bases, meiosis, DNA, and heterozygote are hard for students to grasp from Biology teachers' views. Their study also found that students often struggle to differentiate between nucleotide, gene, DNA, and chromosome due to a lack of activities that help them understand the relationships between these terms.

Additionally, students' struggles with concepts and terminology in Cell Division can lead to memorization issues. According to Sheldon and colleagues (2019), many Biology students memorize the stages of cell division from textbooks. However, without a deep understanding of the underlying biology behind these events, both students (Murtonen et al., 2020; Salleh et al., 2021) and Biology teachers (Dikmenli, 2010) may struggle to comprehend and memorize the processes. Even if students can memorize the content, it does not necessarily mean that they have mastered the topic.

Apart from challenges like the abstract nature of the topic, misconceptions, complex terminology, and memorization issues as mentioned earlier, there are other factors that contribute to difficulties in learning the Cell Division topic. For example, Frederick-Jonah and Tobi (2022) identified factors such as a lack of experienced teachers, insufficient practical classes, incomplete curriculum coverage, the complexity of cell biology, omission of some areas, and limited use of ICT in teaching. Furthermore, a lack of learning resources can hinder students' ability to understand, memorize, and apply knowledge about cell division effectively (Imboy et al., 2025). Therefore, it is evident that the factors hindering students' learning of the Cell Division topic are not only cognitive, such as the abstract nature and misconceptions, but also involve other factors from various perspectives.

2.4 Play in the Learning Context

Psychologists like Piaget and Vygotsky have emphasized the importance of play in cognitive development. Based on Piaget (1962), play helps children activate schemas, allowing them to transcend their immediate reality, such as pretending an eraser is a car to develop symbolic thinking. Similarly, Vygotsky (1978) viewed play as the “leading factor” in development, creating a zone of proximal development where children can achieve beyond their current abilities with adult guidance or peer interaction. Building on these theories of play, Plass and colleagues (2015) suggested that they can be applied to educational game design, where games should aim to be within the player’s zone of proximal development by balancing difficulty to maintain engagement without causing boredom or frustration.

2.5 The Use of Game in Learning

According to Gee (2003), games can facilitate learning by embedding content into gameplay, allowing players to actively engage and acquire knowledge. The fun and playful nature of games has led to their growing use in education to enhance teaching and learning. As a result, gameful approaches like gamification, which applies game mechanics in non-game contexts, and GBL, which enables learning through play, have gained popularity in recent years to boost student motivation and performance.

2.6 Game-Based Learning

GBL is widely recognized for improving players’ real-life skills (Chang et al., 2009). Although many studies show its effectiveness, it is important to understand how GBL aids the learning process. According to Plass and colleagues (2015), GBL can be examined through four foundations, including cognitive, motivational, affective, and sociocultural.

From the cognitive perspective, GBL enhances mental model construction and optimizes cognitive load during gameplay (Plass et al., 2015). The multimedia nature of digital games reduces cognitive load, helping learners store and consolidate visual and verbal information in working memory to link with prior knowledge (Mayer, 2014). Additionally, GBL supports Perkins and Salomon's (1989) theory of knowledge transfer by offering repeated practice and encouraging knowledge abstraction for new applications.

From the motivational perspective, games are effective at motivating players by providing enjoyable experiences (Plass et al., 2015). However, while educational games can enhance learning and motivation, some argue that the high engagement of entertainment games may not transfer to educational contexts (Hoffman & Nadelson, 2009). Hence, Zusho and colleagues (2014) suggested that video games can align with Eccles and colleagues' (1998) key motivational questions, which are "Can I do this?", "Do I want to do this, and why?", and "What do I need to do to succeed?". To deal with these questions, well-designed games should consider players' abilities, guide them through tasks, and foster confidence through trial and error. To answer why players want to play, games should integrate intrinsic and extrinsic motivation, learning goals, and individual interest, ensuring the game mechanics support learning (Plass et al., 2015).

From the affective perspective, GBL focuses on how game design can influence learners' emotions, which in turn impacts learning performance (Plass et al., 2015). Studies show that positive emotions improve learning outcomes (Plass et al., 2014; Um et al., 2012). For instance, Plass and colleagues (2014) found that the visual design of content can affect emotions, while Um and colleagues (2012) discovered that round shapes and warm colours induce positive emotions, leading to better learning. These findings align with neuroscience

theories, which suggest that emotional arousal enhances memory formation (Dolcos et al., 2004). Thus, emotions like joy, happiness, and fear can boost learning performance during gameplay.

From the sociocultural perspective, GBL fosters social interaction and creates a supportive learning environment (Plass et al., 2015). For example, the gamification element of the leaderboard in an educational game promotes social pressure to compete with peers, influencing players to pay more attention and focus on the game, thus putting more effort into learning through gameplay. However, as mentioned earlier, game mechanics should align with intrinsic learning goals rather than just extrinsic motivators. Hence, the sociocultural aspect should be linked to relatedness in self-determination theory (Ryan & Deci, 2000), where players feel connected to others. For instance, a player is more likely to be engaged, satisfied, and eager to play again when they establish a connection with other players during gameplay (Ryan et al., 2006). In sum, the psychological need for relatedness is important for promoting a sense of presence, game enjoyment, and the intention for future play (Plass et al., 2015).

While the theoretical benefits of GBL are well-supported, applying these principles in real-world educational settings remains challenging. Technological limitations such as lack of devices, poor internet connectivity, and infrastructure gaps are common, particularly in under-resourced schools (Yaman et al., 2024). Teachers also face difficulties due to limited training, low game literacy, and uncertainty about how to integrate GBL effectively into the curriculum (Hu & Sperling, 2022; Lindgren, 2018). In addition, rigid school policies and misalignment with curriculum objectives often restrict GBL adoption (Yaman et al.,

2024). Students may also experience stress from competition, unclear instructions, or a perceived disconnect between gameplay and learning goals (Jääskä & Aaltonen, 2022).

To address these issues, researchers recommend participatory and co-creation approaches that involve both teachers and students in game design, as well as selecting between digital, analogue, or hybrid formats based on context (Yaman et al., 2024). With proper support, training, and contextual alignment, GBL can be more effectively and sustainably integrated into formal education.

2.6.1 GBL Research in Biology Learning

There are several GBL research, which is specifically for students to learn Biology was done in these recent years. Stenerson and colleagues (2011) developed “Meta!Blast,” a 3D action game aimed at improving understanding of plant cells, which included an in-game database called as “Biolog” to maintain player engagement and allowed teachers to modify content for classroom integration. Next, an online computer game called “The Medication Game”, was developed by Foss and colleagues (2014) to help nurse students practise standard medical units. Additionally, Christopoulos and colleagues (2022) made “Virtual Reality Escape Room”, a virtual reality game that supports crossed platforms to learn about enzyme for upper secondary students, which improve their learning performance in short term and gets positive affective experience. These games highlighted the potential of GBL in improving students’ understanding and engagement (Stenerson et al., 2011), learning performance after frequent use of game (Foss et al., 2014) or in short term (Christopoulos et al., 2022), and affective experience such as satisfaction and enjoyment (Christopoulos et al., 2022).

2.6.2 GBL Research in Cell Division Learning

Several GBL studies specifically focusing on genetics-related topics, such as Cell Division, have been conducted in the last two decades. For example, Corredor (2011) investigated the implementation of video game called “Virulent!” to learn cell biology in Biology class. Besides that, Kanyapasit and Srisawasdi (2014) developed a digital game called “The Cell Cycle Game”, to facilitate the process of conceptual change in the cell cycle. Next, Panzoli and colleagues (2017) developed a web-based learning game called “Cell Cycle Learn” for undergraduate biology students to learn about the cell-division cycle and develop practical skills for experiments and scientific methods. Additionally, “Geniverse”, a digital game, was developed by Wilson and colleagues (2018) for high school students to learn genetics and improve their understanding. Furthermore, Shamsudin and colleagues (2020) developed a courseware called “Hacking the Science of Cell Division” to deal with misconceptions in meiosis and mitosis among secondary school students. These games provide a joyful and engaging learning experience for students and have been shown to significantly impact their understanding (Corredor, 2011; Kanyapasit & Srisawasdi, 2014; Shamsudin et al., 2020; Wilson et al., 2018), social interaction (Corredor, 2011), and motivation (Shamsudin et al., 2020) for the learning of genetics or Cell Division topic.

2.7 Mobile Game-Based Learning

Similar to GBL, mGBL aims to increase learning motivation, facilitate knowledge acquisition, and enhance learning efficiency, by using mobile phones as the medium. This distinction provides several advantages over traditional GBL.

First, mGBL supports anytime and anywhere learning. For instance, Shonola and colleagues (2016) emphasized that mobile devices enable learners to control their learning

environment without obstacles, fostering personalized learning at their own pace. Similarly, Shippee and Keengwe (2012) noted that educational games accessed via mobile phones encourage personalized learning anytime, anywhere.

Besides that, mGBL positively impacts learning motivation. Most mGBL research focuses on motivation because it has been found that people become more immersed and engaged when playing games (Huizenga et al., 2009). Once learners install and use mGBL applications, they experience increased motivation and engagement (Huang et al., 2017). Similarly, Chen and colleagues (2015a) found that students using mGBL for natural science courses reported higher levels of motivation.

Finally, mGBL improves learning performance. Educational technology is strongly associated with better learning outcomes (Alkhalifah & Rampersad, 2017). For example, Cahyana and colleagues (2017) observed improved performance in chemistry students using mGBL, concluding that mobile games deepen understanding of new knowledge. Similarly, Huang and colleagues (2017) demonstrated that students using the “Super Word King” mobile game improved their English vocabulary learning.

2.7.1 mGBL Research in Biology Learning

There are several mGBL research, which is specifically for students to learn Biology was done in these recent years. For example, Kongvitayanont and colleagues (2017) introduced the mobile RPG “Bloody Buddy,” which effectively improved student learning performance by allowing players to battle viruses and understand the circulatory and immune systems. Next, Rozaidi and Ismail (2018) developed “Kidney Rush Games,” a mGBL system designed to teach Form 5 students about the urinary system, utilizing the EGameFlow model to enhance enjoyment and interest, ultimately received positive feedback

from students despite its 2D graphics. Also, Wommer and colleagues (2023) developed an augmented reality mobile game called “Insects GO” for middle school students to learn entomology and increase their motivation level based on ARCS model. These games have been shown to positively impact students’ learning performance (Kongvitayanont et al., 2017; Wommer et al., 2023), enjoyment (Rozaidi & Ismail, 2018), and motivation (Wommer et al., 2023).

2.7.2 mGBL Research in Cell Division Learning

In recent years, numerous mGBL studies have been conducted with a specific focus on genetics-related topics, including Cell Division. For example, an mGBL with virtual reality called “InCell VR” was developed by Nasharuddin and colleagues (2021) to help secondary school students visualize the cell division process and improve their understanding of the topic. Additionally, Sumandal (2023) developed educational games in mobile devices using Lumi Education for students to learn Biology, including mitosis and meiosis topics. These games provide a joyful and engaging learning experience for students and have been shown to significantly impact their learning performance (Nasharuddin et al., 2021) and motivation (Sumandal, 2023) for the learning of genetics or Cell Division topic.

2.8 Design Models and Development Methodologies

Various design models and development methodologies have been proposed by researchers to develop GBL for different purposes. However, creating mobile educational games poses both technical and conceptual challenges, as most methodologies provide general guidelines rather than focusing specifically on mGBL (Šćepanović, 2015). Furthermore, there is limited research on effective mGBL design and development (Shiratuddin & Zaibon, 2011). To address this gap, recent studies on GBL design models

and mobile game development methodologies were reviewed to identify the most suitable approach for our mGBL. According to Vaishnavi and Kuechler (2015), a design model outlines relationships between components, while a development methodology provides step-by-step guidelines for completing tasks.

2.9 Reviews of GBL Design Models

A total of six GBL design models were reviewed, including Adaptive Digital Game-Based Learning Framework (Tan et al., 2007), DGBL Model for History Educational Games Design (Zin et al., 2009), GBLm4CE Model (Kuk et al., 2012), MDA Framework for Meaningful Enterprise Gamification (Ruhi, 2015), PAT-Game-Based Learning Model with Flow Experience (Abd Elsattar, 2017), and Structural Design Computer Model-Based Games (Yang et al., 2018).

2.9.1 Adaptive Digital Game-Based Learning Framework

It is a framework developed by Tan and his colleagues (2007) to design educational games that combining game features with learner-focused design. The framework emphasizes addressing learners' psychological needs, cognitive development, and behaviour before creating a game. It includes three components, which are multimodal, task, and feedback. Multimodal integrates multimedia for interaction and uses Barendregt and Bekker's (2004) Interaction Cycle to facilitate cognitive and physical user actions. Next, the task component helps learners engage with game content through mechanics like levels, goals, and rules. Last, feedback clarifies information, prevents misunderstandings, and rewards users to boost confidence during gameplay.

2.9.2 DGBL Model for History Educational Games Design

It is a DGBL model developed by Zin and colleagues (2009) to design educational games to learn History course. There are two main components in this model, which are pedagogy and digital games. Pedagogy consists of Learning goal setting, Learning theory setting, Educational Psychology, Country curriculum needs, Patriotism and moral value, Memorization and forgetting theory. Meanwhile, the digital games component consists of the Game story's background, Rules, Immersive, Enjoyment, Feedback, Multimedia technology, Challenge & competition, and Reward/Award. These two main components in this model are to encourage student engagement in learning.

2.9.3 GBLm4CE Model

It is a GBL model proposed by Kuk and other researchers (2012) to develop a GBL for students to learn computer engineering curriculums by integrating game elements with learner profiles and teaching methods. The model incorporates learning theories, strategies, styles, affective traits, and objectives into game design. It is structured with six key aspects, including Domain, Constructivist Method, Personalization, Student Profile, Motivation, and Matching Learning Outcomes. First, the Domain represents the game space with multidimensional interactions that facilitate immersive learning. Next, the Constructivist Method encourages learners to actively engage in the learning process and construct meaning from acquired knowledge. Following this, Personalization ensures that games adapt to diverse learning and playing styles, making the experience more effective for different students. In addition, the Student Profile helps identify individual learning and playing preferences, enhancing the gaming experience. The Motivation component uses game feedback to stimulate student engagement and promote repetition in the learning cycle.

Finally, Matching Learning Outcomes ensures that educational goals align with Bloom's taxonomy, enabling students to achieve the intended objectives.

2.9.4 MDA Framework for Meaningful Enterprise Gamification

It is a game design framework proposed by Ruhi (2015), specific for enterprise gamification. This framework has three components, which are mechanics, dynamics, and aesthetics. The mechanics component describes the game elements and the game rules, such as what are the actions a player can take and what is the process that allows the player to take that action. Next, the dynamics component stands between the mechanics and aesthetics components, which describes the rules in the gameplay based on the player's inputs and interactions among players. The aesthetics component is the "fun" factor of a game, which stimulates the emotion of the player when the player interacts with the game. To have a better understanding of this framework in developing enterprise gamification, Ruhi introduced a list called "20 Cs of meaningful enterprise gamification" which further derives the three main components in the framework.

2.9.5 PAT-Game-Based Learning Model with Flow Experience

It is a GBL design model proposed by Abd Elsattar (2017) when developing a GBL called "A day without computer-mediated technology". The GBL design model is based on the PAT model (Finneran & Zhangy, 2003) and included with flow theory to maximize the learning outcome. Besides the elements from the original PAT model, such as a person, artifact, and task, the model has the other three key elements, which are challenge, response, and feedback. This model focuses the flow of the user during playing the game by creating a "magic circle" and allowing the user to deal with conflicts that are defined by the game rules.

2.9.6 Structural Design Computer Model-Based Games

It is a design model proposed by Yang and his colleagues (2018) to develop a computer game for elementary school students to learn mathematics. There are four main components in the model, which are setting the score, game regulations, story block, and music. All components act as a different type of connection for students and establish a personalized learning experience for students. Setting the score is used to show the performances of students, while the story block controls the learning contents and the flow of study. The music component creates a learning environment and gives hints for students to know which part needs to pay more attention to. Unlike the other GBL models that focused on game design itself, this model required the teacher to supervise students during playing games, so that teacher can adjust game level and monitor the students' progress. All information like scores of the game will be stored in the game database for analysis of students' progress.

2.9.7 Overview of Reviewed GBL Design Models

From the six GBL design models reviewed above, all propose different components and concepts for designing GBL. According to Plass and colleagues (2015), game design should consider the integration of cognitive, motivational, affective, and sociocultural dimensions to fully unleash the potential of GBL for educational purposes. However, each reviewed design model primarily focuses on specific aspects, such as cognitive (Tan et al., 2007; Zin et al., 2009), engagement (Kuk et al., 2012; Zin et al., 2009), motivation (Abd Elsattar, 2017; Kuk et al., 2012), and affective (Ruhi, 2015), with none addressing multiple dimensions simultaneously to provide a more comprehensive perspective. Therefore, a design framework called the Flow Framework for Educational Games (Kiili et al., 2014) was

chosen for the design model of mGBL in the present study, as it covers multiple dimensions at once, aligning with Plass and colleagues' (2015) statement about GBL design.

2.10 Flow Framework for Educational Games

Flow framework for educational games is a framework based on the flow theory proposed by Kiili and colleagues (2014), which aims to evaluate educational games and provide design guidance to the game producers. The framework is grounded in Csikszentmihalyi (1990)'s Flow Theory and focuses on integrating game elements that lead to a state of flow, such as clear goals, immediate feedback, appropriate challenge, and learner control (see Section 2.13.1 for further discussion on Flow Theory). Beyond game mechanics, the framework also includes five “mind lenses”, such as attention, memory, collaboration, engagement, and reflection, which connect flow experiences to cognitive and social learning processes. These mind lenses emphasize how gameplay can support meaningful learning by enhancing concentration, knowledge integration, and peer interaction (Kiili et al., 2012; 2014). In this study, the Flow Framework serves as a game design guide for structuring the mGBL application. It ensures that gameplay tasks are engaging, appropriately challenging, and aligned with learning objectives to support student focus and motivation while learning the Cell Division topic. The framework is as shown in Figure 2.1 below:

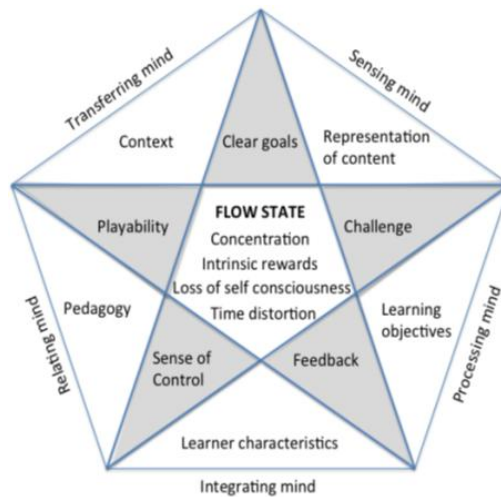


Figure 2.1: Flow Framework for Educational Games

Based on the flow framework, the flow dimensions can be divided into flow antecedents (the grey star in Figure 2.1) and the flow state, where the flow antecedents are the elements that influence the flow state and should be considered when designing educational games, while the elements of flow state describe the sensations of being in the flow. Next, the white triangles surrounding the star represent important elements that influence the design of the learning experience and GBL system. However, it is noteworthy that the sequence of antecedents is irrelevant in the model, and they do not purposefully bind to the elements in their environment. Last, the elements on the planes of the pentagon are the five mind lenses, which give a way to think about the game features systematically from the viewpoints of learning and interaction. The five mind lenses also link the flow dimensions to learning processes in the foundation of cognitivism and social constructivism.

2.10.1 Description of Flow Antecedents

2.10.1.1 Clear Goal

Provide a clear objective to the player so that the player can focus more readily on the learning activities. It is a good idea to have a clear main goal at the start of the game and

split the main goal into sub-goals and represent them at an acceptable level to generate a sense of accomplishment. If the objectives appear to be excessively difficult, the chances of feeling flow experience are few. In addition, the goals should be connected to the game's learning objectives to generate an effective educational experience.

2.10.1.2 Feedback

It aims to inform the player about his performance and progress toward the goals, to allow the tutor to monitor the learner's progress, and to build a feedback loop between the game and the level attained. The feedback element can be split into immediate feedback and cognitive feedback. The player is kept focused by the immediate feedback to prevent the player from waiting too long so that the player will not lose concentration on the learning task and jeopardize his learning process. For cognitive feedback, it allows the player to do reflection on his experiences and try solutions so that he may improve his mental models and playing tactics. In other words, it directs players' attention to material that is relevant to their learning goals.

2.10.1.3 Playability

Playability antecedent is introduced to replace Csikszentmihalyi's action-awareness merging element in the original flow theory, as it is irrelevant in the learning game setting. The reason is the action-awareness merging element states that all flow-inducing activities become spontaneous and automatic, but in fact, learning is an active and conscious process of knowledge production. So, for playability antecedent, it implies that game control should be instinctive and intuitive but learning content relevant to the task should be acquired and reflected consciously by the players. However, game designers should be careful not to oversimplify gameplay to the point that players can merely go through the game without engaging in deeper thought about the content.

2.10.1.4 Challenge

Challenge antecedent can be explained with the extended three-channel model of flow (Kiili et al., 2014) as shown in Figure 2.2 below.

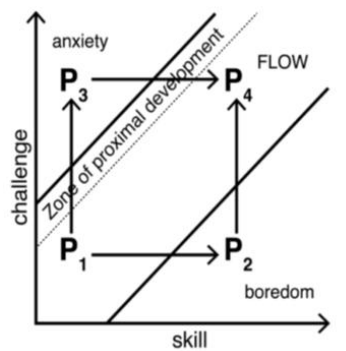


Figure 2.2: Extended Three-Channel Model of Flow

The model's axes represent challenge and skill, which are the key dimensions of flow. Optimal learning occurs when challenge and skill are balanced, creating a flow state free from anxiety and boredom, as shown in the linear channel from P1 to P4 in Figure 2.2. If a player feels bored (P2), increasing the challenge by selecting a harder goal can restore flow. Conversely, if a player is anxious (P3), improving skills helps return to flow. The extended three-channel model integrates Vygotsky's zone of proximal development, expanding the flow channel by encouraging collaboration to solve problems. Thus, designing learning games should consider the challenge-skill balance and include social learning elements like competition to sustain player flow (Kiili et al., 2014).

2.10.1.5 Sense of Control

The challenge-skill balance dimension is strongly linked to the sense of control antecedent. According to Csikszentmihalyi (1990), the sense of control refers to the possibility of the control rather than the fact of the control. In other words, when a person has developed sufficient abilities nearly to perfection, then the experience becomes

pleasurable. For instance, players will strive hard toward their goal to be high-skilled players as long as they are inspired or believe that they can reach the goal, even though unconsciously they are aware that they will never achieve such a level.

2.10.2 Description of Flow State

Based on the flow framework, the four elements in the flow state describe the characteristics of flow experience, which are concentration, intrinsic reward, loss of self-consciousness, and time distortion. When people reflect on their own flow experience, they usually mentioned some or all of the flow characteristics (Kiili, 2005). Using gameplay as an example, a person will be completely concentrated on the gameplay and forget about the unpleasant stuff. There are no cognitive resources left over for irrelevant information since flow-inducing activities require total concentration on the job at hand. As a result, the self appears to vanish from awareness and time seems to speed up or slow down. Last, intrinsic reward refers to an action that is done in a voluntary effort just because it is simply fascinating and enjoyable, without considering any advantages that can be obtained from it. In conclusion, the flow state act as a hook that keeps players engaged and encourages them to play games again and again.

2.10.3 Description of Mind Lenses

2.10.3.1 The Lens of the Sensing Mind

Sensory memory is related to the lens of the sensing mind. It highlights that people cannot pay attention to everything at the same time and must choose areas of interest from what they perceived, which is influenced largely by their prior knowledge. Hence, attention is employed to concentrate our mental capacity for sensory input so that the mind can process the stimulus of interest effectively (Duchowski, 2017). In the context of GBL design,

strategies like audio-visual effects can help capture players' attention, ensuring they focus on essential content aligned with learning goals.

2.10.3.2 The Lens of the Processing Mind

The lens of the processing mind emphasizes the limits of working memory, highlighting its constrained capacity and endurance. Game designers must carefully manage the number of elements presented simultaneously, eliminating unnecessary features to prevent information overload, as each element has a cognitive cost (Ketamo & Kiili, 2010). This aligns with CTML, which recommends removing redundant content in multimedia presentations (Mayer & Moreno, 2003), and CLT, which suggests reducing extraneous load to enhance learning (Sweller, 2010) without overwhelming working memory (Chang et al., 2018). Additionally, CTML's modality principle (Mayer, 2002a) supports using visual, auditory, and tactile channels together to optimize memory capacity.

2.10.3.3 The Lens of the Integrating Mind

The lens of the integrating mind focuses on long-term memory, highlighting its role in processing complex interactions as working memory has limited capacity. Based on CLT, linking prior knowledge with new information is essential for effective integration. Hence, game designers should create strategies to activate long-term memory based on players' knowledge levels, ensuring challenges and content align with target characteristics in GBL design.

2.10.3.4 The Lens of the Relating Mind

The lens of the relating mind, grounded in social constructivism, highlights the importance of shared learning experiences. Lave and Wenger's (1991) concept of legitimate peripheral participation views learning as a social process, where novices gradually gain

knowledge and skills through community involvement, eventually becoming experts. In multiplayer games, this process is evident as new players improve and achieve higher social status. Collaborative learning emphasizes teamwork to reach common goals and enhance outcomes (Zhong, 2019). Therefore, game designers should incorporate social mechanics, such as leaderboards and status systems, to foster interaction and motivation. Additionally, Kiili and colleagues (2014) suggested adding collaboration tools or involving teachers to support teamwork in game-based learning.

2.10.3.5 The Lens of the Transferring Mind

The lens of the transferring mind focuses on the transfer of learning, which is the ability to apply knowledge gained in one context to new situations. In game design, this means helping players apply what they learn in virtual environments to real-world problems. To facilitate this, designers should consider pedagogies like problem-based learning and focus on content representation to enhance learning transfer and maximize its benefits.

2.11 Reviews of Mobile Game Development Methodologies

A total of four mobile game development methodology were reviewed, including Stages in Mobile Game Development (Dulskiy, 2015), The Agile Process for Mobile Game Development and Testing (Helppi, 2015), Mobile Game Development Process (Acharya, 2017), and Android Game Development (Staff, 2018).

2.11.1 9 Stages in Mobile Game Development

Dulskiy (2015) proposed a nine-stage methodology for mobile game development, including generating a game idea, developing the concept, creating a proof of concept, drafting a game design document (GDD), prototyping, designing architecture, development, testing, and ongoing support. The process begins with defining the target audience and

purpose to generate a complete game idea. The concept, including mechanics, setting, technology, and interaction, is then established and verified. A GDD is created to detail the game design, followed by a prototype to test core mechanics and identify design flaws. Flexible architecture is then designed to handle rapid changes. The development and testing phases follow, and finally, the game is supported post-release with regular updates.

2.11.2 The Agile Process for Mobile Game Development and Testing

Helppi (2015) proposed an agile mobile game development process with five phases, including pre-production (concept development and design), production (implementation), post-production (testing), and deployment. Unlike traditional methods, this approach emphasizes continuous testing throughout all phases, not just post-production. He stated that ongoing testing can reduce development and testing time by up to 60%. The process involves logging and testing every activity during development to track progress and address issues immediately. Recommended testing activities include smoke testing, regression testing, connectivity testing, performance testing, localization, and functional testing with automation frameworks.

2.11.3 Mobile Game Development Process

Acharya (2017) proposed a mobile game development process with four steps, including concept, pre-production, production, and post-production. First, in the concept phase, a brief overview of the game is created, covering mechanics, setting, technology, and interaction. Mechanics define the rules, setting includes the story and aesthetics, technology refers to the target device, and interaction focuses on user engagement. Next, pre-production involves creating a game blueprint, visualizing concepts with graphics, and translating ideas into code, typically with the involvement of producers, designers, writers, artists, and

programmers. Then, in the production phase, the actual game development takes place, including creating assets like models and characters, and coding the game rules. Finally, post-production is the last phase, where the game undergoes testing for bugs by the quality assurance team. If any bugs are found, they are fixed before the game is launched.

2.11.4 Android Game Development

Staff (2018) proposed a development process with 9 phases for Android game development by Zco Corporation, consisting of project estimation, requirement analysis, game design, concept art, art development, development, quality assurance testing, launch, and maintenance. First, project estimation is based on client specifications, followed by requirement analysis and the creation of a storyboard. The game design and concept art phases occur simultaneously, with game design focusing on UI flow and mechanics, and concept art creating character sketches. In the art development phase, 3D game assets are made. Then, developers implement gameplay using a game engine, conducting testing and bug fixing. The game is tested on various devices during quality assurance testing to ensure compatibility. After user acceptance tests, the game is launched on the Android platform, with ongoing maintenance to update and fix bugs.

2.11.5 Overview of Reviewed Mobile Game Development Methodologies

From the four mobile game development methodologies reviewed above, all propose step-by-step processes for developing a mobile game. However, they are not suitable for developing mGBL, as they do not integrate learning content and instructional design into the mobile game development process. While these methodologies are generally applicable to mobile game development, they are not specific to mGBL. To develop an mGBL application that incorporates instructional design and provides a detailed step-by-step development

process, the mGBL engineering model (Shiratuddin & Zaibon, 2011) is the best choice and has been selected as the development methodology for mGBL in the present study.

2.12 mGBL Engineering Model

mGBL engineering model is a game development methodology proposed by Shiratuddin & Zaibon (2011), which is specifying for the design of mGBL. This model was introduced to fill the gap, which is a lack of literature exploration on educational game development (Fletcher & Tobias, 2006), especially mGBL.

The mGBL engineering model contains phases, components, activities, and deliverables. It has two layers, where the first inner layer is general phases, such as pre-production, production, and post-production. For the second layer, various detailed components are included for each phase, as shown in Figure 2.3. The flow of the mGBL engineering model starts from the pre-production phase and continues for the next phase in a clockwise direction. After completing each phase, a review will be made to make sure everything is fine, then proceed to the next until the final phase.

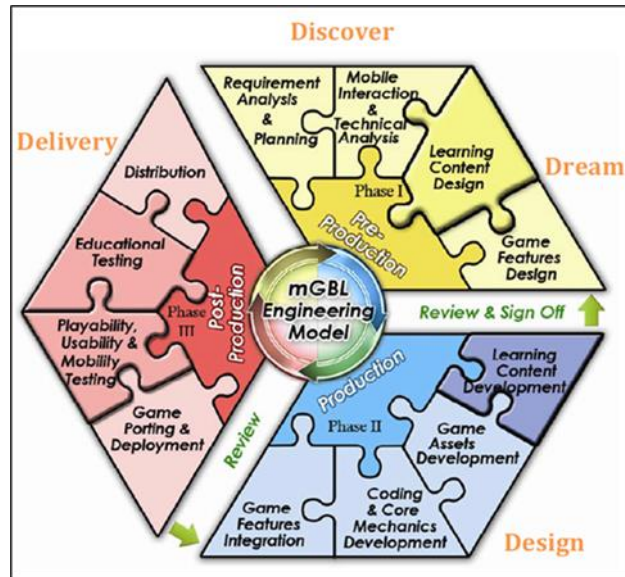


Figure 2.3: mGBL Engineering Model

Besides the step-by-step development guidelines as shown in the figure above, the mGBL model should be also included with several aspects, which are instructional design theories, learning model, learning content, and mGBL game characteristics. These aspects need to be referred by the mGBL developer to develop an educational game that can facilitate the learning process of users.

1M'sia mGBL is an example developed by the mGBL engineering model, which was made by Shiratuddin & Zaibon (2011). 1M'sia is a mGBL that promote the value of 1 Malaysia concept, where a player acts as a Malay character that faces with different situation and quizzes in the game. The mGBL fitted with different ID and learning theories, where it used Nine Events of Instructions as the design model while it used Experiential Learning Model, Problem-based Learning, and Multiple Intelligences as the learning theories behind the game.

2.13 Learning Theories

According to the review study done by Li and Tsai (2013), there are about 30% of the studies were conducted without using any learning theories, among GBL studies in science education. As mentioned by Wu and colleagues (2012), incorporating learning theories into the design of GBL is more likely to produce positive outcomes. Therefore, this section reviews five learning theories that have the potential to contribute to the design of mGBL applications, including flow theory, CLT, CTML, PBL, and collaborative learning. These theories were selected to support different aspects of the game design, where flow theory for engagement, CLT for managing cognitive load, CTML for multimedia learning, PBL for promoting problem-solving, and collaborative learning for enhancing peer interaction during gameplay.

2.13.1 Flow Theory

The Flow framework for educational games described previously is rooted in Flow Theory, originally proposed by Csikszentmihalyi (1990). Flow is defined as a state of complete engagement in a task, where a person is fully immersed and free from distractions (Csikszentmihalyi, 1990). During this experience, individuals feel focused, absorbed, and in control, with a sense of enjoyment and contentment (Chang et al., 2018). To induce flow, Csikszentmihalyi (2000) identified nine flow dimensions, where these dimensions can be divided into flow antecedents and flow characteristics (Swann et al., 2012). Flow antecedents are the essentials of flow, which include challenge-skill balance, clear goals, and unambiguous or immediate feedback dimensions. Flow characteristics explain how a person feels when they are in a state of flow, which includes the sense of control, action awareness merging, loss of self-consciousness, concentration, time distortion, and autotelic experience dimensions.

Flow theory has been widely applied in fields like sports, human-computer interaction, games, and education. Chan and colleagues (2021) suggest it is ideal for analysing how learners interact with GBL, which supporting Nakamura and Csikszentmihalyi's (2014) view that positive experiences, like gaming or studying, can enhance well-being. Recent studies highlight flow's importance in GBL, as it keeps learners engaged and focused. For examples, Lai and colleagues (2013) found that students in GBL experienced higher flow than those in computer-assisted learning. Next, Shen and Chu (2014) demonstrated that game interface design impacts flow, with better visibility and efficiency increasing learner focus. Additionally, Chan and colleagues (2021) found that game flow positively affects learning outcomes and engagement, particularly in cognitive dimensions.

Several game design models based on flow theory have been developed. For instance, Sweetser and Wyeth (2005) proposed GameFlow model that includes concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction. In GBL context, Kiili and colleagues (2012) proposed a flow framework for educational games, which successfully enhanced students' flow, especially in control, goals, and challenge-skill balance. Kiili and colleagues (2014) later adapted this framework by adding mind lenses to connect flow with learning processes from cognitive and social-constructivist perspectives.

In the context of mGBL, flow theory remains equally relevant. Admiraal and colleagues (2011) investigated the application of flow in a collaborative mobile game called "Frequency 1550", which merged digital and physical play spaces to teach secondary students about medieval Amsterdam. The study found that students who experienced greater flow during the game performed better in gameplay, although learning outcomes were influenced more by their engagement level and distractions. This suggests that flow in

mGBL can enhance performance and indirectly influence learning, especially when social and competitive elements are well-integrated and distractions are minimized.

These examples illustrate how flow theory can inform both the design and evaluation of mGBL applications by promoting learner engagement, managing distractions, and supporting motivation and concentration in mobile game environments.

2.13.2 Cognitive Load Theory (CLT)

CLT focuses on managing working memory as learners engage with instructional content (de Araujo et al., 2016). Since working memory has limited capacity, exceeding this limit reduces learning effectiveness (Davis, 2020). CLT aims to align information structures in learning materials with cognitive architecture, thereby optimizing working memory for learning (Paas et al., 2004).

According to CLT, there are three types of cognitive loads, including intrinsic, extraneous, and germane. Intrinsic load depends on task difficulty and the learner's skill level (Sweller et al., 2019) and is unaffected by instructional changes (Davis, 2020). Extraneous load involves distractions that hinder learning (Petko et al., 2020) and can be reduced by adjusting instructional presentation (Hawlitschek & Joeckel, 2017). Germane load refers to efforts to understand and integrate learning material, promoting deeper learning (Petko et al., 2020). The total cognitive load should not exceed the learner's working memory capacity (Huang & Johnson, 2009).

In instructional design, CLT emphasizes minimizing extraneous and intrinsic load to maximize germane load (de Araujo et al., 2016). De Jong (2010) recommended aligning content with prior knowledge, removing unnecessary information, and activating cognitive

processes to increase germane load. Additionally, Xu (2016) suggested reducing extraneous load in GBL by avoiding redundancy and providing helpful hints for mental integration.

Studies on cognitive load in GBL highlight its importance. Shen and Chu (2014) found that cognitive support in GBL systems improved flow, helping learners focus on content. For example, Chang and colleagues (2018) found that digital GBL resulted in better learning performance, flow, and lower cognitive load compared to traditional learning. Similarly, Es-Sajjade and Paas (2020) developed a math GBL system called “MATHERIAL”, which improved student performance. Furthermore, Petko and colleagues (2020) discovered that medium game speed minimized extraneous load while enhancing engagement and learning outcomes.

Several frameworks based on CLT have been developed for GBL. For instance, Huang and Johnson (2009) proposed a model combining game characteristics and cognitive perspectives to improve learning. Next, Davis (2020) developed a Game Framework Analysis model to evaluate educational game design for deeper learning. Finally, Bounajim and colleagues (2020) emphasized the importance of considering task variability, prior knowledge, and memory load in digital GBL design. These frameworks highlight the critical role of cognitive load in optimizing the learning process in GBL systems.

In the context of mGBL, CLT is crucial due to small screens and limited attention. Wang and colleagues (2018) found that students using a mobile app called as “Plant-E” with interactive decision-making showed higher mental effort and better performance than those using static content. This suggests that interactive complexity, when well-designed, enhances learning in mobile settings. Similarly, Liu and colleagues (2023) showed that extraneous load negatively affected both perceived and actual learning in mGBL, while

germane load improved perceived understanding. Their study highlights the importance of reducing distractions and designing meaningful tasks to support cognitive processing in mobile games. These findings confirm that applying CLT principles in mGBL, by balancing task difficulty, simplifying interface, and encouraging active learning can improve student engagement and outcomes.

2.13.3 Cognitive Theory of Multimedia Learning (CTML)

CTML is a learning theory popularized by Richard E. Mayer, which provides guidelines for optimizing learning through multimedia (Schrader & Rapp, 2016). Mayer (2002a) identified three key assumptions, including the dual-channel assumption, the limited capacity assumption, and the active processing assumption. The dual-channel assumption suggests that humans have separate visual and auditory processing channels. The limited capacity assumption states that each channel has a limited capacity for processing material simultaneously. The active processing assumption argues that meaningful learning occurs when learners actively engage in cognitive processing, such as selecting, organizing, and integrating relevant information with prior knowledge (Mayer, 1999, 2002b). Mayer (2002a) also proposed several design principles for multimedia instructional design, as shown in Table 2.2 below.

Table 2.2: The Summary of the Design Principles in Mayer's CTML

No.	Principles	Brief descriptions
1	Multimedia principle	Words and pictures together provide a richer learning experience than words alone.
2	Contiguity principle	Rather than providing words and pictures one after the other, display them all at once for deeper understanding.

Table 2.2 continued

3	Coherence principle	Get rid of unnecessary words, sounds, or pictures instead of adding them to allow deeper learning to occur,
4	Modality principle	When words are delivered as narration rather than on-screen text only, deeper learning occurs.
5	Redundancy principle	When words are delivered as narration rather than both narration and on-screen text, deeper learning occurs.
6	Personalization principle	When words are delivered in a conversational way rather than a formal style, deeper learning occurs.
7	Interactivity principle	When learners have control over the presentation rate, they learn more deeply than when they don't.
8	Signalling principle	When crucial phases in the narration are signalled rather than consignable, deeper learning occurs.

Several studies have explored CTML's design principles. For instance, Schrader and Rapp (2016) assessed the effects of motion and still pictures with or without signalling in multimedia presentations. Contrary to Mayer's signalling principle, they found no significant impact on learning outcomes, though all students showed improvements. In contrast, Xie and colleagues (2019) found that dual-modality signals in an online course helped learners focus on relevant content, enhancing retention and transfer performance.

Furthermore, CTML has been widely applied in educational contexts. Jeu and colleagues (2015) used CTML in language learning software, GBL, and visual presentations, leading to positive outcomes in both learning and motivation. Similarly, Shamim (2018) applied CTML in a medical surgery curriculum using video-based teaching, which resulted in high student satisfaction. Additionally, Baharudin and colleagues (2019) created a Powtoon video for teaching English literature, significantly improving student achievement.

In the mGBL context, Heng and Said (2020) further applied CTML to design a mobile game-based app for mathematics. Their study with Year 3 students showed significant improvements in motivation, performance, and problem-solving ability after the intervention. The design followed Mayer's principles by using narration, visuals, and interactivity to reduce cognitive overload and promote engagement. Positive feedback from student interviews also supported its effectiveness. Such findings affirm the value of CTML in mGBL design by guiding multimedia use to support memory, attention, and learning, especially when content is complex or abstract, such as in science and math subjects.

2.13.4 Problem-Based Learning (PBL)

PBL is a student-centred approach that emphasizes active learning and problem-solving, to boost critical thinking and problem-solving skills (Chang et al., 2015). It encourages applying prior knowledge, acquiring new information, and developing skills across contexts (Jin et al., 2014; Kong et al., 2014). PBL also promotes teamwork and positions teachers as facilitators (Hung, 2013). Its key features include problem-driven instruction, complex problems, and self-directed learning (Hung, 2013). Originally from medical education, PBL is now used across various fields.

Recent studies have examined the effectiveness of PBL. For instance, Loyens and other colleagues (2015) found that it led to greater conceptual changes in learning Newtonian laws. Similarly, Dolmans and other colleagues (2016) highlighted that PBL fosters deep learning and intrinsic motivation, with minimal impact on surface learning. Additionally, a systematic review by Merritt and other colleagues (2017) showed PBL's effectiveness in improving performance in elementary science education.

Moreover, PBL has been integrated into GBL. For example, Khoo and other colleagues (2005) explored how PBL occurred in multiplayer games like World of Warcraft, where players solve mission-related problems. In another study, Chang and other colleagues (2015) developed a PBL game for computer science students, which improved cognitive processes and received positive feedback. Furthermore, Chang and colleagues (2020) created “Programmer Adventure Land”, which enhanced satisfaction, motivation, and user interface experience among students.

In an mGBL context, Lee (2022) compared an AR-based mobile game and a printed game in a language learning setting, where both were designed using PBL principles. The AR game, titled “The Secret Investigation”, involved location-based gameplay and collaborative problem-solving. While both formats produced similar levels of engagement and positive attitudes, the AR game provided a more immersive environment, showing how PBL can be effectively embedded in mobile learning experiences. This supports the integration of narrative-driven and context-aware elements in mGBL to foster deeper learning through meaningful problems.

2.13.5 Collaborative Learning

Collaborative learning is a learning approach based on constructivist theory (Rabbany et al., 2014), which involves students working together towards a common goal, enhancing cognitive, communication, and critical thinking skills (Zhong, 2019). Key forms of collaborative learning include competition, discussion, cooperation, and role-playing (Zeng & Zhang, 2012). Furthermore, teachers play a crucial role in facilitating this process by encouraging students to share knowledge, improving their comprehension through diverse perspectives and critical thinking (Lipponen, 2002).

In terms of GBL, collaboration is widely recognized as a key feature of GBL, particularly for developing 21st-century skills (Qian & Clark, 2016). Specifically, collaboration in digital GBL enables players to interact and work towards common goals, fostering both engagement and persistence in gameplay (Chen et al., 2015b; Erhel & Jamet, 2013). In addition, competition in GBL creates a dynamic environment that motivates players, especially in scenarios involving human opponents (Mandryk et al., 2006).

There are several studies investigated collaborative GBL recently. For example, Terzidou and Tsiatsos (2011) developed a 3D collaborative game for undergraduates to learn “Multimedia Systems”, where students worked together to answer quizzes in a virtual environment. They also proposed the “GrAFiCA” model to guide the game design process. Similarly, Sung and Hwang (2013) introduced the “RACEG” system, a role-playing game for elementary students learning science, which significantly enhanced learning performance. Lastly, Zhong (2019) proposed a systematic game-based collaborative teaching model, integrating design strategies and collaborative approaches to improve educational outcomes.

In the mGBL context, Ramírez-Donoso and colleagues (2017) introduced “MyMOOCSPACE”, a mobile game app designed to support collaboration in online university courses. It increased interaction among learners, showing that mGBL can effectively scaffold collaborative learning even in remote settings. Additionally, Zakaria and colleagues (2018) used Kahoot in a mobile game-based assessment for a MOOC on ethnic relations. Their study revealed different learner performance patterns and highlighted that mGBL tools can boost engagement and support real-time collaboration and formative assessment. These studies reinforce that mGBL can foster collaboration by providing social

interaction, instant feedback, and gamified engagement, which are the key elements for 21st century learning.

2.14 Theoretical Framework of the Study

This study is grounded in a set of learning theories and design models that guide the development of a mGBL application for the Cell Division topic in Biology. The framework integrates both pedagogical and technological elements to ensure the effectiveness of the learning experience.

The game design is informed by the Flow Framework for Educational Games (Kiili et al., 2014), which emphasizes maintaining learner engagement through challenge-skill balance, clear goals, immediate feedback, and learner control. This framework also incorporates “mind lenses” that align with cognitive and social constructivist learning processes, promoting attention, reflection, and knowledge construction during gameplay.

To operationalize the development process, this study adopts the mGBL Engineering Model (Shiratudin & Zaibon, 2011), which provides a structured development lifecycle (pre-production, production, post-production) that incorporates game mechanics, content integration, learning objectives, and multimedia design.

The theoretical foundation is further strengthened by the incorporation of the following five learning theories, as shown in Table 2.3 below.

Table 2.3: Learning Theories and Their Applications in the mGBL Design

Learning Theory	Key Concept	Application in mGBL Design
Flow Theory	Learners achieve optimal engagement when challenges match their skill level, supported by clear goals and feedback (Csikszentmihalyi, 1990).	Informs game mechanics such as difficulty progression, real-time feedback, and immersive gameplay to maintain engagement.
Cognitive Load Theory (CLT)	Working memory has limited capacity. Effective learning occurs when extraneous load is minimized, and germane load is enhanced (Sweller et al., 2019).	Guides the design of interface and content to reduce cognitive overload, chunk information, and scaffold tasks to support memory and learning.
Cognitive Theory of Multimedia Learning (CTML)	Learners process information better through multimedia when words and images are presented together, using dual channels (Mayer, 2002).	Supports the use of audio, visuals, animations, and interactive elements in the game to aid retention and reduce split attention.
Problem-Based Learning (PBL)	Learning occurs through solving real-world problems that promote inquiry, reasoning, and application (Hung, 2013).	Game challenges involve solving tasks that simulate real-life problem-solving and promote deeper understanding.
Collaborative Learning	Knowledge is constructed through social interaction, peer discussion, and teamwork (Zhong, 2019).	Enables team-based features, peer discussion opportunities, and in-game collaboration to enhance social learning.

This integrated framework ensures that the mGBL application is not only engaging and interactive but also rooted in strong pedagogical principles. The alignment of learning theories, design models, and development strategies supports the study’s aim of improving students’ learning of the Cell Division topic.

2.15 Chapter Summary

In summary, this chapter discussed the literature review on broader key concepts related to play in the learning context and the use of games in education, narrowing down to gamification, GBL, and mGBL to provide insight and background on how they can benefit

the learning process. Existing studies on GBL and mGBL related to Biology and Cell Division learning were presented to provide a deeper context for the present study. Since the design and development of an mGBL application for Cell Division learning is the main focus of this study, several design models and development methodologies were reviewed and compared to determine the best choice for mGBL in this research. Ultimately, the Flow Framework for Educational Games (Kiili et al., 2014) was chosen as the design model, and the mGBL engineering model (Shiratuiddin & Zaibon, 2011) was selected as the development methodology for mGBL in this study. Additionally, several potential learning theories that can be incorporated into the design of the mGBL application were reviewed, including CLT, CTML, PBL, and Collaborative Learning.

CHAPTER 3

METHODOLOGY

3.1 Research Design

3.1.1 Design-Based Research

The present study employs a design-based research (DBR) methodology with a mixed-methods approach to address learning challenges in the Cell Division topic. DBR emphasizes collaboration between researchers and practitioners to identify authentic classroom problems, design and implement practical solutions, and iteratively refine both the intervention and theoretical understanding (Reeves, 2006; Scott et al., 2020). DBR offers several advantages for biology education research, including the integration of theoretical and methodological expertise from learning or cognitive scientists, which enhances research rigor and introduces biology educators to interdisciplinary methods (Lo et al., 2019). It also supports the adoption of evidence-based teaching practices by instructors who may not be education researchers and ensures that those involved in the project understand the learning objectives and theories behind the instructional tools they implement (Scott et al., 2020). By aligning practice with research, DBR helps ensure that interventions are both pedagogically sound and relevant to real-world teaching contexts.

3.1.2 Design-Based Research Framework for the Study

This study adapted DBR framework based on Reeves (2006), which consists of four iterative phases, which are Preliminary Research and Problem Analysis, Design and Development, Implementation and Evaluation, and Analysis, Reflection, and Iteration. Each phase was conducted collaboratively with Biology teachers and students and was

contextually embedded in the Malaysian Form 4 Biology curriculum to ensure that the intervention addressed authentic classroom needs.

At the centre of this DBR process was the principle of Context and Collaboration, which infused every phase of the study. The study was embedded in the Malaysian secondary school context and conducted in partnership with teachers and students. Biology teachers served as expert collaborators in problem identification, design validation, and classroom coordination, while students provided valuable user feedback during evaluation. This approach aligns with Reeves’ (2006) emphasis on researcher-practitioner collaboration to ensure that research outcomes are both scientifically robust and practically relevant to real-world teaching and learning. Figure 3.1 illustrates the DBR framework adapted for the present study.

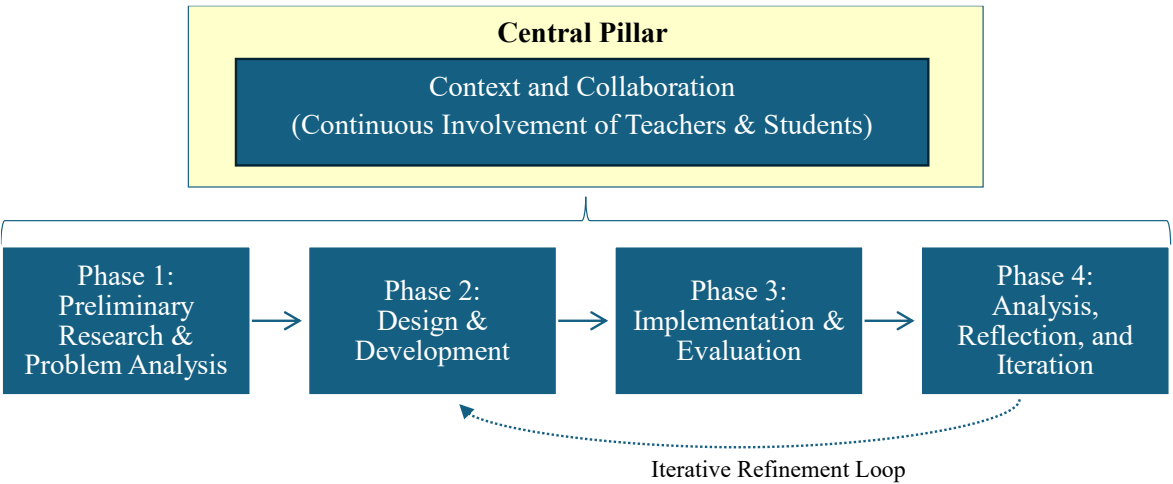


Figure 3.1: Design-Based Research Framework of Present Study

3.1.2.1 Phase 1: Preliminary Research and Problem Analysis

This phase aimed to ground the design process in real educational problems. The study began with a literature review and the development of a research plan, followed by a preliminary study to identify learning challenges in the Cell Division topic. Due to the COVID-19 pandemic in 2021, online interviews with Biology teachers and student self-administered questionnaires were used to diagnose these challenges. Semi-structured interviews were conducted to explore challenges from the teachers' perspectives, while student questionnaires via Google Forms gathered insights from a larger sample.

As presented by Quílez-Robres et al. (2021), many studies focus on cognitive factors affecting learning performance, often overlooking motivational, emotional, and social aspects. Therefore, the preliminary study collected data on learning challenges across cognitive, motivational, affective, social, and other perspectives to provide a more comprehensive understanding. Suggestions from students and teachers on improving learning were also gathered to guide the development of the mGBL application. The outputs of this phase were the problem statements, user-derived design requirements, and suggested strategies to support learning. These outputs directly informed the next phase of design and development.

3.1.2.2 Phase 2: Design and Development

This phase focused on constructing the mGBL application based on the findings of Phase 1. The development process was guided by learning theories such as Flow Theory, CLT, the CTML, PBL, and Collaborative Learning. The Flow Framework for Educational Games (Kiili et al., 2014) served as the instructional design framework, while the mGBL Engineering Model (Shiratuddin & Zaibon, 2011) provided a structured development

lifecycle. Collaboration with Biology teachers ensured that the game content was accurate and aligned with the national curriculum.

The application was reviewed and validated by software experts and Biology teachers to confirm its usability and content relevance. Pilot tests were then conducted to verify functionality before classroom implementation. The details of the design and development of the mGBL application will be discussed in detail in Chapter 5. The primary output of this phase was a high-fidelity, functional mGBL application ready for testing in real classroom settings. The application was then taken forward into the implementation and evaluation phase.

3.1.2.3 Phase 3: Implementation and Evaluation

This phase tested the feasibility, playability, and effectiveness of Cell% in authentic classroom settings. The researcher visited secondary schools to explain the study's purpose and demonstrate the application to students and Biology teachers. Informed consent forms were distributed before beginning the intervention. After that, students and teachers downloaded the application via a provided link and used it at home for two weeks as part of the intervention. The intervention schedule was coordinated with Biology teachers to align with their syllabus, while the researcher monitored participants' progress through the game's online database and provided support as needed.

After the intervention, participants evaluated the mGBL application's playability and effectiveness using a Google Forms questionnaire. The evaluation included both Likert-scale ratings and open-ended feedback from students and teachers to assess how well the game addressed the identified learning challenges. To ensure accurate responses, an online meeting was held via Google Meet, where the researcher explained each questionnaire item

and answered any participant questions. To reduce potential biases such as social desirability, students were reminded that their feedback would not affect their grades or standing in class and were encouraged to answer honestly based on their actual experience. The outputs of this phase were rich datasets on playability, user satisfaction, and evidence of the game's effectiveness in addressing learning challenges. These findings formed the basis for the final phase of reflection and iteration.

3.1.2.4 Phase 4: Analysis, Reflection, and Iteration

The final phase involved analysing the collected data and reflecting on the outcomes in relation to the research objectives. After completing data collection, the researcher organised the results in Microsoft Excel and analysed them using both quantitative and qualitative approaches. The details of the data analysis procedures are presented in Section 3.4.

The analysis evaluated whether the intervention achieved high playability and successfully addressed the challenges identified in Phase 1. The findings also highlighted contributing factors, limitations, and potential areas for improvement. Based on these reflections, recommendations were made for refining the game in future iterations. The outputs of this phase were twofold, which are practical insights in the form of specific improvements to the Cell% application, and theoretical contributions in the form of design principles for mGBL in Biology education.

3.2 Participants

The studies, including the preliminary study, were conducted in two urban secondary schools in Perak, Malaysia, referred to as “School X” and “School Y” to maintain anonymity. Purposive sampling was used to select participants who were most relevant to the study

objectives. Specifically, Biology teachers and Form 4 Biology students who had previously learned the Cell Division topic were selected, as they could provide informed perspectives on the learning challenges and effectiveness of the intervention. The number of participants varied depending on the number of Biology students in each school.

3.3 Instruments

Three instruments were used in the present study, including the Teacher Interview Protocol and the Student Self-Administered Questionnaire for the preliminary study, and an mGBL Evaluation Instrument for data collection to evaluate the mGBL application developed by the researcher. All instruments were slightly modified to suit the Malaysian secondary school context, especially by using simple English so that Form 4 students and their teachers could understand the questions easily. The content was also tailored to the Cell Division topic covered in Chapter 6 of the Form 4 Biology textbook, which is part of the Malaysian national curriculum.

3.3.1 Teacher Interview Protocol

According to Zohrabi (2013), the semi-structured interview is the most preferred type of interview because it is flexible and allows interviewees to provide more information than other formats. Therefore, the teacher interviews were conducted using a semi-structured approach, guided by an interview protocol. After explaining the purpose of the study and obtaining voluntary participation from the Biology teachers, the interview began with gathering demographic information about the teacher, such as their experience working as a Biology teacher. Next, questions were asked to identify students' challenges in learning the Cell Division topic from the teacher's perspective. These questions were adapted from Cimer's (2012) self-administered questionnaire on diagnosing learning difficulties in

Biology, with the interview questions modified to the learning challenges in the Cell Division topic from cognitive, motivational, affective, social, and other perspectives. Additionally, the interview included a request for suggestions from the Biology teachers on how to improve students' learning in this topic, as in Cimer's (2012) study. Table 3.1 below shows how items from Cimer's (2012) questionnaire were adapted to fit the present study's context.

Table 3.1: Adaptations of Cimer's (2012) Questionnaire for the Interview

Items in Cimer's (2012) questionnaire	Interview questions
Please write the possible reasons why you have found these topics, or biology in general, difficult to learn and understand?	Do you think students have difficulties in learning Cell Division topic from cognitive/ motivational/ affective/ social/ other perspective? Why?
What do you think makes your biology learning effective?	What do you think can help students to learn Cell Division topic more effectively?

3.3.2 Student Self-Administered Questionnaire

This questionnaire was designed by the researcher to determine students' difficulties in learning the Cell Division topic. It collects demographic information, such as name, school, and class, and includes questions to understand why students struggle with this topic from cognitive, motivational, affective, social, and other perspectives. Similar to the questions posed in the teacher interviews, the questions in this questionnaire were adapted from Cimer's (2012) self-administered questionnaire and distributed through an online Google Form to gather a large sample of student responses.

After demographic information section, the questionnaire begins by asking about the problems students face when learning the Cell Division topic from various perspectives, followed by questions that explore the reasons behind these difficulties. However, considering that secondary school students may find it challenging to express their struggles

in detail, predefined options were provided instead of open-ended questions to identify learning challenges. Each multiple-choice question required students to select only one option that best reflected their experience, rather than allowing multiple selections. This forced-choice format was intended to encourage students to reflect on their primary difficulty and allowed the researcher to identify the most prominent themes more systematically across the large sample. For instance, options like “the concept is hard to understand” and “hard to memorize” are provided to reflect common anticipated difficulties, allowing students to quickly select responses that are relevant to their experiences (see Figure 3.2). An “Other” option was also provided for each question, allowing students to write their own responses if the options did not capture their experience.

Following these multiple-choice questions, the questionnaire includes open-ended questions that explore the reasons behind these difficulties. Finally, it ends with an open-ended question requesting suggestions for improving students’ learning on the Cell Division topic.

1(a) From cognitive perspective, do you face any problems in learning Cell Division topic? (Please tick the most relevant option; if you didn't face the problem, please tick "No";) *

- ☐ The concept is hard to understand
- ☐ The concept is too abstract
- ☐ There are many foreign and complex terms in the topic
- ☐ Hard to memorize
- ☐ No, I didn't face any problems in learning Cell Division topic from cognitive perspective
- ☐ Other: _____

Figure 3.2: Example of a Multiple-Choice Question in Student Self-Administered Questionnaire

3.3.3 mGBL Evaluation Instrument

This questionnaire was developed by the researcher to evaluate the mGBL application. It contains three sections, including demographic information (Section A), the mGBL's playability evaluation questionnaire (Section B), and the evaluation of Cell% in addressing learning challenges (Section C).

In Section A, the questionnaire collects demographic information, such as name, school, and class for students, and teaching experience in Biology for Biology teachers.

Section B aims to evaluate the playability of the mGBL application developed by the researcher. This section was adapted from an instrument created by Zaibon & Shiratuddin (2010) to assess the playability of an mGBL application in terms of Game Usability, Mobility, Gameplay, and Learning Content using a Likert scale. The Game Usability component describes the player's interaction with the game through the game interface and game controls. Game Mobility refers to how easily a player can access the game world and play at any time and from any location. Gameplay assesses how the game functions, ensuring it runs smoothly and consistently while providing an engaging and meaningful experience that keeps players interested and entertained. Learning Content emphasizes delivering informative, useful, and comprehensible material to users while they engage with the mGBL application. Playability is calculated by averaging these components. An mGBL application with high playability indicates good quality in usability, mobility, gameplay, and learning content aspects as an educational mobile game. Considering that secondary school students may find it difficult to understand the questions in the questionnaire, the original questions from Zaibon & Shiratuddin (2010) were rephrased in simpler words with the assistance of

the supervisor and were accompanied by relevant screenshots from the game scenes to ease the participants' comprehension and ensure they fill out the questionnaire accurately.

Section C aims to evaluate the effectiveness of the mGBL application developed by the researcher in addressing the learning challenges identified in the preliminary study. The questionnaire in this section was developed by the researcher with the assistance of the supervisor. It begins by asking participants to rate a particular learning experience while using the mGBL application on a 5-point Likert scale, in which indicating their agreement with the statement. This is followed by an open-ended question asking for the reasons behind their rating in the previous question. Each question corresponds to a specific learning challenge identified in the preliminary study, as shown in Table 3.2 below. Finally, this section ends with an open-ended question to collect comments and suggestions for improving the mGBL application.

Table 3.2: Questions Correspond to Specific Learning Challenges Identified in the Preliminary Study

Perspectives	Questions	Corresponding Problems
Cognitive	Do you think that playing Cell% can help students remember the learning content of the Cell Division topic more easily?	Hard to memorize the content
	Do you think that playing Cell% can help students distinguish and understand the complex terms in the Cell Division topic?	Complex terminology
	Do you think that playing Cell% can help students understand the concept of Cell Division topic more easily?	The concept is hard to understand
	Do you think that playing Cell% can help prevent students from being confused when learning the Cell Division topic?	Misconceptions
	Do you think that playing Cell% can help students learn the abstract topic of Cell Division better?	The topic is too abstract

Table 3.2 continued

Motivational	Do you think that playing Cell% can increase students' interest on the learning content of Cell Division topic?	Not interested in the learning content
	Do you think that playing Cell% motivates students to learn the Cell Division topic, regardless of its difficulty?	Lack of motivation due to the topic's difficulty
	Do you think that playing Cell% make students more active when learning the Cell Division topic?	Students are passive in class
Affective	Do you think that playing Cell% make learning of the Cell Division topic more enjoyable?	Learning process is not enjoyable
	Do you think that playing Cell% makes students feel more positive toward the Cell Division topic?	Have negative feelings towards the topic
Social	Do you think that playing Cell% can increase students' social interaction with others when learning the Cell Division topic?	Lack of social interaction in class
	Do you think that playing Cell% makes students feel they are learning with others when studying the Cell Division topic?	Feeling of isolation during topic study
	Do you think that playing Cell% gives students more opportunities for group learning when studying the Cell Division topic?	Lack of opportunities for group learning

3.4 Data Analysis

The present study employs a mixed-methods approach, involving both quantitative and qualitative data. In this section, the analysis of both types of data collected from the study is presented based on five specific analyses derived from the research objectives, as shown below:

- i. Learning challenges in the Cell Division topic from students' and teachers' views.

- ii. Strategies from students and teachers to improve Cell Division learning.
- iii. Playability of the mGBL application.
- iv. Effectiveness of the mGBL application in addressing learning challenges.
- v. Feedback from students and teachers to enhance the mGBL application.

3.4.1 Learning Challenges in the Cell Division Topic From Students' and Teachers' Views

For this section, qualitative data collected from the preliminary study, including teacher interview recordings and responses from open-ended questions in the student self-administered questionnaire, were used for data analysis.

The audio recordings from the teacher interviews represent the views of Biology teachers on the learning challenges students face in the topic of Cell Division. The analysis involved transcribing the audio recordings, reviewing the transcripts, and highlighting key words or phrases related to learning challenges. After that, similar codes were grouped into main categories, which were then organized into cognitive, motivational, affective, social, and other perspectives. Last, the findings were summarized and explained in a report. The data analysis process is as shown in Figure 3.3 below.

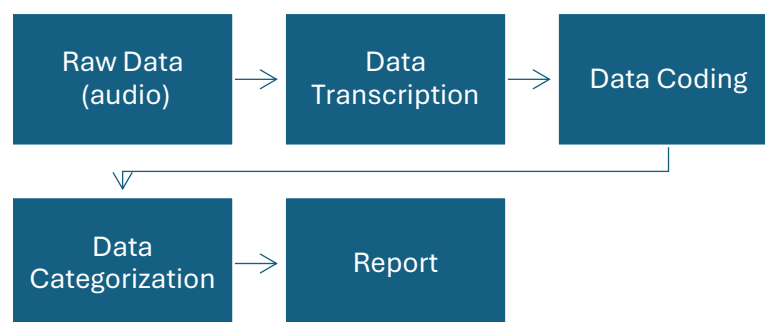


Figure 3.3: The Data Analysis Process for Interviews

The responses from open-ended questions in the student self-administered questionnaire represent the students' views on the learning challenges they face in the topic

of Cell Division. The data analysis followed a process similar to the teacher interview analysis but without transcription. First, data from Google Forms was imported into Microsoft Excel for organization and cleaning. Key words, phrases, or sentences related to learning challenges were highlighted, coded, and grouped into main categories. These categories were organized into cognitive, motivational, affective, and other perspectives, with their frequencies calculated. The findings were summarized and explained in a report, as shown in Figure 3.4 below.

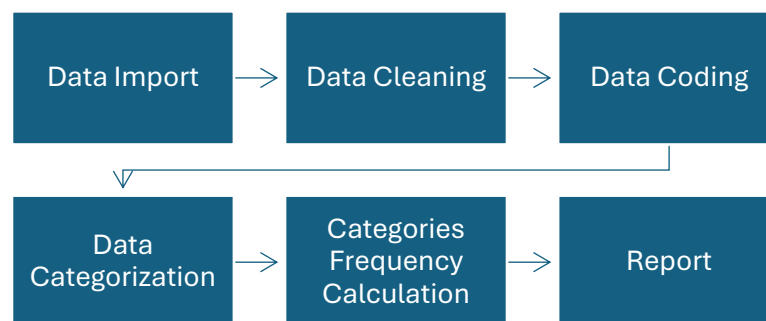


Figure 3.4: The Data Analysis Process for Open-Ended Questions

Overall, by following these data analysis processes, the learning challenges in the topic of Cell Division from both students' and teachers' views could be identified.

3.4.2 Strategies From Students and Teachers to Improve Cell Division Learning

For this section, qualitative data collected from the preliminary study, including teacher interview recordings and responses from the last open-ended question asking for suggestions and strategies in the student self-administered questionnaire, were used for data analysis.

The teacher interview recordings and student questionnaire responses provided strategies to enhance learning in the Cell Division topic from the views of teachers and

students, respectively. Both datasets were analysed similarly to the processes in Figures 3.3 and 3.4, including coding, categorization, and frequency calculations.

Overall, by following these data analysis processes, the strategies from both students and teachers to improve Cell Division learning could be identified. Since the main research objective is to design and develop an mGBL application, the potential strategies that are relevant to this goal were highlighted and used as references in the design and development process of the mGBL application.

3.4.3 Playability of the mGBL Application

For this section, the quantitative data collected from Section B of the mGBL evaluation instrument was used for data analysis. Since both students and Biology teachers were the users of the mGBL application developed by the researcher, data from all participants were included in the analysis to evaluate the playability of the application.

Section B of the mGBL evaluation instrument is a questionnaire adapted from Zaibon and Shiratuddin's (2010) study to evaluate the playability of an mGBL application using a 5-point Likert scale. There are a total of 27 questions in the questionnaire, divided into four components, including Game Usability (GU), Mobility (MO), Gameplay (GP), and Learning Content (LC). Before starting the data analysis, each question was labelled with its corresponding item code and component, as shown in Table 3.3 below, to organize the data and facilitate the analysis process later.

Table 3.3: Components and Their Corresponding Questions in Section B of mGBL Evaluation Instrument

Components	Code	Questions
Game Usability	GU1	I think the game's sounds and visuals are helpful
	GU2	I think the screen layout is clear and looks nice
	GU3	I think the device's interface and the game's interface are designed well for their own purposes
	GU4	I find the navigations in the game easy to use (Example: It is easy for me to navigate to other screens in the game)
	GU5	I think the game control keys always follow the usual way
	GU6	I think that the game controls are easy to use and adaptable
	GU7	I feel that the game provides responses to what the player does
	GU8	I believe that if I make a mistake in the game, I can fix it later
	GU9	I think the game does not require me to remember unnecessary things
	GU10	I think the game provides assistance or help when needed (Example: The game provides instructions during gameplay)
Game Mobility	MO1	I think it's easy to start the game and play sessions quickly
	MO2	I think the game fits well with the surroundings (Example: I can play the game anywhere without any problems)
	MO3	I think that the game deals with interruptions in a reasonable way (Example: I can pause the game at any time and continue to play later)
Gameplay	GP1	I think the game clearly sets goals or helps players create their own goals
	GP2	I can see my progress in the game and compare it
	GP3	I receive rewards in the game and these rewards are meaningful (Example: Get badges when unlocked achievements)
	GP4	I have control over the game (Example: I know what happening in the game and I know what to do in the game)
	GP5	I think that the game's difficulty, strategy, and pace are well-balanced (Example: The game levels are not too easy and too hard for me, and I can play the game with my own way and pace)
	GP6	I had a good experience when I played the game for the first time

Table 3.3 continued

	GP7	I think that the game story helps the gameplay and is meaningful
	GP8	I think the tasks in the game are not repetitive and boring
	GP9	I think that the game keeps progressing smoothly without getting stuck or becoming boring
		I think the game is consistent
	GP10	(Example: The actions or the way to play the game are uniform and logical)
	LC1	I can learn the Cell Division topic easily by playing the game
	LC2	I think the game teaches about the Cell Division topic
	LC3	I think the game accomplishes its learning goals (Example: I learned all Cell Division phases such as Mitosis, Meiosis I and Meiosis II from the game)
	LC4	I think the learning content is easy to understand

The data analysis for this section followed the same approaches as Shiratuddin and Zaibon (2011). First, the mean score for each item was calculated based on the ratings given by the participants. The mean score for each item indicates the overall level of agreement among the participants regarding that specific item. Next, an overall mean for each component was calculated to obtain the overall rating for the components. A higher overall mean for a component indicates a higher rating of the mGBL application in that area. To assess the playability value of the mGBL application, the average of the four components was calculated, as shown in Equation 3.1 below.

$$\text{Playability} = \frac{GU + MO + GP + LC}{4} \quad \text{Equation 3.1}$$

Since a 5-point Likert scale was adopted, the response classifications from Brace (2004) were used to determine the Playability for the mGBL application, as suggested by Shiratuddin and Zaibon (2011). The response classifications are shown in Table 3.4 below.

Table 3.4: Response Classifications by Brace (2004)

Interval	Classes
1.00 - 1.80	Highly low
1.81 - 2.60	Low
2.61 - 3.40	Moderate
3.41 - 4.20	High
4.21 - 5.00	Highly high

To ensure that the mGBL application developed by the researcher meets the needs of all users, a benchmark for high playability was set. The playability value should be at least 3.41 to fulfil the research objective of designing and developing an mGBL application with high playability.

3.4.4 Effectiveness of the mGBL Application in Addressing Learning Challenges

For this section, both quantitative and qualitative data collected from Section B of the mGBL evaluation instrument were used for data analysis. The quantitative data consisted of participants' ratings of their learning experiences while using the mGBL application on a 5-point Likert scale, while the qualitative data came from participants' responses to open-ended questions asking for reasons behind each learning experience.

Before starting the data analysis, the data from the mGBL evaluation instrument was imported from Google Forms into Microsoft Excel for organization and data cleaning. Then, the data was divided into two spreadsheets, one for the students' group and one for the teachers' group, based on the demographic information provided by participants. This step is to allow the comparison between these groups in the analysis.

3.4.4.1 Quantitative data

The analysis of the participants' ratings of their learning experiences with the mGBL application followed these steps. First, the mean score for each item was calculated, reflecting the overall agreement on that item. Higher mean scores indicated greater effectiveness in addressing learning challenges identified in the preliminary study (see Table 3.2). Using a 5-point Likert scale, Brace's (2004) response classifications (Table 3.4) were applied to describe the effectiveness of the mGBL application. With the study's goal of addressing learning challenges, the benchmark was set to "high" or "highly high", with a mean score of at least 3.41. Finally, the findings for both student and teacher groups were presented and explained in a report.

3.4.4.2 Qualitative data

The qualitative data analysis of participants' open-ended responses is similar to the process in Figure 3.4, involving reviewing, coding key words or phrases, and calculating code frequencies. Findings for both student and teacher groups were then presented and explained in a report.

3.4.5 Feedback From Students and Teachers to Enhance the mGBL Application

For this section, qualitative data collected from the final open-ended question in Section C of the mGBL evaluation instrument, which asked for comments and suggestions to enhance the mGBL application developed by the researcher, were used for data analysis.

Before analysis, data from the mGBL evaluation instrument was imported from Google Forms into Excel for organization and cleaning. It was divided into separate spreadsheets for students and teachers, to enable group comparison. Then, the responses were coded and categorized, by following the steps in Figure 3.4.

Overall, by following these data analysis processes, suggestions from both students and teachers to enhance the mGBL application were identified. These suggestions serve as references for the researcher to improve the mGBL application in the next design-based research cycle for future studies.

3.5 Reliability and Validity

Based on Kubai (2019), the research instruments should be created to accurately measure what the study aims to investigate and to make sure the results are useful and meaningful. Hence, reliability and validity of the instruments should be checked to ensure the trustworthiness of the research findings. Validity refers to what an instrument measures and how effectively it does so, while reliability focuses on the accuracy of the data collected and how well a measuring tool minimizes random errors (Ahmed & Ishtiaq, 2012).

The reliability and validity of the study's instruments were established through several methods. First, the teacher interview protocol and student self-administered questionnaire were based on validated tools from prior research, which were adapted from Cimer's (2012) instrument for identifying learning challenges in Biology. Also, Section B of the mGBL evaluation instrument was adapted from Zaibon & Shiratuddin's (2010) tool, which evaluates the playability of mGBL application. Using these recognized tools helped make sure that the study's instruments were reliable and met research standards.

Section C of the mGBL evaluation instrument, which was used to evaluate the effectiveness of the application in addressing learning challenges, was developed by the researcher. To enhance content validity, this section was reviewed and validated by the researcher's academic supervisor, an expert in learning sciences. Her feedback ensured that the questions were aligned with the challenges identified in the preliminary study and were

clearly understandable for the participants. The supervisor's guidance also helped simplify the complex language in the instruments, especially in the mGBL evaluation instrument, making the questions more understandable for secondary school students. These expert inputs were important to ensure that each instrument accurately measured its intended purpose, in which supporting the study's validity.

Although no statistical reliability index such as Cronbach's alpha was calculated for the adapted or self-developed items, efforts were made to ensure clarity and consistency. A pilot test was conducted with a small group of former Form 4 Biology students to confirm the clarity of the instruments. Feedback from these pilot tests helped the researcher ensure that the questionnaire items were understandable and appropriate. This process supported the content validity of the instruments used in the study.

Additionally, data collection was conducted through online meetings rather than simply sharing the Google Form link with participants. During these meetings, the researcher explained each question and allowed participants to ask clarifying questions if they found any items confusing. This approach improved the accuracy of participants' responses, thereby enhancing the reliability and validity of the data.

To minimize potential biases such as social desirability, participants were reminded that their responses would not affect their academic performance. They were encouraged to answer honestly based on their actual experiences and were assured that there were no right or wrong answers.

3.6 Ethics

Before conducting the study in government schools to collect data, the researcher sought permission from various local authorities, including the Education Planning and Research Division (EPRD) of the Ministry of Education Malaysia, the State Education Department (JPN), the District Education Office (PPD), and the school administrators. Data collection in government schools was initiated only after obtaining approval letters from all these departments.

Prior to conducting data collection, all participants in the study were provided with informed consent forms, which they signed to indicate their voluntary participation. The informed consent form of students was signed by their parent or guardian. The informed consent form clearly explained the purpose of the study and informed participants about its nature. Furthermore, it assured participants that their identities and all collected information, including audio recordings during interview sessions, would be treated as confidential and used solely for research purposes. Additionally, participants were informed of their right to withdraw from the research intervention or decline to complete the questionnaire at any point without any consequences or obligations. This ensured that the study was conducted in an ethical and respectful manner, respecting the autonomy and privacy of the participants.

The study has also acquired consent form UNIMAS Research Ethics Committee (Social Sciences). The instruments have been vetted and verified.

3.7 Chapter Summary

In summary, this chapter discussed how the present study was conducted to obtain findings that align with the research objectives. The study employs design-based research with mixed methods, following the cyclical process of design-based research while collecting quantitative and qualitative data. It began with a preliminary study to diagnose learning challenges in Cell Division from the views of both teachers and students, by using interviews with Biology teachers and self-administered questionnaire for students. Based on the learning challenges identified in the preliminary study, an mGBL application was developed and implemented for students and Biology teachers to use for about two weeks. The mGBL application was then evaluated by the participants using the mGBL evaluation instrument. This chapter also discussed data analysis, reliability and validity of the instruments to ensure the findings from the study were meaningful. Finally, this chapter ends up with the ethical statements to clarify the ethics of the present study.

CHAPTER 4

LEARNING CHALLENGES IN THE CELL DIVISION TOPIC

4.1 Overview

A preliminary study was conducted in 2021 to identify the challenges faced by secondary students learning the Cell Division topic, where the schools were still operating in online class mode. Self-administered questionnaires were used to investigate the issues from students' perspectives, while teacher interviews were conducted to understand the problems from teachers' perspectives. This section presents demographic information, data coding and tabulation, learning challenges from multiple perspectives, and strategies that could help in learning the Cell Division topic based on both students' and teachers' views.

4.2 Demographic Information

A total of 34 participants from School X and School Y were involved in the study, including 31 students and 3 teachers. Their demographic information is presented below.

4.2.1 Demographic Information of Students

There were 31 Form 4 Biology students have participated in the preliminary study, where 23 students were from School X and 8 students were from School Y. Their demographic details are as shown in Table 4.1.

Table 4.1: Demographic Information of Students

Information		Number of students
School	School X	23
	School Y	8
Total		31

Table 4.1 continued

Gender	Male	13
	Female	18
	Total	31
Age	15 years old	1
	16 years old	29
	17 years old	1
	Total	31
Race	Malay	8
	Chinese	18
	India	5
	Total	31

Besides demographic questions, the question “Do you play mobile games?” was included in the demographic section of the questionnaire to obtain the number of students who play mobile games. Table 4.2 shows the number of students who play mobile games. There were 77% of students play mobile games while the remaining 23% don’t play mobile games. Therefore, it can be concluded that a majority of students play mobile games, and most of the students were familiar with mobile gaming.

Table 4.2: Number of Students Who Play Mobile Games

Do you play mobile games?	Number of students	Percentage
Yes	24	77%
No	7	23%
Total	31	100%

4.2.2 Demographic Information of Teachers

Three Biology teachers from two different schools, which are School X and School Y were interviewed for the preliminary study. The summary of the teachers' demographic information is manipulated in Table 4.3 below.

Table 4.3: Demographic Information of Teachers

Teacher	School	Working experience as a Biology teacher
Teacher A	School X	20 years (Form 4 & Form 5)
Teacher B	School Y	12 years (8 years for Form 4 & Form 5 + 4 years for Form 6)
Teacher C	School Y	5 years (Form 4 & Form 5)

4.3 Data Coding and Tabulation

In this part, the data collected from the students' questionnaires and the transcripts of the teacher interviews were coded and categorized into two main categories, which are the definite problem and indefinite problem, as described below:

- i. **Definite problem:** The data that clearly identifies specific problems faced by the respondent. These problems are well-defined and provide concrete examples of difficulties, such as "hard to memorize the content" and "not interested in the learning content". The data was presented with the coded problems in data tabulation.
- ii. **Indefinite problem:** The data that is vague or lacks specificity regarding the problem. This data reflects uncertainty or does not specify any problem, such

as “no problem” and “not sure”. The data was presented with “Indefinite problem” in data tabulation.

After categorizing the data into two main categories, the responses were further classified into different reason categories, which were derived from recurring themes in the responses. For each problem, the given reasons and sample quotations by the respondents were presented as support. The frequency of these problems and their reasons was calculated. The results were presented in tables from the students’ and teachers’ views, based on cognitive, motivational, affective, social and other perspective.

The coding and theme development were conducted by the researcher based on recurring patterns and key ideas in the data. While no formal inter-rater validation was conducted, efforts were made to ensure consistency and transparency throughout the process. Future studies may consider involving additional coders to further strengthen the reliability of the qualitative analysis.

4.4 Learning Challenges in Cell Division Topic from Different Perspectives

In this section, the learning challenges in the Cell Division topic are discussed from cognitive, motivational, affective, social, and other perspectives. Each perspective is divided into students’ views, teachers’ views, and an overall summary.

4.4.1 Cognitive Perspective

4.4.1.1 Students' Views

Table 4.4: Students' Views on the Cognitive Challenges in the Cell Division Topic

Problem	Reason	Sample excerpts	Frequency
Hard to memorize the content	Many contents/ concepts need to be memorized	"There are so many contents I have to memorize it" (S15)	25.81%
	Spent more time memorizing the topic	"...I need time to memorize this chapter even more" (S22)	6.45%
Total			32.26%
The concept is hard to understand	A lot of concepts and differences from the Form 3 syllabus	"There are a lot of concepts that are different and elevated from the form 3 syllabus" (S23)	9.68%
	Cannot understand the explanation of the teacher	"...When the teacher explained it, I couldn't understand it at all..." (S14)	3.26%
Total			12.90%
Complex terminology	Hard to memorize and confuse the new terms in the topic	"It is hard to memorize the terms in the topic. I always confuse the terms 'chromosomes' and 'chromatids'" (S13)	12.90%
Total			12.90%
Indefinite problem	No problem as the topic is easy	"It is an easy topic" S16	6.45%
	No problem found	-	35.48%
Total			41.94%

Table 4.4 shows the problems faced by students in learning Cell Division topic from the cognitive perspective. According to the data, there are three main problems faced by students in the cognitive perspective, which are hard to memorize the content, the concept is

hard to understand, and complex terminology. First, students have memorization problem in learning Cell Division topic because there are too many contents and concepts in the topic need to be memorized, such as the stages in the cell division process. Also, students need to consume more time to memorize the content of the topic. Next, the concept in Cell Division is hard to understand by students as the topic is very different from the previous Form 3 syllabus, which may cause a huge gap when studying the topic. Besides that, there is a student who cannot understand the explanation of the teacher in class, which leads to difficulty in understanding the concepts in Cell Division topic. Last, there are many foreign and complex terms in the topic, which made the students hard to memorize and confuse about them, such as the terms of “chromosomes”, “chromatids”, and “cytokinesis”. For indefinite problem, 41.94% students found no problems in cognitive perspective, where 6.45% of them provided reasons with the topic is easy. Overall, there are eighteen students faced problems in learning Cell Division topic from cognitive perspective, while the remaining thirteen students have no problem with it.

4.4.1.2 Teachers' Views

Table 4.5: Teachers' Views on the Cognitive Challenges in the Cell Division Topic

Problem	Reason/ Elaboration	Sample excerpts
Hard to memorize the content	There are many stages in cell division that need to be memorized	“...the cell division has many stages starting from mitosis and meiosis... They have to memorize each stage in the cell cycle, during the cell division” (Teacher A) “...they need to know and memorize the sequences, the stages, what happen in a certain stage... The problem is there are a lot of cell division processes that need to be learned by the students...” (Teacher B)

Table 4.5 continued

Misconception	Difficult to differentiate the cell division processes	“There are two processes, mitosis and meiosis and certain students cannot differentiate them” (Teacher A)
	Confuse in learning chromosome behaviour	“For example, the chromosomal behaviour during each stage in mitosis or meiosis... they're a bit confused the stage” (Teacher A)
		“...they faced the problem of differentiating the process between prophase and metaphase” (Teacher C)
Complex terminology	Many specific terms need to be memorized	“... there are a lot of specific terms for them to memorize” (Teacher C)
	Confuse with some similar specific terms	“Yes, like homologous chromosomes, chromatids... they sound alike. Maybe the students are confused about it” (Teacher B)
The topic is too abstract	Hard to visualize the concept	“...the students need to imagine and at the same time, they need to memorize the order of the cell division process...” (Teacher B)

Table 4.5 presents the teachers’ view on the problems in learning the Cell Division topic from the cognitive perspective. First, all teachers agreed that memorization challenges are a significant issue for students in learning Cell Division topic. This memorization challenge arises from the vast learning content that students need to memorize, such as the stages in the cell division process. Next, Teacher A and Teacher C noted that students often have misconceptions while learning Cell Division topic. According to them, the students usually struggle to differentiate between processes such as mitosis and meiosis, or stages like prophase and metaphase. Also, the students always confused about the chromosome behaviour in mitosis and meiosis. Additionally, the topic’s complex terminology, including many similar sounding terms, adds to the confusion of students in learning Cell Division topic. As mentioned by Teacher C, there are a lot of specific terms in the Cell Division topic that need to be memorized by the students. Teacher B further emphasized that many of these

terms are sound alike, which can confuse the students and lead to misconceptions. Last, the abstract nature of Cell Division topic makes learning process even challenging, as students must visualize the cell division processes like chromosomal behaviours which cannot be observed with the naked eye. Teacher B explained that visualizing these processes, such as the chromosomal behaviours in mitosis and meiosis, is essential but difficult for students.

Overall, teachers found that memorization challenges, misconceptions, complex terminology, and the topic's abstract nature were the problems in learning the Cell Division topic from the cognitive perspective. During the interview, Teacher B also described Cell Division as one of the most challenging topics in Biology, as it requires students to engage in multiple cognitive processes simultaneously, as shown in the excerpt below:

For me, there's a lot of cognitive process in learning this process, like comprehension, memorization, and misconception also may happen at the same time. (Teacher B)

4.4.1.3 Overall for Cognitive Perspective

From the cognitive perspective, one primary challenge is the extensive amount of content in Cell Division topic that students need to memorize. This includes various stages of cell division, and students have reported difficulties due to the bulk of memorization that had to be covered in the topic required for the topic (Cimer, 2012; Hadiprayitno et al., 2019; Ozcan et al., 2014). Evidence of this struggle is reflected in the findings, where 32.26% students and two teachers noted that memorizing the content was difficult. Furthermore, the complex terminology poses a problem, as indicated by feedback from 12.90% students and two teachers, who reported that students often confuse with the terms like “chromosomes” and “chromatids”. This problem aligns with Kılıç and colleagues (2016), who argued that similar-sounding or visually alike terms can confuse students.

Additionally, 12.90% students indicated challenges in understanding the concepts in Cell Division topic, supporting the claims made by Doğru and Özsevgeç (2018) that concepts in Cell Division and genetics were hard to grasp and comprehend. Another notable challenge mentioned by participants (2 teachers) was the misconceptions, especially regarding the differences between mitosis and meiosis, which led to difficulties in distinguishing between the two processes (Dikmenli, 2010; Murtonen et al., 2020). These difficulties in memorizing content and understanding concepts may be interrelated. Students who do not fully grasp the underlying processes of cell division are more likely to rely on surface memorization, making it harder to retain complex sequences such as the stages of mitosis and meiosis. Without conceptual clarity, memorization becomes mechanical and less meaningful, increasing the likelihood of confusion and forgetfulness. Lastly, the abstract nature of Cell Division topic is another challenge pointed out by one teacher, because the topic requires higher-order thinking skills to comprehend processes that are not directly observable, as supported by Kılıç and colleagues (2016).

4.4.2 Motivational Perspective

4.4.2.1 Students' Views

Table 4.6: Students' Views on the Motivational Challenges in the Cell Division Topic

Problem	Reason	Sample excerpts	Frequency
Not interested in the learning content	The topic is too boring	"It is boring when learning about cell division" (S25)	19.35%
Total			19.35%

Table 4.6 continued

Lack of motivation due to the topic's difficulty	The topic is too complicated	“The topic is complicated and difficult, which make me less motivation to learn cell division” (S28)	6.45%
Total			6.45%
Indefinite problem	No problem because interested in the topic	“I like to understand the subjects” (S21)	6.45%
	No problem found	-	67.74%
Total			74.19%

Table 4.6 shows the problems faced by students in learning Cell Division from the motivational perspective. According to the data, there are two main problems faced by students in the motivational perspective, which are not interested in the learning content and lack of motivation due to the topic's difficulty. First, 19.35% students were not interested to learn Cell Division topic because they think that the learning process in studying Cell Division is very boring. Next, 6.45% students thought that the Cell Division topic is too complicated, which affects their motivation to learn the topic. For indefinite problem, 74.19% students found no problems in motivational perspective, where 6.45% of them are interested with Cell Division topic. Overall, 25.81% students faced problems in learning Cell Division topic from the motivational perspective, while the remaining 74.19% students have no problem with it.

4.4.2.2 Teachers' Views

Table 4.7: Teachers' Views on the Motivational Challenges in the Cell Division Topic

Problem	Reason/ Elaboration	Sample excerpts
Lack of motivation due to the topic's difficulty	The topic is difficult for students	"...for the motivational perspective usually there's no problem. But after learning, there will come the problem... Yes, quite difficult, because ... the stage of the chromosome they have to memorize, that's the main problem" (Teacher A)
		"From my experience, once the students learn this topic for the first time, they will be confused and think the topic is difficult, which affects their motivation to learn this topic" (Teacher B)
	Cannot answer exam questions	"Also, when examination, the students may cannot answer the objective or structure questions, then their motivation to learn this topic may be decreased indirectly" (Teacher B)
Students are passive in class	Don't want to involve in activities	"They don't want to involve, they just look and see their friends make the model and so on" (Teacher A)
	Shy to ask questions	"They are more passive, shy to ask questions... They like to ask me personally, instead of asking questions during class. I think maybe they don't like to ask questions in public" (Teacher C)

Table 4.7 presents the teachers' view on the problems in learning the Cell Division topic from the motivational perspective. First, a lack of motivation due to the topic's difficulty was highlighted. According to Teacher A, students initially do not face motivational problems. However, after starting the Cell Division topic, they often find it difficult to learn. These difficulties stem from cognitive challenges, such as memorization issues and misconceptions, as mentioned earlier. Similarly, Teacher B observed that students perceive the Cell Division topic as challenging and struggle to answer related questions in

examinations. Consequently, their motivation to learn the topic is negatively impacted. Next, students' passivity in class was also noted. Teacher A mentioned that some students remain passive during group activities, merely observing their peers instead of actively participating. Teacher C further explained that students tend to be shy to ask questions in class publicly, and they prefer to ask questions with teacher privately. Overall, teachers found that a lack of motivation due to the topic's difficulty and students' passivity in class were the problems in learning the Cell Division topic from the motivational perspective.

4.4.2.3 Overall for Motivational Perspective

From the motivational perspective, the results indicate that 19.35% students are disinterested in the Cell Division topic because they perceive it as boring and unengaging. This lack of interest may stem from the teaching methods employed, as Hadiprayitno and colleagues (2019) noted that a teacher-centred approach that relies heavily on textbooks and lacks real-life connections can diminish students' motivation. Additionally, the difficulty of the topic appears to negatively affect motivation, with 6.45% students and two teachers indicated a relationship between the difficulty of the Cell Division topic and the students' motivation to learn, as suggested by Hadiprayitno and colleagues (2019).

Furthermore, low motivation levels lead to student passivity in the classroom, where students prefer to observe rather than engage actively, as pointed out by two teachers in the findings. This behaviour can be explained by Etobro and Fabinu (2017), who found that students often adopt a passive learning approach in classrooms that prioritize teacher-centred methods, failing to address students' needs and preferences.

4.4.3 Affective Perspective

4.4.3.1 Students' Views

Table 4.8: Students' Views on the Affective Challenges in the Cell Division Topic

Problem	Reason	Sample excerpts	Frequency
Learning the topic is not enjoyable	The topic is too boring	"The learning process is too boring" (S14)	9.68%
	The topic is hard to understand	"The topic is hard to understand of course cannot enjoy the topic..." (S4)	19.35%
Total			29.03%
Have negative feelings towards the topic	Felt frustrated when learning the topic	"I feel frustrated because I can't understand some part" (S22)	3.23%
	Felt stressed when learning the topic	"...when hard to understand make me so stress" (S25)	3.23%
Total			6.45%
Indefinite problem	No problem because the topic is enjoyable to study	"I enjoy learning about it." (S21)	6.45%
	No problem found	-	58.06%
Total			64.52%

Table 4.8 shows the problems faced by students in learning Cell Division from the affective perspective. According to the data, there are two main problems faced by students in the affective perspective, which are learning the topic is not enjoyable and having negative feelings towards the topic. First, 29.03% students do not enjoy the learning process of the Cell Division topic because of two reasons, which are the topic is too boring, and the topic is hard to understand. From that, we can see that the motivational and cognitive aspects contribute to the students' learning problem from the affective perspective. Next, 6.45% students have negative feelings towards the topic, such as feeling frustrated and felt stress.

Both have those negative feelings when they faced difficulties in understanding the learning content of the topic. For indefinite problems, 64.52% students found no problems in affective perspective, where 6.45% of them enjoy the study of Cell Division topic. Overall, 35.48% students faced problems in learning the Cell Division topic from the affective perspective, while the remaining 64.52% students have no problem with it.

4.4.3.2 Teachers' Views

Table 4.9: Teachers' Views on the Affective Challenges in the Cell Division Topic

Problem	Reason/ Elaboration	Sample excerpts
Learning the topic is not enjoyable	Don't want to involve in activities	"...certain students have problems to enjoy the activity, they don't want to involve..." (Teacher A)
Indefinite problem	No problem as did not meet any student that have affective problem	"I didn't meet a student that feels anxious about learning so far... I think it depends on how the teacher teaches. If the teacher just literally writes and talks only, sure the students will not enjoy the learning process..." (Teacher B)
	Not sure because students are passive in class	"I'm not sure, I can't see it... because the students are passive, but they do the exercise" (Teacher C)

Table 4.9 presents the teachers' view on the problems in learning the Cell Division topic from the affective perspective. Teacher A found that some students did not enjoy the class activities. Based on her observations, a few students appeared passive and might not have engaged fully in the activities related to the Cell Division topic. Other teachers reported either no issues or expressed uncertainty regarding affective problems. According to Teacher B, he believed that students had no affective issues based on his experience. However, he noted that students' enjoyment of the learning process depends significantly on the teacher's teaching style. For Teacher C, he was uncertain about the affective challenges students faced

in learning the Cell Division topic. He explained that he could not determine this as the students appeared passive in class. Overall, the teachers identified the lack of enjoyment in the learning process as a problem in learning the Cell Division topic from an affective perspective.

4.4.3.3 Overall for Affective Perspective

From affective perspective, the results indicate that many students find learning Cell Division topic is not enjoyable. As shown in result, 29.03% students expressed their dislike for the topic, citing its difficulty and the boredom associated with learning it. Teacher B, during the interview, noted that this issue arises from a lack of interactive teaching methods. Additionally, 6.45% students mentioned experiencing negative emotions while studying the Cell Division topic. The result showed that the problems were intrinsic in nature to the topic, leading to frustration and stress if students had problems in understanding and mastering the content. This finding is in agreement with the previous-mentioned motivational problems since students' interest in studying Biology would be lost if they face difficulties learning it.

4.4.4 Social Perspective

4.4.4.1 Students' Views

Table 4.10: Students' Views on the Social Challenges in the Cell Division Topic

Problem	Reason	Sample excerpts	Frequency
Lack of social interaction in online class	Cannot gather in school due to pandemic	"Because of this pandemic, we can't go to school and the interaction between students and teachers is lesser" (S2)	19.35%
Total			19.35%

Table 4.10 continued

Feeling of isolation when studying the topic	No one to discuss with	“I’m interested in learning cell division, but all of my friends do not like this topic, I have no one to discuss with” (S4)	3.23%
	Felt helpless when faced difficulties in learning	“When I can’t understand some parts in this topic, I tried to ask the others, but they can’t help me, this made me felt helpless and alone” (S14)	3.23%
Total			6.45%
Lack of opportunities for group learning	Home study	“Because home study” (S6)	3.23%
	Listen to the teacher in class only	“Usually we listen to the teacher in class only, I prefer more on group learning” (S28)	3.23%
Total			6.45%
Indefinite problem	No problem because don’t have internet problem in online class	“I didn’t have internet problems during online class” (S21)	3.23%
	No problem found	-	64.52%
Total			67.74%

Table 4.10 shows the problems faced by students in learning Cell Division topic from the social perspective. According to the data, there are three main problems faced by students in the social perspective, which are lack of social interaction during lessons, felt isolated when studying the topic, and lack of opportunities for group learning. First, 19.35% students thought that their lessons in Cell Division topic are lacking social interaction, either with their peers or teachers. This problem is due to the online class during the pandemic period, where the students cannot study at school as used to be, which leads to jeopardizing the

social interaction in learning. Next, 6.45% students felt isolated when studying the Cell Division topic, where 3.23% of them don't have friends to discuss the topic with her, while the other felt helpless when facing difficulties in learning. Furthermore, 6.45% students thought that they are lacking opportunities for group learning because of home study due to the pandemic situation and they usually listen to the teacher in class only. For indefinite problem, 67.74% students found no problems in social perspective, where there was a student gave the reason of have no internet problem in online study. Overall, 32.26% students faced problems in learning the Cell Division topic from the motivational perspective, while the remaining 67.74% students have no problem with it.

4.4.4.2 Teachers' Views

Table 4.11: Teachers' Views on the Social Challenges in the Cell Division Topic

Problem	Reason/ Elaboration	Sample excerpts
Lack of social interaction in online class	Cannot gather in school due to pandemic	"Yes, because we are in the status of PdPR (online class), so we have no choice and don't have any other ways for teaching, and group learning for students also. We cannot gather in school in this current situation..." (Teacher C)
Indefinite problem	No problem as having class activities	"...there are no difficulties in the social interaction because when doing the activities, they are very enjoying, and they are learning in their group" (Teacher A)
	No problem, it depends on the base knowledge of the students	"...if the students have strong basic knowledge about a topic, they will have no problem in communication or the discussion in group learning" (Teacher B)

Table 4.11 presents the teachers' view on the problems in learning the Cell Division topic from the social perspective. First, there is a difficulty of teaching online classes. According to Teacher C, due to the pandemic, teachers and students can no longer gather in school as they once did. As a result, online classes became the only option for teaching,

which negatively affects social interaction in class. During this time, he could only rely on homework. Other teachers reported no issues related to social problems. Teacher A stated that there were no social issues because she always incorporates class activities such as group learning and presentations for students. Teacher B also believed that students had no social problems unless they lacked a strong foundational knowledge of the topic, which could lead them to feel confused in class and engage passively. Overall, the teachers identified the lack of social interaction in online classes as a problem that students face when learning the Cell Division topic from a social perspective.

4.4.4.3 Overall for Social Perspective

From the social perspective, the transition to online classes during the pandemic has greatly impacted the social aspect of learning. Students reported feeling isolated due to the lack of face-to-face interaction and group activities. Teacher C also pointed out that reduced social interaction is a common challenge in online learning environments. This is supported by 19.35% of students who mentioned the lack of social interaction, and 6.45% who specifically expressed feelings of isolation while studying. In addition, 6.45% of students highlighted the lack of opportunities for group learning, which made it harder for them to collaborate and solve problems together. This may have affected their understanding of the Cell Division topic, as peer discussions and group work often help students clarify confusing concepts and correct misconceptions. Without this peer support, students may have struggled more to comprehend abstract processes like mitosis and meiosis. While these findings reflect learning during the pandemic, it is worth considering that in post-pandemic face-to-face classrooms, the return of peer interaction and group activities may help address some of these challenges and improve conceptual understanding.

4.4.5 Add-on Problems

4.4.5.1 Students' Views

Table 4.12: Students' Views on the Other Challenges in the Cell Division Topic

Problem	Reason	Sample excerpts	Frequency
Lack of learning resources	Cannot buy reference book due to pandemic	"During this pandemic time there's no way to buy reference books..." (S31)	3.23%
Total			3.23%
Indefinite problem	No problem to add-on	-	96.77%
Total			96.77%

A question was included in the open-ended section to allow students to mention any other problems they faced while studying the Cell Division topic. The results are shown in Table 4.12 above. Only one issue was reported in response to this question, which was a lack of learning resources. The student, S31 explained that she was unable to purchase a reference book for her studies during the pandemic. Meanwhile, the remaining 96.77% students reported no additional problems.

4.4.5.2 Teachers' Views

Table 4.13: Teachers' Views on the Other Challenges in the Cell Division Topic

Problem	Reason/ Elaboration	Sample excerpts
Internet problem	Internet coverage problem due to geographical area	"...a student is living in Kota Bharu and the signal in that region is not strong enough, which makes the student can't follow me in the online class" (Teacher C)
Indefinite problem	No other problems need to add-on	"No... I think I had mentioned all the problems already" (Teacher B)

Table 4.13 continued

No serious issues on students' attitude	"So far there are no serious issues such as the students' attitude while learning this topic" (Teacher A)
No problem as taught Cell Division topic before the online class started	"Luckily for the Cell Division topic, I did teach them face to face before starting the online class" (Teacher A)

Teachers were asked whether they had any additional problems related to learning the Cell Division topic that they wanted to mention in the interview. The results are shown in Table 4.13 above. Teacher C mentioned the internet problem, explaining that one of his students faced difficulty following the lessons in the online class due to poor internet coverage in the student's geographical area. However, the remaining students did not have this issue. Other teachers reported no additional problems. Teacher A stated that she had no other issues because there were no serious problems with her students' attitudes. She also mentioned that she was fortunate to have taught the Cell Division topic before online classes began. Teacher B also claimed that he had no other issues to add, as he had already mentioned all the problems. Overall, internet problem was identified as the additional problem in learning the Cell Division topic.

4.4.5.3 Overall for Add-on Problems

There are two other additional challenges related to Cell Division learning from other perspective, including lack of learning resources and internet problems. According to the results, one student found difficulties to access reference materials during the pandemic, and Teacher C mentioned a student who faced internet connectivity issues because of where they live. This highlights the necessity of providing students with the resources and infrastructure

they need for effective learning. However, these two learning challenges are not very significant, as each challenge was reported by only one participant.

4.5 Summary of the Problems Faced by Students in Learning Cell Division Topic From Students' Views and Teachers' Views

The problems faced by students in learning the Cell Division topic from students' views and teachers' views were merged and tabulated in Table 4.14 below.

Table 4.14: Summary of the Learning Challenges in Cell Division Topic

Perspectives	Problems
Cognitive perspective	Hard to memorize the content
	Complex terminology
	The concept is hard to understand
	Misconceptions
Motivational perspective	The topic is too abstract
	Not interested in the learning content
	Lack of motivation due to the topic's difficulty
Affective perspective	Students are passive in class
	Learning process is not enjoyable
Social perspective	Have negative feelings towards the topic
	Lack of social interaction in online class
	Feeling isolation when studying the topic
Other	Lack of opportunities for group learning
	Lack of learning resources
	Internet problem

From the table 4.14 above, there is the most number of problems from the cognitive perspective, which is followed by the problems from the motivational and social perspective. The problems in cognitive perspective from the result are aligning with the previous studies which investigated the difficulties of learning Biology and Cell Division topic, such as memorization problem (Cimer, 2012; Hadiprayitno, 2019; Ozcan et al., 2014), including

foreign terms (Cimer, 2012; Kılıç et al., 2016; Ozcan et al., 2014), difficult to comprehend the concepts (Doğru and Özsevgeç, 2018), misconceptions (Dikmenli, 2010; Etobro & Fabinu, 2017; Murtonen et al., 2020;), and abstract topic (Agboghoroma & Oyovwi, 2015; Cimer, 2012; Etobro & Fabinu, 2017; Kılıç et al., 2016; Ozcan et al., 2014).

From the motivational perspective, the students are not interested in the learning content, and being passive in class might be due to the teaching style of the teacher. As mentioned by Hadiprayitno (2019), the teacher-centred teaching method which depends largely on textbooks and didn't connect the learning content with daily life would jeopardize the motivation of students and lose the students' interest to learn. Same as well with Etobro and Fabinu (2017), who claimed that students tend to learn passively in the classroom due to the teacher-centred teaching method that does not consider the requirements of the students. Furthermore, the difficulty of the topic affects the students' motivation was supported by Hadiprayitno (2019), who mentioned there will be a great negative impact on students' motivation and achievement if the students experience difficulties in learning Biology.

From the affective perspective, the students have negative feelings and do not enjoy the learning of Cell Division topic can be related to the teaching style of the teacher, which was supported by Teacher B in the interview. Also, according to the results from the students' views, these problems stem from the difficulties associated with the topic, which may be related to cognitive issues such as memorization and comprehension challenges. This finding aligns with Lenhard and Lenhard (2013), who noted that cognitive, motivational, and emotional aspects of learning influence one another, often leading to negative outcomes when one area is affected. For example, when a student struggles to master the Cell Division

topic due to memorization or comprehension issues, their motivation to learn decreases, resulting in having negative feelings like anxiety or frustration during the learning process.

From the social perspective, the challenges might be mainly caused by the implementation of the online class during the pandemic period. As mentioned by Teacher C in the interview, the online class did not allow students and teachers to gather in the classroom, which limited the opportunities for group activities and interaction among each other. Besides, based on S4 and S14, the students who participated in the preliminary study, they felt isolated because nobody can help them when they faced difficulties in learning. This isolation was likely intensified by the shift to online learning, which limited opportunities for students to ask questions in real time, engage in group work, or receive immediate feedback from teachers, which are particularly important when learning abstract and complex topics like Cell Division.

There are two other problems in learning the Cell Division topic, which are the lack of learning resources and internet access. The lack of learning resources was claimed by S31 who wished to buy reference books for her study. Meanwhile, the internet problem was mentioned by Teacher C where he had a student who has an internet coverage problem due to geographical area. However, these two learning challenges are not very significant, as each challenge was reported by only one participant.

In sum, the problems faced by students in learning the Cell Division topic were mainly caused by cognitive challenges, which appeared most frequently compared to other perspectives. This is not surprising, as many past studies on Cell Division learning difficulties have also highlighted cognitive issues (Basri & Abdullah, 2020; Chattopadhyay, 2012; Dikmenli, 2010; Kılıç et al., 2016; Murtonen et al., 2020; Özbudak & Özkan, 2014).

Motivational and affective problems also seem to come from similar causes, such as the teacher-centred approach and the difficulty of understanding the topic. In contrast, social challenges mainly came from the shift to online learning during the pandemic. Online learning likely made these problems worse, especially in terms of student interaction, motivation, and understanding. Without face-to-face teaching and hands-on activities, students had fewer chances to actively take part in lessons, making it harder for them to understand the topic and stay interested. As for the additional problems, such as lack of resources and internet issues, they were less significant since each was only mentioned by one participant.

4.6 Strategies That Students and Teachers Think Can Help in Learning Cell Division Topic

4.6.1 Students' Views

Table 4.15: Students' Strategies to Learn Cell Division Effectively

Category	Sub-category	Reason	Sample excerpts	Frequency
Games	Video game	More interesting and stimulates student's visual and auditory senses	"Prefer video games, because games use theoretical and practical applications-like vivid and colourful images and stimulating sound effects" (S23)	1
	Any forms of games		"Make some game about cell division to make interesting to learn about cell division" (S25)	3
Total				4
Visual learning materials	Animation	Better visualization in learning	"More animations" (S1)	1
	Picture		"Learn using picture..." (S5)	1

Table 4.15 continued

	Video		“By watching video with the explanation of a Biology teacher” (S29)	5
Total				7
Memory aids	Flash card	To aid memorization	“... flash cards to remain fresh in our memories.” (S13)	2
	Note		“I think have a short note can help me memorize easily” (S18)	8
Total				10
Teaching style	Teach in more interesting way	Make learning process more fun	“The bio teacher can teach with more interesting ways” (S19)	2
	Student-centred teaching style	Teacher should focus on student’s learning progress	“Teachers should focus on whether each student understands the subject or not, and let the students understand the subject at the slowest speed during the lecture” (S14)	1
	More interactive	More interaction in the learning process	“More interaction” (S10)	1
Total				4
Student effort	Reading	Students should make their own effort in their study	“Read more...” (S2)	1
	Tuition		“Tuition” (S3)	1
	Self-study		“Study by self” (S12)	1
	Study hard		“Study hard” (S21)	2
Total				5

Table 4.15 continued

Other	Physical class	Resuming physical classes in school	“I think physical class should be open as soon as possible” (S16)	1
Total				1
No strategy	-	-	-	3
Total				3

Note. The cumulative number is bigger than the number of the participants in the study because the participants can report more than one answer.

Table 4.15 shows the strategies and suggestions that students think can help them in learning the Cell Division topic. The data are divided into five categories, which are games, visual learning materials, memory aids, student effort, and others. First, three students suggested the usage of games in learning Cell Division topic with the reasons that they think using games is a more interesting way in learning and can stimulate their visual and auditory perceptions. Next, seven students recommended the usage of visual learning materials, such as animation, pictures, and video. Most of the students suggested the usage of memory aids, such as flashcards and notes to simplify the information and organize them into main points for easier memorization, instead of reading the long explanation in the textbook. Furthermore, some students gave the suggestions that are more on the student effort on the study, like reading, tuition, self-study, and studying hard. For the other strategies or suggestions, there was a student who like to have physical class as earlier as possible to study face to face in school. Last, three students did not provide any strategies.

4.6.2 Teachers' Views

Table 4.16: Teachers' Strategies to Teach Cell Division Effectively

Category	Sub-category	Reason	Sample excerpts
Collaborative realia	Using plasticine	To promote visualization and active learning of students	"I did activities like learning mitosis and meiosis by using plasticine" (Teacher B)
	Flipped classroom		"I suggest using the flipped classroom, where to give videos to students through social media, allow them to imagine, to visualize the concept first before starting a topic" (Teacher B)
	Role-play		"I think role-play is a good idea also. Role-play is like assigning the students into groups, and for each group, every group member will play a specific role..." (Teacher B)
	Jigsaw puzzle		"... maybe can do the jigsaw puzzles, let the students arrange the pictures of the cell division stages" (Teacher B)
	Gallery walks		"... do the gallery walk... let the students move, or have an animation for the students to imagine, it will be easier for them to learn" (Teacher B)
Visual learning materials	3D elements	Demonstrate the concepts of cell division effectively	"Maybe teaching through 3D elements... can show the concept of mitosis and meiosis process through videos with 3D" (Teacher C)
Teaching tools for online class	Visualizer	Display learning materials during online class	"I think teaching by visualizer is a good way also... can display and write things on the screen" (Teacher C)
Games	Mobile game	More interesting and attractive for students nowadays	"... that is more interesting for the students as students nowadays are more attracted to the mobile game" (Teacher A)

Table 4.16 continued

	“Yes, I love the idea of the mobile game... I like the RPG game genre, allowing the players to adventure... maybe can be like adventure inside the world of the chromosome” (Teacher B) “I really agree with the usage of mobile games in teaching...” (Teacher C)
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Table 4.16 presents the teachers’ strategies or suggestions that would help them teach the Cell Division topic.

First, Teacher B provided several suggestions for collaborative learning using teaching aids. He shared his experiences with group activities in class that encourage student interaction, such as using plasticine to help students arrange the stages of mitosis and meiosis. Additionally, Teacher B recommended the flipped classroom approach, where videos are shared with students through social media. He also proposed role-playing activities, where students are assigned into groups to act out chromosome behaviours during the cell division process, allowing them to experience it firsthand. Lastly, Teacher B suggested using jigsaw puzzles and gallery walks, emphasizing the importance of visualization and physical movement to facilitate easier learning.

For Teacher C, he suggested for incorporating more 3D elements in teaching, such as 3D videos that visually represent the concepts of mitosis and meiosis, making the learning experience more engaging and attractive. In terms of online learning, Teacher C shared his experience of using a visualizer during online classes, which enabled him to display learning materials effectively in a virtual environment.

As this study aims to develop an mGBL system for students to learn the Cell Division topic, the teachers were asked about their thoughts on learning through mobile games. All teachers strongly agreed with the idea, citing that students today are more familiar with technology and find learning through mobile games to be both interesting and engaging. Teacher B also offered suggestions for the design of the mGBL application, recommending an RPG game genre like an adventure game, incorporating gamification mechanics such as points, experience points, and levels, as well as quizzes that allow students to solve problems related to the Cell Division topic.

4.6.3 Overall

The strategies or suggestions from both students' and teachers' views, were consolidated and presented in Table 4.17 below.

Table 4.17: Summary of the Strategies to Learn Cell Division Topic

Category	Sub-category
Games	Video game
	Mobile game
	Any form of games
Visual learning materials	Animation
	Picture
	Video
	3D elements
Memory aids	Flash card
	Note
Teaching style	Teach in a more interesting and fun way
	Student-centered teaching style
	More interactive
Student effort	Reading
	Tuition

Table 4.17 continued

	Self-study
	Study hard
Collaborative realia	Using plasticine
	Flipped classroom
	Role-play
	Jigsaw puzzle
	Gallery walks
Teaching tools for online class	Visualizer
Others	Physical class

According to the results, both teachers and students suggested using games as an effective learning method, as they create a more engaging and enjoyable experience for students. This finding aligns with the current trend in science education, where digital games are increasingly favoured for teaching science concepts (Li & Tsai, 2013). Additionally, both groups suggested for the use of visual learning materials, which was supported by Basri and Abdullah (2020), who highlighted the importance of visualization techniques in helping students understand abstract genetic concepts. To manage the overwhelming amount of detailed information in the curriculum, students recommended using memory aids to help them organize the material more effectively (Cimer, 2012; Ozcan et al., 2014).

The findings suggest that improving teaching styles and encouraging student efforts can significantly enhance the learning process. This observation aligns with the findings of Cimer (2012), which identified teaching styles and student involvement as critical factors affecting the difficulty of learning Biology. Furthermore, teachers recommended incorporating collaborative realia into lessons to enhance student learning. This suggestion aligns with Salleh and colleagues (2021), who emphasized the need for creative teaching methods and aids to make learning enjoyable and to improve students' understanding of

Biology. In the online learning context, teachers proposed using tools like visualizers to bridge the gap between students and teachers during the pandemic. Lastly, students expressed a desire to return to face-to-face classes after the pandemic.

Overall, these strategies and suggestions provide valuable insights for the educators and researchers looking to enhance the learning experience of the Cell Division topic. The results indicate that both students and teachers agree with games, particularly mobile games, as effective tools for learning this subject, making mGBL a relevant approach to addressing learning challenges in Cell Division topic. Some suggestions from the results, such as the implementation of games (RPG game, as suggested by Teacher B), visual learning materials (animation, picture, video, and 3D elements) and memory aids (flash card and note), could serve as references for the researcher in designing the mGBL application.

4.7 Chapter Summary

In summary, this chapter discussed the findings of the preliminary study. The preliminary study revealed several learning challenges from different perspectives, including cognitive, motivational, affective, social, and others, according to both students and teachers. Cognitive challenges stood out the most, as students had difficulties memorizing content, distinguishing between similar terms, and understanding abstract concepts. Furthermore, both students and teachers proposed strategies to enhance learning about the Cell Division topic, such as incorporating games, using visual learning materials, providing memory aids, and implementing collaborative learning methods. Although that the preliminary study was conducted during the pandemic period, but the findings still could be a helpful reference for the current face-to-face class setting.

CHAPTER 5

SYSTEM DESIGN AND DEVELOPMENT

5.1 Overview

In this study, an mGBL application called Cell% was developed to assist students in learning the Cell Division topic, which is Chapter 6 of the Form 4 Biology textbook (Gan et al., 2019). This topic was chosen due to numerous studies reporting that Cell Division poses significant challenges in Biology (Agboghoroma & Oyovwi, 2015; Cimer, 2012; Doğru & Özsevgeç, 2018; Fauzi & Mitalistiaini, 2018; Hadiprayitno et al., 2019; Salleh et al., 2021). Cell% primarily aims to address the difficulties encountered by students in learning the Cell Division topic from both students' and Biology teachers' views, thereby enhancing students' learning of the topic.

The development of Cell% followed the mGBL Engineering Model proposed by Shiratuddin and Zaibon (2011). This model served as the development process, guiding the project through three iterative stages, which are pre-production, production, and post-production. Each stage integrates activities such as requirement analysis, learning content design, prototyping, evaluation, and deployment, making it suitable for developing mobile game-based learning applications. The development of Cell% is discussed in terms of Pre-production, Production, and Post-production, based on the model.

5.2 Pre-production

5.2.1 Requirement Analysis & Planning

The requirements analysis has been conducted through a literature review (Please refer to the Chapter 2) and a preliminary study (Please refer to the findings from Chapter 4).

In general, the literature review reveals that Cell Division is one of the most difficult topics in Biology, and a solution should be implemented to enhance students' learning of that topic. This finding is further supported by the preliminary study, which indicates that both students and teachers face learning challenges from cognitive, motivational, affective, social and other perspectives in Cell Division topic. In particular, the findings highlighted issues such as difficulty in memorizing stages, misconceptions, confusion with similar terms, and reduced motivation, especially in an online learning environment with limited face-to-face interaction and practical activities. These specific challenges formed the foundation for defining the game's learning objectives, ensuring that Cell% would directly target the actual problems faced by students.

Among the strategies and suggestions provided by the teachers and students who participated in the preliminary study, mobile game emerges as one of the most effective solutions for better learning or teaching of the Cell Division chapter. Hence, it is concluded that Cell %, the mGBL application designed to learn Cell Division topic, was relevant to meet the requirements of both teachers and students. To create a problem-based environment and foster competition among peers, Cell% was designed in RPG game genre and built with an online gaming setting. This allows players to learn through solving puzzles and compete with others through online leaderboards.

5.2.2 Learning Content Design

The learning content in Cell% is based on the Cell Division topic, specifically Chapter 6 in the Form 4 Biology textbook. The content of Cell% focuses solely on the phases of Mitosis, Meiosis I, and Meiosis II, which correspond to subchapters 6.2 (Mitosis) and 6.3 (Meiosis). Two language versions, English and Malay, were prepared for the learning

content of Cell% to accommodate Biology teachers from different schools who use different languages to teach the subject.

The learning content comes in two formats, which are notes and quiz questions. The notes provide detailed information and visuals about cell division phases and are embedded within the game levels of Cell% to facilitate knowledge acquisition for players. Meanwhile, quiz questions are integrated into the quiz game of Cell% to examine players' understanding of the learning content presented in the notes while playing the game.

5.2.3 Game Features Design

In general, the game features and the design of Cell% were based on the Flow Framework for Educational Games design framework (Kiili et al., 2014) and embedded with learning theories as well. The game features were designed specifically in dealing with the difficulties faced by teachers and students in learning or teaching Cell Division chapter.

5.2.3.1 Game Genre and Setting

Cell% adopts an RPG genre, embedding a storyline that offers contextual information for learning and gameplay, as suggested by Teacher B in the preliminary study. Players become adventurers in the Cell% world, exploring and uncovering its entire map. The map guides players to diverse locations such as Mitosis Forest, Meiosis I Desert, and Meiosis II Snowland, each covering specific learning content related to the Cell Division subtopic. Various cells, including Prophase Cell, Metaphase Cell, and the others, are situated in different locations, with each representing a phase in the cell division process. Each location serves as a game level, encompassing the learning content of a particular cell phase in the division process.

5.2.3.2 Game Play

To complete a game level, players must fulfil four distinct quests from different quest givers. After completed all quests, the players need to go to the portal to pass the game level.

The flow of the gameplay is as shown in Figure 5.1.

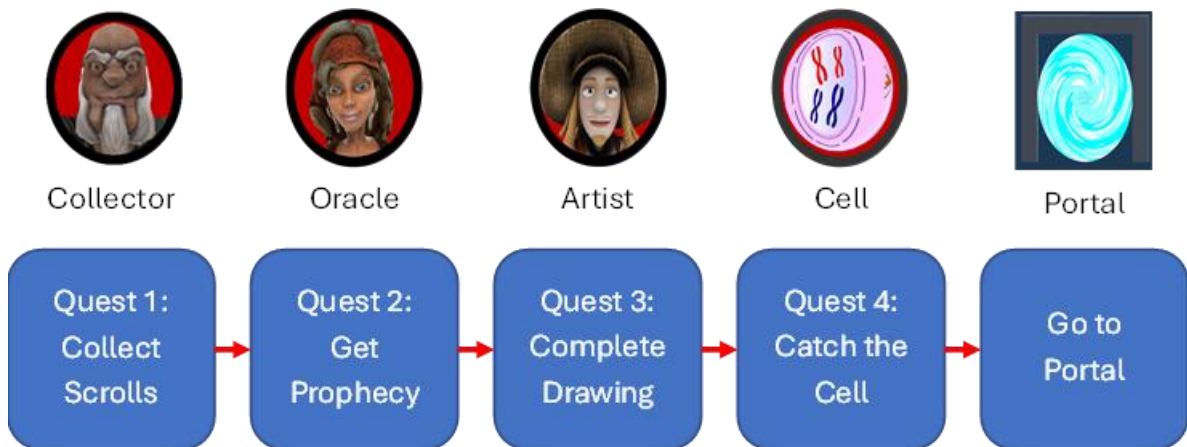


Figure 5.1: The Quest Givers and Their Quests in a Game Level of Cell%

i. Quest 1: Collect Scrolls

At the beginning, players seek out the Collector to accept the first quest, which is collecting all scrolls within the game level. Successfully collecting a scroll requires players to locate and approach it, then read the note contained within (Figure 5.2). This note provides essential learning content about the cell division phase, followed by a simple quiz that must be answered correctly to successfully collect the scroll as shown in Figure 5.3. Failure prompts players to revise the note and retry the quiz again to ensure they really read and understood the note content.

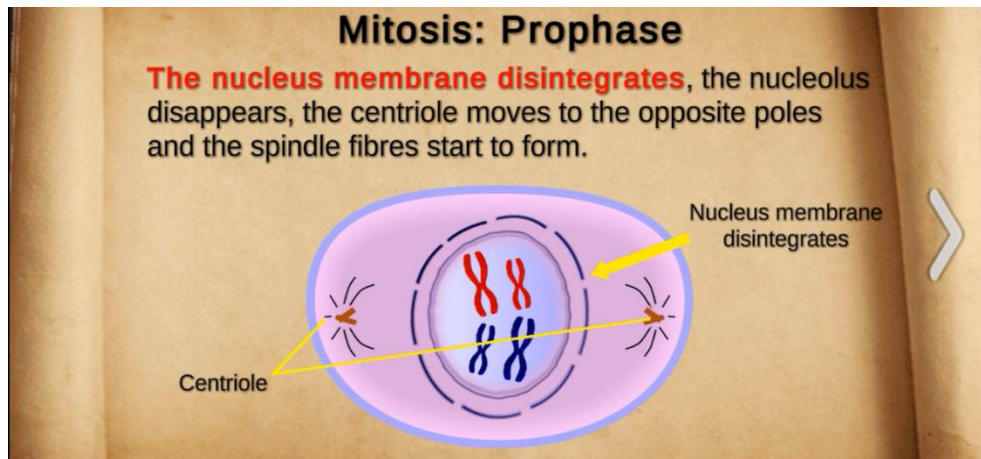


Figure 5.2: The Note in the Scroll

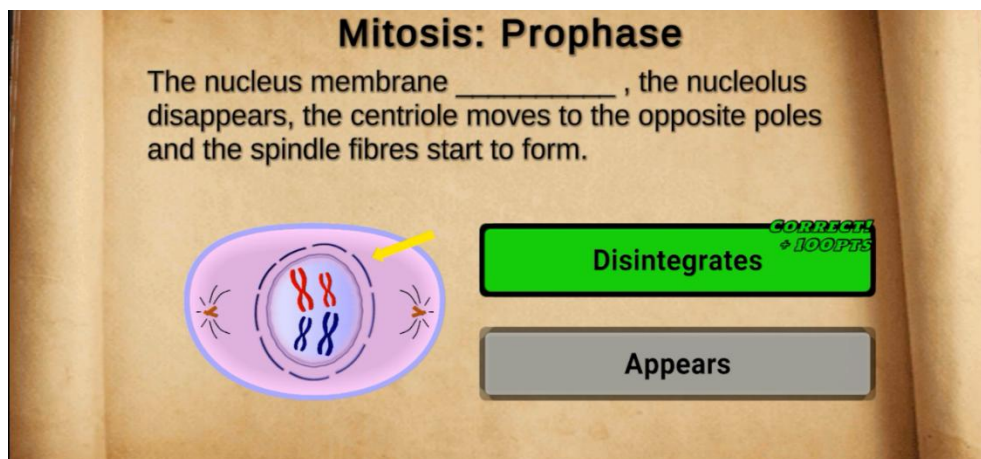


Figure 5.3: The Quiz in the Scroll

ii. Quest 2: Get Prophecy

After collecting all scrolls, players proceed to the second quest, meeting the Oracle to receive the prophecy. The prophecy comprises a video illustrates the cell division phase through 3D animation, as shown in Figure 5.4. Completion of this quest entails watching the entire video, which typically takes about 30 seconds.



Figure 5.4: Animation Video About Mitosis Prophase in the Prophecy

iii. Quest 3: Complete Drawing

The subsequent quest involves assisting the Artist in completing a drawing, presented as a drag-and-drop puzzle game. The puzzle game begins with a picture of a cell in a cell division phase, and players must memorize it within a time limit, as shown in Figure 5.5. Afterward, they must correctly place all cell components to the cell within a time limit (Figure 5.6). Failure prompts players to retry the puzzle game.

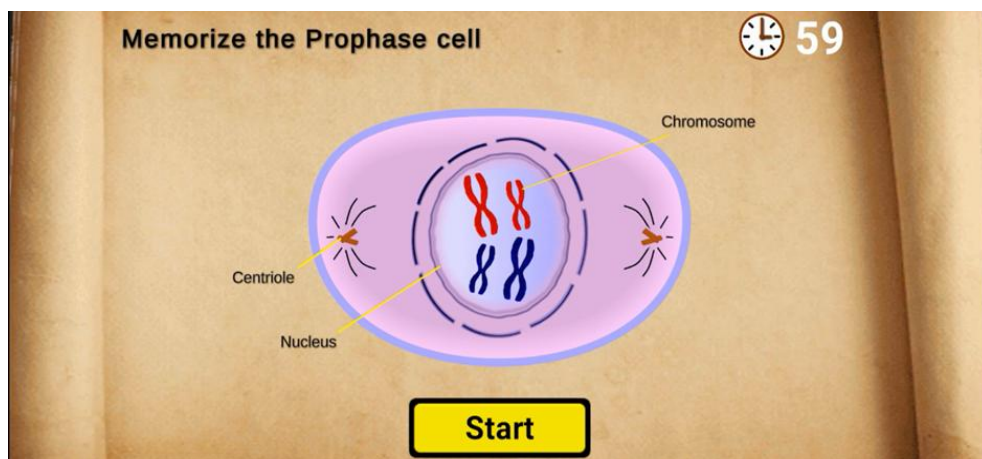


Figure 5.5: Cell Picture in Memorization Section

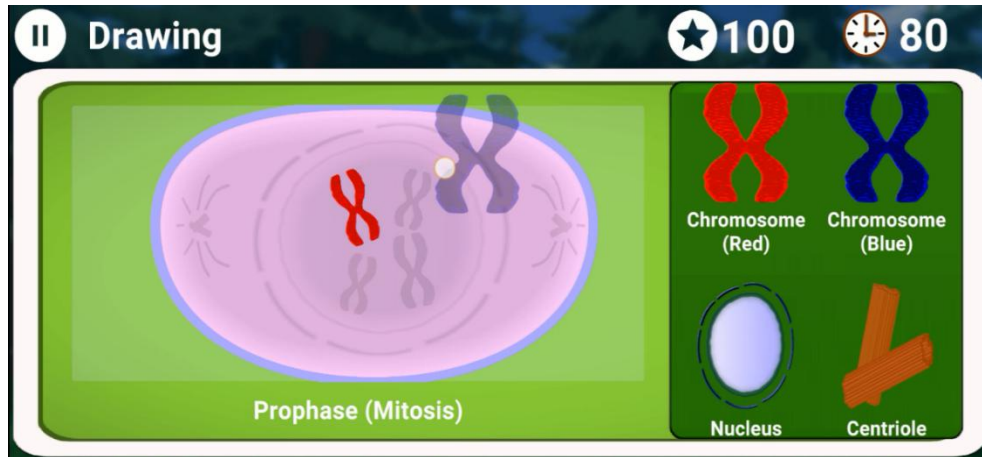


Figure 5.6: Drag and Drop the Cell Components to the Correct Places

iv. Quest 4: Catch the Cell

The final quest asks players to capture the cell by battling it in the quiz game (Figure 5.7). Players must answer questions about the cell division phase within a time limit. Correct answers allow players to attack the cell, scoring points and reducing its health, while incorrect answers result in a counterattack, lowering both score and health. To win, players must deplete the cell's health within the time limit. Failure prompts a retry.

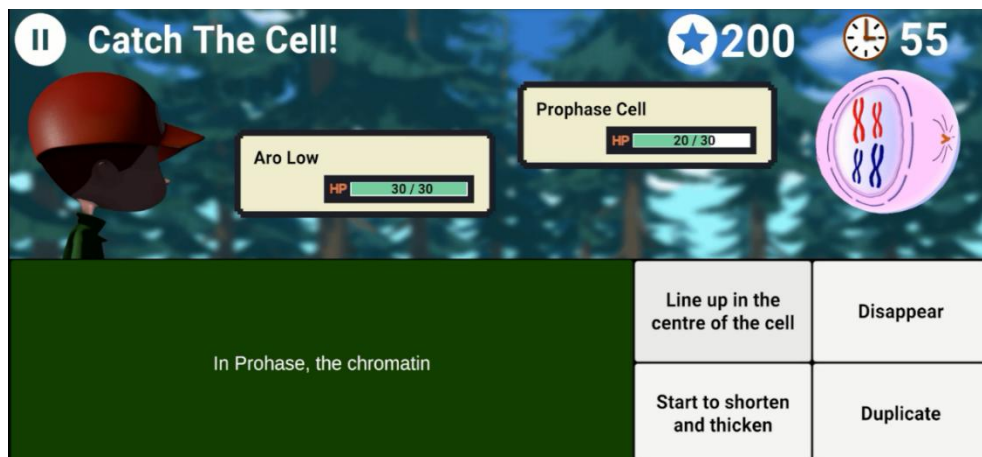


Figure 5.7: The Quiz Game in Catch the Cell

v. Portal

Upon completing all quests, players proceed to the portal to finish the game level. A results panel will pop out and display the points and stars earned by the players in the game level (Figure 5.8). Stars are awarded based on the percentage of maximum points achieved. After that, the players will unlock and continue to the next game level, which becomes more challenging. This process repeats until the players complete all game levels and discover all locations in Cell% world.



Figure 5.8: The Result Panel After Completed a Game Level

5.2.3.3 Game Features

Cell% was embedded with various features including Profile, Map, Collections, Clan, Leaderboard, Forum, and Supervise (please refer to Appendix I for the screenshots).

i. Profile

The Profile enables players to manage their information, featuring Personal Info, Badges, and Avatar sections. Personal Info allows players to view or modify their information, while Badges showcase earned achievements. Avatar enables players to

customize their in-game appearance. This section is crucial for fostering a sense of identity within the virtual gaming environment.

ii. Map

In the Map, the players can choose the game level they want to play. Four themes, namely Starter Village, Mitosis Forest, Meiosis I Desert, and Meiosis II Snowland, are available in the Map, and each theme covers specific learning content related to Cell Division. Except for Starter Village that has only a tutorial level, each theme comprises four game levels such as Prophase level, Metaphase level, Anaphase level, and Telophase level. At the beginning, all levels are locked except the tutorial, and players need to pass levels to unlock the next ones.

iii. Collections

The Collections allow players to review learning content from unlocked levels. By selecting a game level, players can revisit notes from Scroll, videos from Prophecy, and cell pictures from Drawing. This feature facilitates learning by enabling players to recap what they've learned from the game.

iv. Clan

Clan is a game feature that allows players to form a group, or “clan”, with a maximum of three members, enabling collaboration to compete with the other clans. Within the Clan feature, players can view their clan status, join other clans, and even create their own for others to join.

v. **Leaderboard**

The Leaderboard is where players can view their ranking in Cell%. The game has both player ranking and clan ranking, which display the scores of players and clans respectively, to foster a competitive environment. Additionally, players can view the rankings based on school.

vi. **Forum**

The Forum is where players can engage in discussions, such as asking questions about Cell Division topics or seeking help to pass game levels. Additionally, teachers can contribute by answering students' questions, thereby enhancing interaction between teachers and students. The Forum consists of Post and Create Post sections. In the Post section, players can view posts and respond to questions by commenting on the post. In the Create Post section, players can make a post by selecting the category and providing the content.

vii. **Supervise**

The Supervise feature is accessible only to teacher accounts. It enables teachers to view their students' progress and detailed information in the game. Teachers can monitor student progress by accessing the student list and selecting individual students for more detailed information.

5.2.3.4 Game Mechanics

Seven game mechanics are applied in the design of Cell%, including dashboard, score, levels, experience, badges, leaderboard, and avatar. Descriptions of the game mechanics are provided in Table 5.1 below:

Table 5.1: Game Mechanics and Their Descriptions in Cell%

Game mechanic	Description
Dashboard	The dashboard serves as a central hub or interface where players can access various game features such as Profile, Map, and others.
Score	Game scores are calculated for each game level, with stars awarded based on the percentage of maximum points achieved. Achieving less than 80% earns one star, while scoring at least 80% earns two stars. To earn all three stars, players must achieve at least 90% of the maximum points. Player scores are saved and used to calculate rankings in the leaderboard.
Levels	There are two types of levels, which are game level and player level. In game levels, each one represents a subtopic of Cell Division, collectively covering the entire topic. These game levels are designed with increasing difficulty to challenge players. As for player levels, players can advance by gaining experience points. This levelling system aims to keep players engaged with Cell% over the long term.
Experience	Players gain experience points for each attempt at a game level, regardless of success. These points contribute to levelling up the player's level.
Badges	Players earn badges as rewards upon completing specific game levels or meeting certain requirements. Cell% offers a total of 11 badges, including Fresh Graduate, Mitosis Master, Meiosis I Expert, Meiosis II Genius, Cell Division Champion, Top Adventurer, Top Adventurer (School), Top Clan, Top Clan (School), Curious Philosopher, and Good Samaritan.
Leaderboard	The leaderboard displays the rankings of players and clans based on their game scores. The leaderboard encourages players to improve and engage in friendly competition.
Avatar	Avatar is the virtual representation of players to interact with Cell%. This mechanic enhances player immersion and motivation by allowing them to connect with their in-game character. In Cell%, players can choose their profile picture and 3D avatar for gameplay.

5.2.4 Design Framework

Flow Framework for Educational Games proposed by Kiili and colleagues (2014) is adapted as the design framework of Cell% because it covers the design aspects of GBL from different perspectives such as cognitive perspective and sociocultural perspective. The

dimensions of the flow framework that contributed to the design aspect, which are the flow antecedents and mind lenses were discussed with the corresponding learning theories and game or design features of the Cell%.

5.2.4.1 Flow Antecedents

The flow antecedents, which are the clear goal, feedback, playability, challenge, and sense of control are responsible to induce the flow experience of the players during gameplay based on the flow theory. The flow is taken into account in the design of educational games to provide a pleasant experience and engage the players during gameplay.

i. Clear Goal

As mentioned by Kiili and colleagues (2014), it is a good idea to split the main goal of a game into the main goal and multiple subgoals. For our case, we divided the goals of the Cell% into main goals and subgoals, where each of them contains learning gameplay goals and learning goals. Gameplay goal refers to the objective of the task in gameplay context, such as how to complete a game task or win a game level. For learning goal, it refers to the learning objective, such as what knowledge would be obtained after playing the game-based learning application.

For the main goals of the Cell%, the main goal in the gameplay is for the players to discover the whole map in the game by unlocking all the game levels. Meanwhile, the main learning goal is for the players to learn and master the whole chapter of Cell Division. As the map itself is the metaphor of the player's learning progress, so unlocking all game levels means the players learned the whole learning content of the Cell Division topic.

For subgoals of Cell%, the subgoals of the gameplay are completing the quests given by the quest givers in each level. On the other hand, each game level corresponds to the subtopic of the Cell Division chapter, which are the subgoals in learning.

ii. Feedback

In general, Cell% will show the progress of a player toward the main gameplay goal by having a map that reveals the player's discovered locations. Besides that, the player's own information such as player's level, experience point, badges, and the other are shown in the profile tab. For immediate feedback, the feedback for the correctness of players' responses in the game will be implemented. As an example, during playing quiz game at a game level, there will be signals in visuals and sounds to indicate to the players whether chose the right answer or not (Figure 5.9). The game also enables the players to try and errors in gameplay, so that the players can do reflections on mistakes and try other solutions until directed to the right answer, which resulted in the development of players' mental model (Kiili et al., 2014).

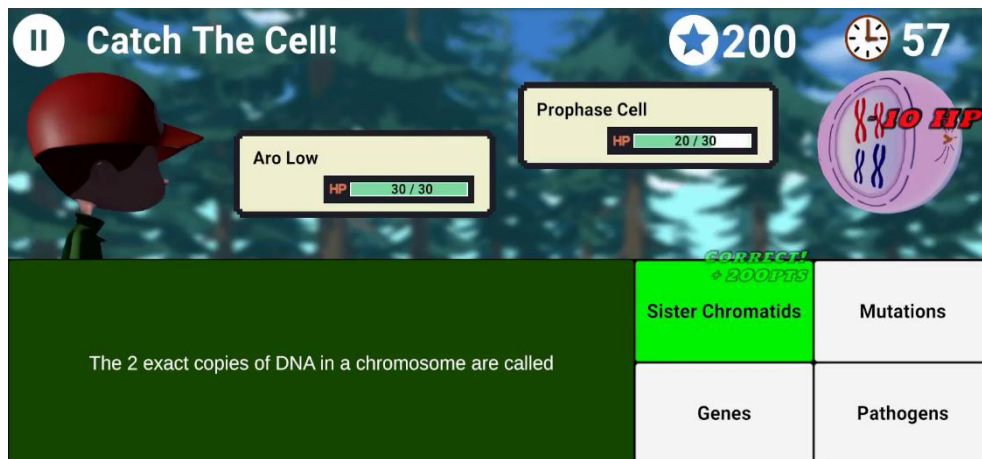


Figure 5.9: Feedback to Indicate Correctness of Answer in Quiz Game

iii. Playability

Generally, playability antecedent is to ensure the enjoyment of players during gameplay. Hence, Cell% is set with the RPG genre, which includes puzzle games and game mechanics as well. This strategy is to provide a fun gameplay experience while holding the concentration of the players in the learning process at the same time. Besides, Cell% uses the touch interaction technique commonly used in smartphones today to prevent jeopardizing playability due to confusion with complicated game controls.

iv. Challenge

Cell% is designed with game levels of increasing difficulty, where challenges are introduced through time limits and the complexity of completing quests during gameplay. The difficulty of the game levels increases in each map theme, as shown in Figure 5.10. For example, as players progress from level 1 to level 4, the map size increases and additional obstacles are implemented, making it harder to find scrolls. Additionally, the time limits for the puzzle and quiz games become shorter, adding further challenges for players.

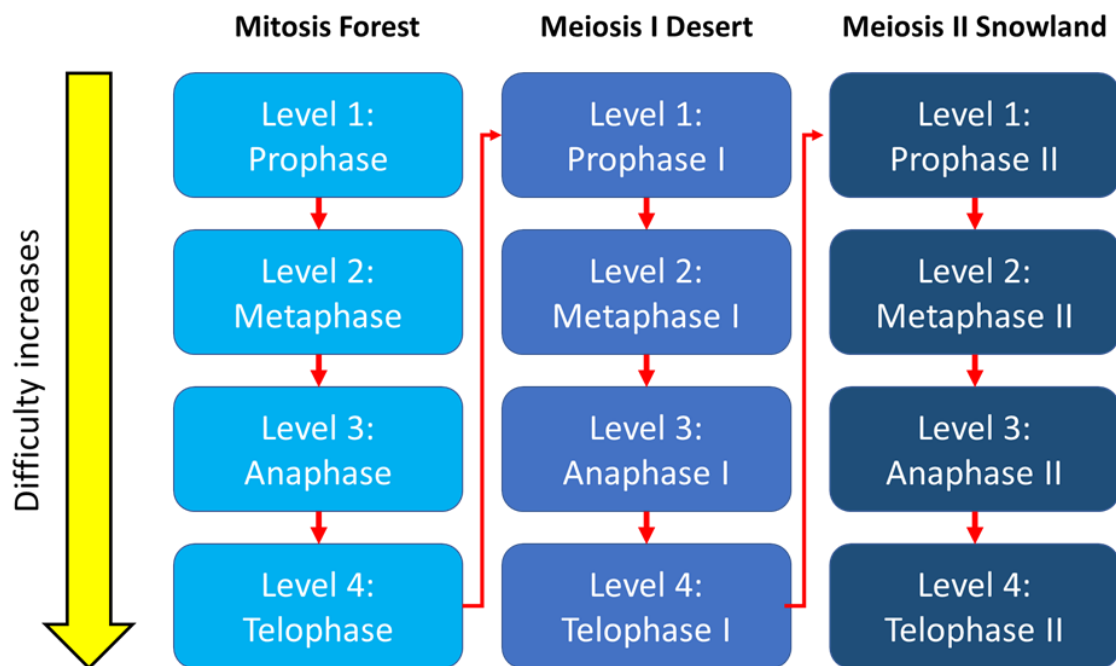


Figure 5.10: The Difficulty of the Game Levels Increases in Each Map Theme

To make sure the players have enough knowledge before starting a game level with new learning content, the next game levels are set in a locked state in default until the player has completed the current game level. Also, the social aspect of the Cell% such as forum and clan features can act as the support for the players to work together to complete the game tasks. These strategies are employed to fulfil the challenge-skill balance dimension in the extended three-channel model of flow proposed by Kiili and colleagues (2014).

In addition, the design of challenges in Cell% was carefully aligned with CLT to prevent cognitive overload. The game gradually increases intrinsic load by expanding map size and adding obstacles, requiring players to apply knowledge gained in earlier levels. At the same time, extraneous load is reduced by keeping the interface simple and focusing only on essential tasks. The Drawing puzzle game promotes germane load by reducing the time and opacity of hints as levels progress, encouraging players to internalize knowledge instead of depending on cues. Similarly, in the Catch the Cell quiz game, the time allowed to answer

questions decreases at higher levels, promoting schema automation and faster recall. These scaffolding strategies ensure that challenges increase step by step, balancing difficulty with student capacity to keep players engaged without being overwhelmed.

v. Sense of Control

As mentioned in the description of the challenge antecedent, the Cell% is set in a challenge-skill balanced way. In other words, the gameplay of Cell% will not be too hard or too easy for the players, in which the learning content is based on the Cell Division chapter of the Form 4 Biology syllabus. Hence, the players supposedly will not be frustrated by getting stuck in a game level. Also, the game mechanics in the Cell% such as player's level, badges, and the likes act as the motivator to keep the players continue to play until become an expert that fully mastered the Cell Division topic.

5.2.4.2 Mind Lenses

The mind lenses are responsible for linking the game features and interaction to the learning process. For our case, learning theories such as CLT, CTML, PBL, and collaborative learning are embedded in the mind lens dimensions to provide deeper insight into the design of Cell%.

i. The Lens of the Sensing Mind

To grab the attention of the players to focus on the relevant information, the design principles of CTML (Mayer, 2002a) such as signalling principle and modality principle were applied in the design of the Cell%. The signalling principle and the modality principle are incorporated with each other by signalling or clueing the crucial elements that appeared in the game interface (signalling principle) with audio-visual effect (modality principle). For instance, keyword such as 'sister chromatids' is highlighted in a contrasting colour in the

scroll notes, as shown in Figure 5.11. Additionally, images and sound effects respond to the player's actions, providing feedback with visual and auditory cues during the quiz game to indicate whether the player's answers are correct or incorrect (see Figure 5.9).



Figure 5.11: Keyword Is Highlighted in Red Colour in Scroll Note

ii. The Lens of the Processing Mind

To utilize the working memory of the players for learning purposes while playing Cell%, both CLT and CTML were employed in the Cell% design. In terms of CLT, the extraneous cognitive load should be eliminated for learning effectiveness (de Araujo et al., 2016). Hence, the design of Cell% implements essential game elements only and focuses more on learning context instead of gameplay to avoid unnecessary information (extraneous cognitive load) that will overload the players' working memory. The elimination of extraneous cognitive load is supported by the design principles of CTML. Mayer (2010) suggested removing unnecessary information (coherence principle), highlighting important information (signalling principle), avoiding redundancy in written and spoken words (redundancy principle), and positioning words near the visuals (contiguity principle). The design of Cell% follows these suggestions. For instance, when players open the scrolls, gameplay elements such as the virtual joystick and maps are hidden to remove unnecessary

information. The notes in the scrolls appear in full screen to focus on the learning content. Keywords in the notes are highlighted in bold, and the note contents are supplemented with visuals and word labels to help players focus on the important information while learning.

iii. The Lens of the Integrating Mind

This mind lens emphasizes integrating information by linking it with prior knowledge. Therefore, the order of quests in each game level of Cell% was designed so that players first read the notes (Quest 1) and watch the video (Quest 2) for the learning process. Then, their knowledge will be examined through the puzzle game (Quest 3) and the quiz game (Quest 4). This sequence ensures that players have prior knowledge before attempting the next quest. Additionally, a game tutorial level is provided as the first game level to teach players how to play Cell%. These design features aim to build prior knowledge for the players before they start the game, facilitating their playing and learning process. Furthermore, since the learning content of Cell% is based on the Cell Division topic in the Form 4 Biology syllabus and features challenge-skill balanced game levels, the gameplay of Cell% is expected to increase players' germane cognitive load, helping them process the knowledge of Cell Division into their long-term memory.

iv. The Lens of the Relating Mind

Cell% was developed as an online multiplayer game instead of a single-player game to allow social interaction among peers in the learning process. The forum and clan features were implemented based on the foundation of collaborative learning to maximize learning outcomes. The forum enables students to discuss various topics within the game, while the clan feature allows them to collaborate and form clans to achieve common goals, as supported by the study of Zhong (2019). Furthermore, Cell% encourages competition among

peers by incorporating a leaderboard. Additionally, game mechanics such as the player's level and badges serve as indicators of social status within the game community. These design elements aim to motivate players to engage with Cell% actively.

v. The Lens of the Transferring Mind

As the transferring mind lens emphasizes the transfer of knowledge, PBL theory is applied to this concept. According to Hung (2013), PBL can facilitate the transfer of learning by creating an environment where knowledge acquisition, immediate application, and potential novel application occur simultaneously. Hence, Cell% is designed as an RPG and puzzle game, fostering the problem-solving abilities of players. This approach is supported by Khoo and colleagues (2005), who investigated how PBL occurred in multiplayer role-playing games. Furthermore, the storyline of Cell%, where players embark on an adventure to catch all cells by discovering all game levels in the Cell% world, is highly related to the Cell Division topic syllabus. This storyline setting is intended to help students transfer the knowledge they acquire in the Cell% virtual environment to real-world contexts.

5.2.4.3 Design for Sustained Engagement

To maintain students' interest and learning over a prolonged period, Cell% incorporates several gamification features designed for sustained engagement. While puzzles and quizzes are repeated across levels, their difficulty and time constraints increase progressively, ensuring that tasks remain challenging rather than monotonous. In addition, long-term motivational elements such as the clan system, leaderboard rankings, and badges encourage ongoing participation by fostering competition and collaboration among peers. The storyline progression and gradual unlocking of new maps also provide a sense of discovery, motivating students to return over weeks or months to complete the adventure.

These design choices align with Flow Theory, which emphasizes balancing challenge and skill, and with motivational principles of gamification that support both short-term excitement and long-term engagement.

5.2.4.4 Instructional Design Framework and Theoretical Mapping

Building on the flow antecedents and mind lenses discussed previously, this subsection summarizes how the underpinning learning theories were embedded into the design of Cell% through the Flow Framework for Educational Games. While the mGBL Engineering Model provided the development backbone, the Flow Framework for Educational Games (Kiili et al., 2014) functioned as the instructional design framework. It integrates both flow antecedents and mind lenses, providing a structure to align learning theories, namely CLT, CTML, PBL, Collaborative Learning, and Flow Theory, with the game features.

Table 5.2 presents the mapping of the game features in Cell% with the underpinning theories and their corresponding Flow Framework for Educational Games components.

Table 5.2: Mapping of Game Features in Cell% with Underpinning Theories and Flow Framework Components

Design/ Game Feature	Learning Theories	Framework Component
Highlighting keywords	• CTML: Signalling principle • CLT: Reduces extraneous load	• Sensing Mind
Signals with multimodalities	• CTML: Modality principle (audio + visuals) • CLT: Optimises working memory	• Sensing Mind
Positioning words near visuals	• CTML: Spatial contiguity principle • CLT: Reduces extraneous load	• Processing Mind

Table 5.2 continued

Memorization games (Drawing, Scrolls)	• CLT: Germane load for schema building • CTML: Interactivity	• Integrating Mind
Quiz games	• CLT: Reinforcement and schema testing • CTML: Signalling and feedback	• Integrating Mind
3D videos	• CTML: Modality and coherence principles • CLT: Reduces intrinsic load	• Processing Mind
Notes (scrolls)	• CTML: Coherence and signalling principles • CLT: Reduces extraneous load	• Processing Mind
Game mechanics (points, badges, avatars, levels)	• Flow Theory: Clear goals, feedback, sense of control	• Flow Antecedents (Clear Goal, Feedback, Sense of Control)
Challenge-skill balanced levels	• Flow Theory: Challenge-skill balance • CLT: Manageable cognitive load	• Flow Antecedents (Challenge)
RPG & puzzle game genre	• PBL: Problem-solving in context • Flow Theory: Playability and immersion	• Transferring Mind • Flow Antecedents (Playability)
Storyline (catching cells adventure)	• PBL: Contextual problem-solving • Flow Theory: Overarching goal	• Transferring Mind • Flow Antecedents (Clear Goal)
Forum	• Collaborative Learning: Peer-to-peer interaction	• Relating Mind
Clan feature	• Collaborative Learning: Teamwork and shared goals	• Relating Mind
Leaderboard & competition	• Flow Theory: Motivation through feedback • Collaborative Learning: Peer comparison	• Relating Mind; Flow Antecedents (Feedback, Clear Goal)

5.2.5 Relationship Between Design Framework and Learning Challenges in Cell Division Topic

The design framework of the Cell% is linked with the learning challenges faced by students in learning Cell Division topic from both students' views and teachers' views (please refer to Table 4.14) obtained from the preliminary study, as shown in Figure 5.12 below. The lack of learning resources and internet problems from other perspectives are not included in the design plan because these challenges are not significant, as each issue was reported by only one participant in preliminary study. Additionally, the lack of learning resources due to unavailable to purchase reference books by S31 in preliminary study is not relevant to the design of the mGBL application. The internet problem was excluded from the design plan because online features such as leaderboards, clans, and forums are essential for addressing learning challenges from social perspective.

In this section, we will discuss how the design or game features address with each of the learning challenge from each of the perspectives.

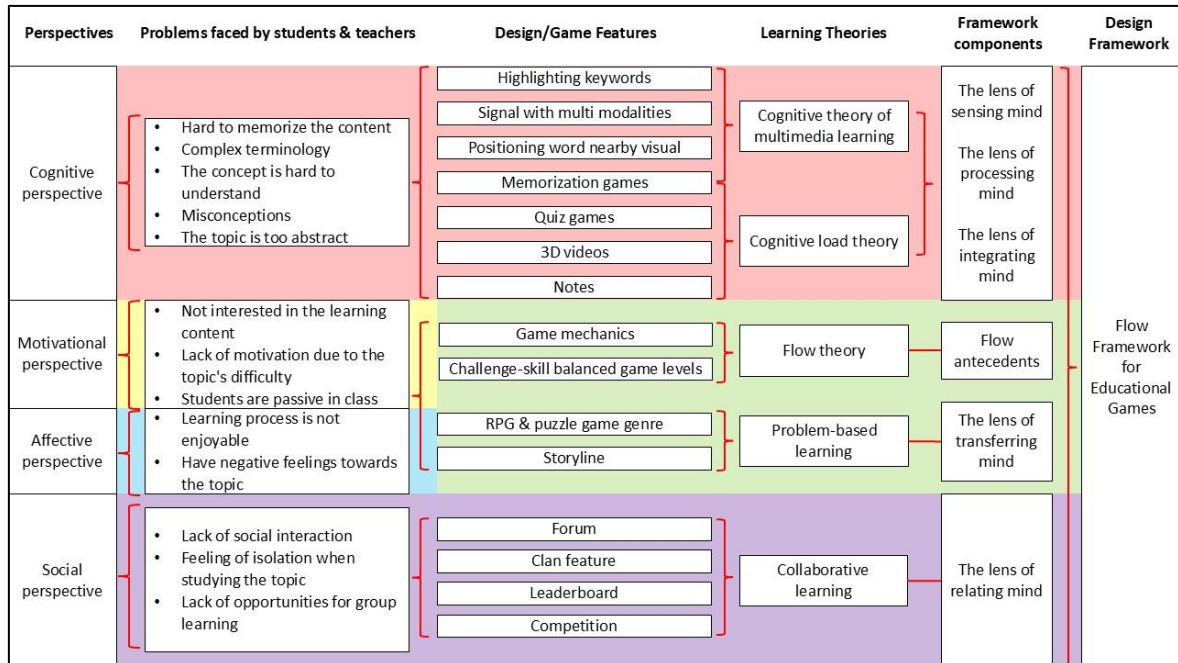


Figure 5.12: The Relationship Between Design Framework and Learning Challenges in Cell Division Topic

5.2.5.1 Cognitive Perspective

There are five learning challenges found from cognitive perspective, which are hard to memorize the content, complex terminology, the concept is hard to understand, misconceptions and the topic is too abstract. To deal with these problems, several design and game features have been implemented in Cell%.

i. Hard to Memorize the Content

To address students' memorization challenges while learning the Cell Division topic, memorization game elements were incorporated into Cell%. One example is the puzzle game, Drawing, featured in Quest 3 of the game levels. In Drawing, players must memorize the cell structure in a cell division phase within a time limit before dragging and dropping the cell components (see Figure 5.5). This element is designed to enhance students' ability to recall the cell structure during different phases of cell division.

Another example is Quest 1, where players collect all scrolls in a game level. When a player approaches a scroll, a note with learning content pops up. The player must read the note (see Figure 5.2) and then answer a quiz question (see Figure 5.3) about its content to ensure they have thoroughly memorized and understood the information.

Overall, the implementation of these memorization game elements in Cell% aims to help students remember the learning content related to Cell Division in a fun and engaging environment, thereby facilitating their learning and memorization of the topic. From the context of CLT, the memorization game elements contribute to germane cognitive load in the students' learning process, supporting schema construction by encouraging students to internalize and recall key information about cell division phases.

ii. Complex Terminology

To address the issue of complex terminology faced by students, foreign and complex terms were highlighted in red and bold text in the notes (see Figure 5.2). By emphasizing these keywords, players are more likely to focus on and understand these terms, aiding in their ability to distinguish them. This approach is supported by the signalling principle in CTML, which suggests that highlighting important information helps learners focus on and absorb crucial content more effectively by preventing cognitive overload, thus leading to better learning outcomes (Mayer, 2002a). To test whether players recognize and understand these complex terms, confusing terms such as “chromatin”, “chromatids”, “chromosome”, and “homologous chromosome” were included as answer options in the quiz games within Cell%. For example, the answer options in the quiz while collecting scrolls include confusing terms like “sister chromatins” and “sister chromatids” to assess players' understanding of the learning content, as shown in Figure 5.13.

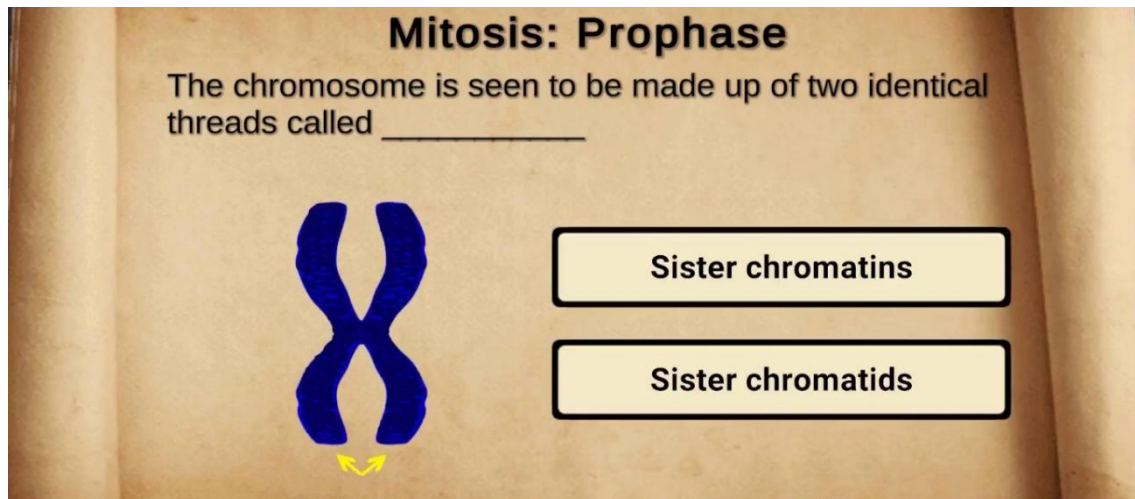


Figure 5.13: Quiz Game With Similar Terms As Answer Options

iii. The Concept Is Hard to Understand

To help students understand the learning content of the Cell Division topic more easily while playing Cell%, the interface and presentation of the learning content were carefully designed. First, the interface in Cell% highlights keyword and reduces unnecessary information. This approach facilitates the players' working memory by directing their attention to important information through signalling, preventing cognitive overload. As a result, the game enhances their understanding of the learning content. This is supported by CLT, which suggests that learning effectiveness can be improved by reducing extraneous and intrinsic cognitive load, thus freeing up working memory to optimize germane load (de Araujo et al., 2016). By having appropriate presentations of information or media, extraneous cognitive load can be reduced, thereby improving learning (Chang et al., 2018).

Additionally, the presentation of learning content in Cell% includes both text and visuals, with texts positioned near the visuals. This is supported by the CTML, which recommends that displaying texts and pictures together provides a richer learning experience

and fosters deeper understanding by facilitate the construction of referential links between the texts and pictures (Mayer, 2002a).

For instance, the notes in Cell% are displayed in full screen and focus solely on the learning content without redundant information, thereby reducing extraneous cognitive load. Keywords are highlighted in red and bold, helping players to focus directly on useful information without confusion. Moreover, all learning content in the notes is accompanied by visuals, enabling students to understand the material better (please refer to Figure 5.2 for the interface of note).

iv. Misconceptions

The strategy to address students' misconceptions while learning the Cell Division topic involves careful design of the interface and presentation of learning content in Cell%, based on CLT and CTML principles as mentioned in previous parts. Keywords are highlighted, and both text and visuals are used in the presentation of learning content. This approach helps players better understand and distinguish complex terms related to Cell Division topic. Additionally, each game level in Cell% corresponds to a subtopic of Cell Division, breaking down and categorizing the content by subchapter to prevent confusion.

To address confusion regarding chromosome behaviours, the puzzle game "Drawing", featured in Quest 3, requires players to drag and drop cell components such as chromosomes and spindle fibres into their correct positions. This activity reinforces their understanding of cell structure and chromosome behaviours through gameplay. To ensure players comprehend the learning content before moving to a new level, the quiz game "Catch the Cell" is featured in Quest 4 to test their knowledge of the content learned in the current level. Signals with multimodalities, such as visuals and sound effects, are implemented in

the quiz game to provide feedback, so players know whether their answers are correct or incorrect (see Figure 5.9).

v. Abstract Nature of the Topic

Several strategies were used to visualize the abstract concepts in the Cell Division topic. As mentioned previously, the presentation of learning content in Cell% includes both text and visuals to help convey and visualize the underlying concepts. Additionally, the drag-and-drop puzzle game “Drawing” in Quest 3 allows players to interact with visuals of cell components, thereby reinforcing their understanding of cell structures during different cell division stages. This approach aligns with the Interactivity principle in CTML, which suggests that learners gain deeper understanding when they have control over the presentation rate (Mayer, 2002a).

Furthermore, students tend to pay more attention and learn better with videos compared to traditional teaching methods (Baharudin et al., 2019). Therefore, the “Get the Prophecy” in Quest 2 provides 3D animation videos that significantly aid in visualizing chromosome activities in various cell division stages (see Figure 5.4). This is supported by Basri and Abdullah (2020), who claimed that visualizing abstract concepts can lead to meaningful learning and improve learners’ understanding in genetics. These videos not only offer visuals but also incorporate multimodalities, such as visual and audio elements, to enhance learning. This multimodal approach supports deeper understanding by engaging multiple sensory channels simultaneously.

5.2.5.2 Motivational Perspective

There are three learning challenges found from motivational perspective, which are not interested in the learning content, lack of motivation due to the topic's difficulty, and students are passive in class. To deal with these problems, several design and game features have been implemented in Cell%.

i. Lack of Interest in the Learning Content

To engage students who are not initially interested in the Cell Division topic, Cell% incorporates several strategies designed to make learning more interactive and enjoyable. The game uses various mechanics such as levels, badges, leaderboards, and avatars to motivate students. As noted by Ismail and colleagues (2018), the use of game mechanics in gamification can encourage learners' extrinsic motivation. By turning learning into a game, students are more likely to engage with the content. Cell% rewards players with points, stars, and badges for completing levels and achieving high scores. This creates a sense of achievement and motivates students to keep playing and learning. Additionally, Cell% allows players to choose their own avatars and profile pictures, helping them feel more connected to the game. This personalization can increase their interest and motivation to engage with the learning content.

Cell% also incorporates flow theory to enhance players' motivation. By dividing the Cell Division topic into manageable subgoals and main goals, students experience a sense of accomplishment as they progress, maintaining their engagement. Clear goals and immediate feedback further support flow by providing specific objectives for each quest, such as collecting scrolls in Quest 1 or completing a drag and drop puzzle in Quest 3. Instant feedback, especially in the quiz game "Catch the Cell" (Quest 4), informs students whether

their answers are correct or incorrect, helping them learn and adjust in real-time (see Figure 5.9). The various quests and interactive challenges in Cell% are designed to be so engaging that students may lose track of time while playing, a key indicator of being in a flow state where the activity becomes intrinsically rewarding.

ii. Lack of Motivation Due to the Topic's Difficulty

To address students' lack of motivation due to the difficulty of the Cell Division topic, Cell% employs several strategies aimed at making the learning process more engaging. The game breaks down the complex topic into smaller, manageable subtopics, with each game level representing a specific aspect of Cell Division topic. This approach helps students tackle the subject in stages, reducing the overwhelming feeling that can come with trying to learn a difficult topic all at once. Furthermore, the game rewards persistence and effort. By earning points, stars, badges, and unlocking new levels, students receive positive reinforcement for their hard work, which can be particularly motivating when dealing with difficult subjects. The sense of achievement from these rewards can boost their confidence and drive them to continue learning. Cell% also implemented elements of flow theory, where it ensures that the challenges presented are balanced with the players' skill levels, as suggested by Kiili and colleagues (2014). Cell% is designed with game levels that gradually increase in difficulty. This ensures that the challenges match the players' growing skills, preventing boredom from tasks that are too easy and frustration from tasks that are too hard. Further by providing clear goals and achievable tasks, students are more likely to experience a flow state, where they are fully immersed and engaged in the activity.

iii. Students' Passivity in Class

Cell% addresses the issue of students being passive in class by providing an interactive and engaging learning environment. By turning learning into a game like Cell%, students are encouraged to take an active role in their learning journey. This statement is supported by Kanyapasit and Srisawasdi (2014), who claimed that digital games can promote more meaningful learning and better student engagement compared to traditional teaching or learning methods. Furthermore, the game mechanics, such as quests, levels, and challenges, were implemented to foster active participation from the players to progress and succeed. This is supported by Ismail and colleagues (2018), where the use of game mechanics in gamification can encourage learners' extrinsic motivation. Additionally, features like the forum and clan system promote collaboration and interaction among students, fostering a sense of community and encouraging them to engage with the learning material. By making learning more dynamic and participatory, Cell% aims to motivate passive students to become more active in their learning.

5.2.5.3 Affective Perspective

There are two learning challenges found from an affective perspective, which are the learning process is not enjoyable, and students have negative feelings towards the topic. To deal with these problems, several design and game features have been implemented in Cell%.

i. Lack of Enjoyment in Learning Process

Cell% incorporates several strategies designed to make learning more enjoyable. Basically, the strategies are the same with the previous strategies in promoting students' motivation as discussed previously, which are employing gamification techniques to transform learning into an interactive and entertaining experience. Through quests,

challenges, and levels, students are encouraged to actively participate and progress through the content. Additionally, Cell% incorporates rewards such as points, stars, and badges to provide positive reinforcement and a sense of achievement as students advance in the game. Moreover, Cell% is designed within the RPG game genre that featuring an immersive storyline, where the players embark on an adventure to capture cells, creates a narrative context that merges the players' actions with their learning goals. This immersive experience helps students lose themselves in the activity, promoting deeper engagement. Lastly, as Cell% itself is an mGBL application that allows the players to learn through playing, it is believe that the game can make the learning process more enjoyable. This is supported by Kongvitayanont and colleagues (2017), who noted that GBL attracts learners and makes the learning process enjoyable through gameplay.

ii. Negative Feelings Toward the Topic

To address with issue of students having negative feelings towards the Cell Division topic, Cell% integrates gamification elements such as quests, challenges, and rewards, with the aim to create a positive and motivating environment that can counteract negative perceptions of the topic. Additionally, Cell% incorporates immersive storytelling within the RPG game genre, providing students with a captivating narrative context for their learning journey. This narrative framework helps to contextualize the learning content within an exciting adventure, which may help to shift students' attitudes towards the topic from negative to positive. Furthermore, Cell% also follows suggestion from Killi and colleagues (2014) by implementing elements of flow theory to ensure that the challenges presented are balanced with the players' skill levels, thus preventing players from becoming frustrated with tasks that are too hard.

5.2.5.4 Social Perspective

There are three learning challenges identified from a social perspective, which are lack of social interaction in online classes, feelings of isolation when studying the topic, and lack of opportunities for group learning. To address these issues, Cell% has implemented several design and game features.

i. Lack of Social Interaction in Class

Cell% addresses the lack of social interaction in classes primarily through its forum feature. This feature serves as a platform for students to engage in discussions, ask questions, and share insights related to the Cell Division topic. By facilitating peer-to-peer interaction, the forum encourages students to actively participate in the learning process and collaborate with their peers. Additionally, teachers can also participate in the forum, providing guidance, answering questions, and fostering a supportive learning community. Through the forum, students have the opportunity to connect with others, exchange ideas, and feel more engaged in their online learning experience. This social aspect of the game is supported by Chen and colleagues (2015b), who noted that collaboration features in digital GBL enable players to work together towards common goals.

ii. Feeling of Isolation When Studying the Topic

Cell% addresses the issue of students feeling isolated when studying the Cell Division topic by fostering a sense of community and collaboration among players. One way it achieves this is through the implementation of the clan feature. This feature allows players to form groups or “clans” with other students, creating a supportive environment where they can work together towards common goals. By joining a clan, students can connect with others, which resulted in reducing feelings of isolation and providing a sense of belonging.

Furthermore, Mohamad and colleagues (2017) claimed that the leaderboard showcases each player's rank for easy recognition and aims to enhance peer pressure, in which encouraging students to compete against one another. Hence, the leaderboard was featured in the game to encourage peer competition among students and clans, motivating them to strive to achieve high scores to promote their player's ranking or clan's ranking. Additionally, the forum feature provides a platform for students to interact with each other, ask questions, and share their experiences, further strengthening the sense of community within the game.

iii. Lack of Opportunities for Group Learning

Cell% addresses the lack of opportunities for group learning by incorporating the clan feature, which enables players to form groups and collaborate with each other. As mentioned by Zhong (2019), creating group or team setting allow learners collaborate and support one another to achieve optimal learning outcomes under the same goals. Hence, by implementing clans feature in the game, players can work together to complete quests, share strategies, and support each other in understanding the Cell Division topic. The clan feature encourages teamwork, as all clan members have the same goal, which is to work together to boost their clan's ranking on the leaderboard.

5.2.6 Mobile Interaction & Technical Analysis

In Cell%, various interaction modes are designed to enhance gameplay and user engagement. The most common interaction is the tap, where players tap on the mobile screen to perform actions such as selecting options, clicking buttons, and triggering events. This straightforward interaction forms the backbone of the game's functionality.

Building on this, the drag & drop functionality is employed in the puzzle game. The users must drag the cell components and drop them into the correct position to win the puzzle

game (see Figure 5.6). Moreover, the pinch interaction is utilized in the note and puzzle sections of Cell%, allowing players to zoom in to examine the content of the notes or scrolls they collect in the game levels. Additionally, players can zoom in on the cell in the puzzle game for their convenience in dragging and dropping cell components into the correct position, as shown in Figure 5.14.



Figure 5.14: Zoom in the Cell in Puzzle Game

For locomotion in Cell%, virtual joystick, drag interaction, and buttons are utilized in the game levels, as shown in Figure 5.15.



Figure 5.15: The Locomotion Tutorial Screen in Tutorial Level

To facilitate movement, the virtual joystick is implemented on the left side of the screen, enabling players to control movement. By touching and dragging their left thumb on this joystick, players can move the avatar in various directions. Also, the drag screen feature on the right side of the screen can rotate the camera or change the player's viewpoint. When players touch and drag their right thumb across the screen, the camera rotates accordingly, offering different perspectives of the game world. Additionally, players can use the sprint and jump buttons located at the bottom right of the screen. These buttons enable players to perform actions such as sprinting or jumping by simply tapping or holding them.

For technical analysis, it was planned to build Cell% as an Android application using Unity3D. This decision was made because Android is the most widely used operating system in mobile devices (Subscribed.fyi, 2024), and Unity is a versatile game engine capable of building games in various formats, including mobile applications in the Android format.

5.2.7 Low-Fidelity Prototype

Before proceeding to the production stage, a low-fidelity prototype was created using Figma (<https://www.figma.com/file/xhLc4uu9yKBNTto6nANqgDa/Cell%?type=design&node-id=0-1&mode=design&t=qmeWuSRmHoKyyC5Y-0>), as shown in Figure 5.16. The development of the Cell% used a heuristic evaluation strategy, where a low-fidelity prototype was assessed by three experts specializing in learning science, mobile systems, and user experience, from the Faculty of Cognitive Sciences and Human Development at the Universiti Malaysia Sarawak. Additionally, the learning content in Cell% was validated by domain experts, which are the Biology teachers who participated in the study. This evaluation process ensured that feedback from various fields was considered before proceeding with the development of Cell%.

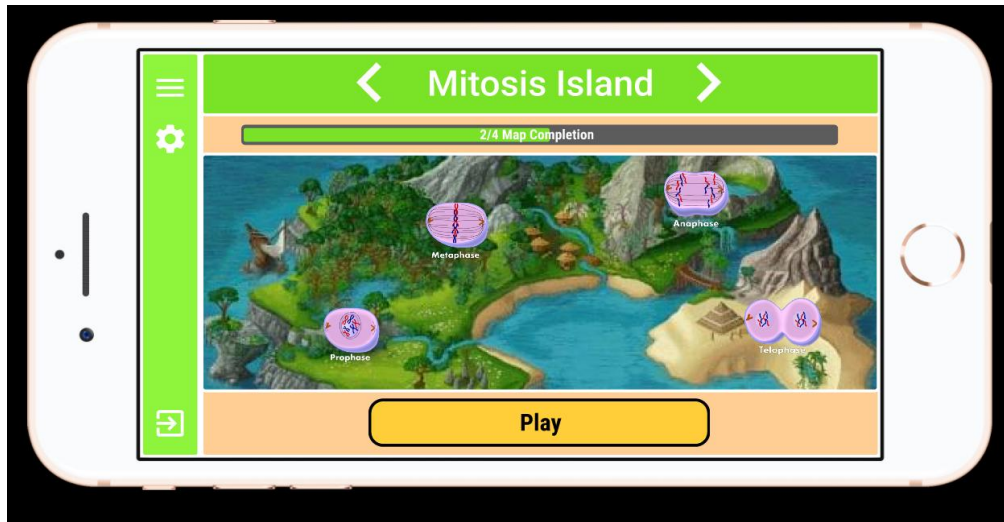


Figure 5.16: The Screenshot of Low-Fidelity Prototype in Figma

5.3 Production

5.3.1 Learning Content Development

The learning content was embedded in the scrolls (Quest 1) and quizzes (Quest 4) in the game level of Cell%, where different game level represents different phase of cell division and delivered different learning content corresponding to the game level. For example, when the player collects a scroll in mitosis's prophase level, learning content about prophase in mitosis will be displayed for the player to read and understand it. After the player has done the reading, a simple quiz will appear for the player to answer. If the player answers correctly, then the player collects the scroll successfully, else the player needs to revise the scroll and do the quiz again. This is to make sure that the player understands the learning content thoroughly before they proceed with the next task. At the last quest of the game level, the player needs to do a final quiz to examine what they learned in the game level in order to pass a game level.

5.3.2 Game Assets Development

Most of the game assets used in Cell% are downloaded from the Unity Asset Store website (<https://assetstore.unity.com/>). The 3D models and animations of the avatars in Cell% use free assets from the Mixamo website (<https://www.mixamo.com/#/>). The pictures of the cells used in Cell% utilize free visual resources for education from the EduPic Graphical Resource website (<http://www.edupic.net/cells.htm>). Finally, the videos used in Cell% to teach cell division phases are sourced from YouTube.

5.3.3 Coding & Core Mechanics Development

Cell% was developed using Unity and programmed in C#. The game was designed as an Android application, targeting API level 28 (Android 9.0 ‘Pie’) with a minimum API level of 22 (Android 5.1 ‘Lollipop’). Firebase Realtime Database was selected to support online functionality, enabling real-time data manipulation for immediate responses in an online environment. To ensure compatibility with most mobile phones and tablets, Cell% was optimized for 16:9 and 18:9 aspect ratios in landscape mode. The application requires 300MB of memory.

5.3.4 Game Features Integration

As outlined in the game design section in this chapter, Cell% incorporates a variety of features designed to enhance the learning process and address the learning challenges identified in the preliminary study. These features were integrated into the game through coding in Unity. From interactive puzzles to engaging quizzes, each aspect of Cell% was carefully crafted to promote problem-solving, competition, and knowledge retention among players.

5.3.5 High-Fidelity Prototype

Before advancing to the post-production stage, the Cell% app underwent the evaluations by experts in learning science, mobile systems, and user experience from the Faculty of Cognitive Sciences and Human Development at the Universiti Malaysia Sarawak, as well as the Biology teachers who participated in the study. Additionally, pilot tests were conducted to test the functionality of Cell%. These measures ensure that Cell% functions properly and is ready for deployment without any issues.

5.4 Post-production

5.4.1 Game Deployment

Cell% was published as an Android app on Google Play in open testing mode for the purpose of data collection for the study (<https://play.google.com/store/apps/details?id=com.SweatingOrangeProduction.CellDivisionApp>).

5.4.2 Playability, Usability & Mobility Testing

The playability, usability, and mobility of Cell% were tested by the students and Biology teachers during data collection, by filling the Section B in mGBL Evaluation Instrument adapted from Zaibon & Shiratuddin's instrument (2010), as described in the Methodology chapter (Chapter 3).

5.4.3 Educational Testing

Cell% was used by the students and Biology teachers from School X and School Y who are participating in the data collection process. The Section C in mGBL Evaluation Instrument was used to assess the effectiveness of Cell% in addressing the learning challenges in the Cell Division topic from both students' and teachers' views. Suggestions

and feedback from the participants were also gathered through this instrument to guide improvements to Cell%.

The feedback from students and teachers during the intervention aimed not only to highlight the effectiveness of Cell% but also to guide its refinement. For example, if students indicated that certain text was too small, adjustments would be made to improve readability and usability. In addition, if participants encountered technical issues such as software bugs or glitches, these would be resolved to ensure smoother gameplay. These refinements would be guided directly by the results of the intervention, ensuring that gameplay, usability, and learning content of Cell% could be improved in response to authentic user feedback.

5.4.4 Distribution

After the study is completed, Cell% will be published in production status to distribute the game and make it easily accessible to a wide audience of players.

5.5 Chapter Summary

In summary, this chapter discussed the system design and development of the mGBL application, Cell%. Cell% is an Android mobile game in the RPG genre, where players are adventurers in a cell world, aiming to unlock all levels and complete the map. Various game mechanics, including points, experience, levels, and badges, were integrated into the gameplay. The game was designed using the Flow Framework for Educational Games, addressing learning from multiple perspectives. For development, Cell% followed the mGBL Engineering Model, progressing through pre-production, production, and post-production stages with a heuristic evaluation approach.

CHAPTER 6

EFFECTIVENESS OF MGBL APPLICATION IN ADDRESSING LEARNING CHALLENGES

6.1 Overview

A data collection was conducted to evaluate the playability of Cell% and the effectiveness of Cell% in addressing the learning challenges faced by students in the Cell Division topic, from both students' and teachers' views. The mGBL Evaluation Instrument was used to assess the Playability of Cell% in terms of Game Usability, Game Mobility, Gameplay, and Learning Content, as well as to evaluate the effectiveness of Cell% in addressing learning challenges in Cell Division through open-ended questions developed by the researcher. In this section, the demographic information, playability of Cell%, its effectiveness in addressing the learning challenges in Cell Division topic, and suggestion to improve Cell% will be presented.

6.2 Demographic Information

A total of forty-five participants from School X and School Y were involved in the study, including forty-two students and three teachers. The demographic information of the students and teachers is presented in the following section.

6.2.1 Demographic Information of Students

There were forty-two Form 4 Biology students have participated in the study, where twenty-eight students were from School X and fourteen students were from School Y. Their demographic details are as shown in Table 6.1.

Table 6.1: Demographic Information of Students

Information		Number of students
School	School X	28
	School Y	14
	Total	42
Gender	Male	29
	Female	13
	Total	42
Age	16 years old	42
	Total	42
Race	Malay	18
	Chinese	16
	India	7
	Bumiputera	1
	Total	42

Before the intervention of the study was carried out, the researcher conducted a simple pre-survey during school visits by asking students whether they owned a mobile phone and what their phone's operating system was. It was found that one student from School Y did not own a mobile phone. Among those who did, one student in School X used an iOS phone, another used a phone running HarmonyOS, and one student in School Y also used an iOS phone. The remaining students used Android phones. Students who did not have a mobile phone with Android operating system were asked to borrow an Android phone from their parents or siblings to participate in the study.

Another question was asked to examine how many students play mobile games, and it was found that all students have experience in playing mobile games.

6.2.2 Demographic Information of Teachers

Three teachers from two different schools in Perak, which are School X and School Y participated in the study. The summary of the teachers' demographic information is manipulated in Table 6.2 below.

Table 6.2: Demographic Information of Teachers

Name of teacher	School	Working experience as a Biology teacher
Teacher D	School X	23 years (Form 4 & Form 5)
Teacher E	School Y	15 years (8 years for Form 4 & Form 5 + 7 years for Form 6)
Teacher F	School X	3 years (Form 4 & Form 5)

6.3 Playability of Cell%

In this section, the mean ratings for the Game Usability, Game Mobility, Gameplay, and Learning Content components were calculated by averaging the ratings from all 45 participants, including both students and teachers. The results were presented using bar charts for data analysis. Then, the Playability of Cell% was determined by averaging the four components, and the findings were analysed and discussed in the report.

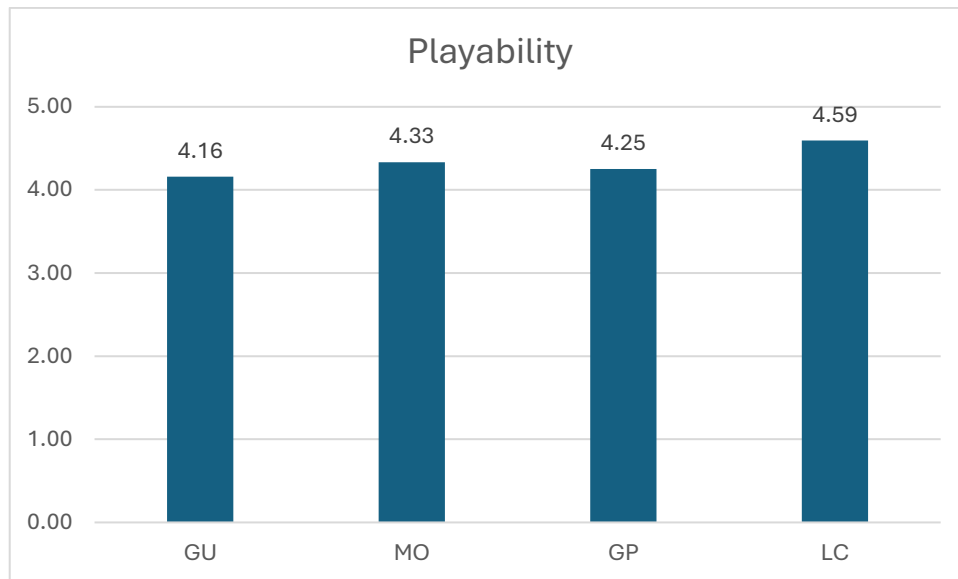


Figure 6.1: The Mean Values of the Four Dimensions of Cell% Playability

Figure 6.1 illustrates the mean values of the four components of Cell% playability, which include Game Usability (GU), Mobility (MO), Game Play (GP), and Learning Content (LC). According to the chart, LC received the highest mean score of 4.59, indicating that users found the learning content in Cell% to be highly satisfactory. MO was the second-highest rated dimension, with a mean score of 4.33, reflecting the ease of players to access the game world at anywhere by using mobile phones. GP scored 4.25, suggesting that the gameplay experience was also well-regarded. GU received a mean score of 4.16, which is still a good rating, although it was the lowest compared to the other dimensions. The lowest-rated items in this category were those assessing the efficiency and visual appeal of the screen layout and the ability of the game to reduce memory load. In addition, some participants encountered minor technical issues such as bugs or glitches, which may have affected their perception of usability. These results suggest that while Cell% was generally usable, refinements to the interface design, smoother performance, and efforts to minimize unnecessary cognitive effort could further enhance the user experience. All four dimensions

achieved mean scores above 4.00, indicating that participants generally had positive perceptions of Cell%'s playability across various aspects.

The playability of Cell% can be determined by calculating the average of the four components, as shown in Equation 3.1. Hence, the playability of Cell% was calculated as below:

$$\text{Cell\%'s Playability} = \frac{GU + MO + GP + LC}{4} = \frac{4.16 + 4.33 + 4.25 + 4.59}{4} = \mathbf{4.33}$$

Based on Brace's (2004) classification criteria (see Table 3.4), as suggested by Shiratuddin and Zaibon (2011), Cell% falls within the "highly high" category as it has playability score of 4.33, which is in between 4.21 and 5.00. This indicates that Cell% offers an exceptionally favourable playability experience for users across all assessed dimensions. In conclusion, Cell% fulfilled the research objective of the study, which was to design and develop an mGBL application with high playability.

6.4 The Effectiveness of Cell% in Addressing Learning Challenges in Cell Division Topic

In this section, the results of the effectiveness of Cell% in addressing learning challenges are presented based on the questions in Section C of the mGBL Evaluation Instrument, where each question represents a specific learning challenge faced by students. The results are presented from cognitive, motivational, affective and social perspectives. Finally, an overall discussion is provided to give an overview of Cell%'s effectiveness in addressing the learning challenges in Cell Division topic.

6.4.1 Data Coding and Tabulation

Each question and its corresponding learning challenge is presented in two parts. The first part shows the tabulation of ratings from participants for the question, and the second part presents the reasons participants provided for their ratings.

6.4.1.1 Tabulation of Ratings from Participants

The data collected from the questions asking for ratings to evaluate the effectiveness of Cell% in addressing learning challenges were reviewed. First, the data were divided into student and teacher groups to enable comparison between the two groups for data analysis. Then, the frequency and the mean of the participants' ratings was calculated. All data were displayed using a diverging stacked bar chart, which is the best way to visualize Likert scale data to understand how participants responded to the questionnaire (Bounthavong, 2019). Finally, the data were analysed and discussed in the report.

6.4.1.2 Reasons Participants Provided for Their Ratings

The data collected from the open-ended questions asking for reasons behind the participants' ratings were reviewed. First, the data were categorized into positive, neutral, and negative feedback to facilitate analysis and interpretation, with each type of feedback corresponding to the rating given by the participant. For instance, if a participant rated Strongly Disagree (1) or Disagree (2), the response was classified as negative feedback; if the participant rated Neutral (3), the response was classified as neutral feedback; and if the participant rated Agree (4) or Strongly Agree (5), the response was classified as positive feedback.

After categorizing the data by feedback type, the responses were further classified into different reason categories, which were derived from recurring themes in the responses. Examples of reason categories are as follows:

Conciseness of Notes: This category included responses that emphasized how detailed or simplified notes aided learning process.

Visual Aids: This category included responses regarding the use of visual elements such as pictures and animations.

Gamified Learning: Responses that are related to the use of games in the learning process was coded under this category.

Clarity: Responses concerning the ease of understanding the content was coded under this category.

To organize these qualitative data for data tabulation, the responses were divided into student and teacher groups to facilitate comparison in the data analysis. Feedback, reason categories, and their frequencies were then presented. Each reason category was accompanied by a sample quotation from a participant to provide insights and support their rating. All data were tabulated in tables to provide a clear overview of the reasons of participants gave for their ratings. Note that the total frequency of reasons is not equal to the total number of participants, because a participant could provide multiple reasons for their rating. Finally, the data were analysed and discussed into a report.

6.4.2 Cognitive Perspective

6.4.2.1 Hard to Memorize the Content

The effectiveness of Cell% in addressing the problem of “Hard to memorize the content” was evaluated by asking the question, “Do you think that playing Cell% can help students remember the learning content of the Cell Division topic more easily?” in the questionnaire. The results are presented below.

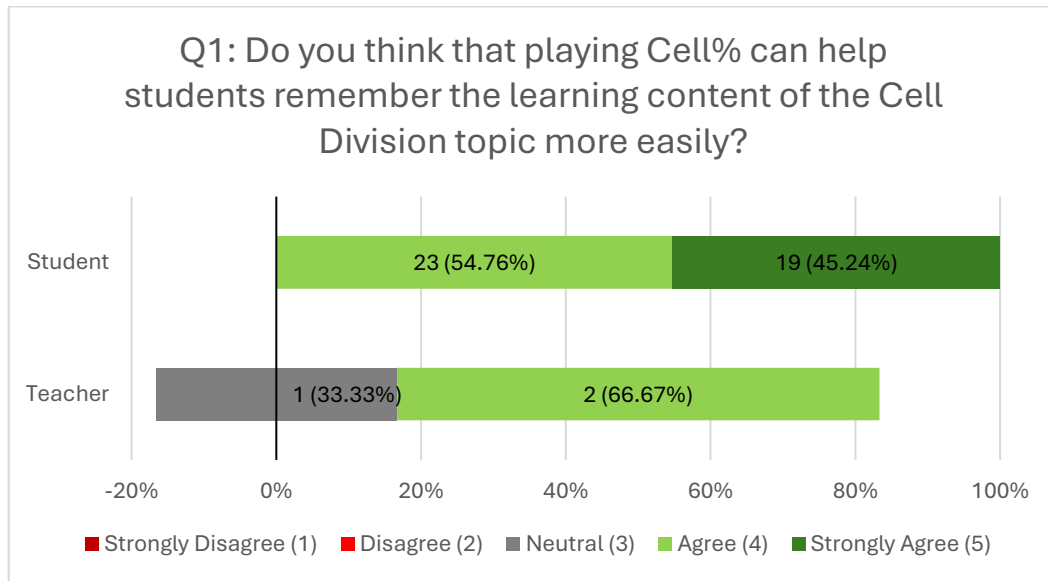


Figure 6.2: Responses for Q1

Figure 6.2 shows the responses of students and teachers on whether playing Cell% can help students remember the learning content of the Cell Division topic more easily. Among students, 54.76% agreed and 45.24% strongly agreed, resulting in a mean score of 4.45. No students expressed negative or neutral views. Teachers were divided as 66.67% agreed while 33.33% neutral, resulting in a mean score of 3.67. Overall, both groups found the game effective for memorization, with students showing stronger agreement.

Table 6.3: Feedback for Q1

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Conciseness of Notes	“Notes with highlighted keywords and pictures help understanding” (S18)	18
		Clarity	“Easy to understand topic” (S5)	9
		Gamified Learning	“Game explains and then tests memory” (S38)	9
		Visual Aids	“Pictures help remember and understand” (S11)	9
	Total			45
Teacher	Positive	Gamified Learning	“Game levels with corresponding cell division stages” (Teacher F)	2
	Total			2
	Neutral	Reinforcement Learning	“The students have to play the game repeatedly to memorise the contents” (Teacher D)	1
	Total			1

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.3 presents feedback from students and teachers on whether playing Cell% can help students to remember the learning content of the Cell Division topic.

From the students’ perspective, all feedback was positive (45 mentions), citing concise notes (18 mentions), clarity (9 mentions), visual aids (9 mentions), and gamified learning (9 mentions) as key factors. For instance, S18 appreciated the highlighted keywords in the notes, aligning with Mayer’s (2002a) CTML signalling principle, which emphasizes directing attention to critical information to reduce cognitive overload. Similarly, S5 found the clear and simplified content helpful for recall, as supported by CLT, which stresses minimizing cognitive load for effective learning (de Araujo et al., 2016). Visual aids, as

noted by S11, further reinforced retention through Mayer's CTML principles, which connect visual and working memory (Heng & Said, 2020). The gamified learning also noted as a beneficial feature for memory, with S38 explaining that the game tests memory after explaining the content, reinforcing learning and retention.

From the teachers' perspective, feedback ranged from neutral to positive. Teacher F praised the game levels align with cell division stages, making the content easier for students to remember. In contrast, Teacher D provided neutral feedback and suggested that repeated gameplay might be necessary to achieve full retention. This feedback highlights the importance of refining the game mechanics to make repetition more effective and less tedious. For instance, varying quiz questions and introducing adaptive difficulty can help sustain engagement while maintaining an appropriate challenge–skill balance, as suggested in Flow Theory (Kiili et al., 2014). Similarly, incorporating spaced-repetition features could support schema automation and long-term retention, consistent with CLT (Sweller et al., 2010).

In summary, the feedback suggests that playing Cell% can help students remember the learning content of the Cell Division topic more easily, with concise notes, clarity, visual aids, and gamified learning being key factors. While students found the game beneficial for memorizing the learning content, one teacher raised the point that repetition might be necessary for full content retention. Overall, the positive response highlights the game's effectiveness in helping students to memorize the learning content.

6.4.2.2 Complex Terminology

The effectiveness of Cell% in addressing the problem of “Complex terminology” was evaluated by asking the question, “Do you think that playing Cell% can help students distinguish and understand the complex terms in the Cell Division topic?” in the questionnaire. The results are presented below.

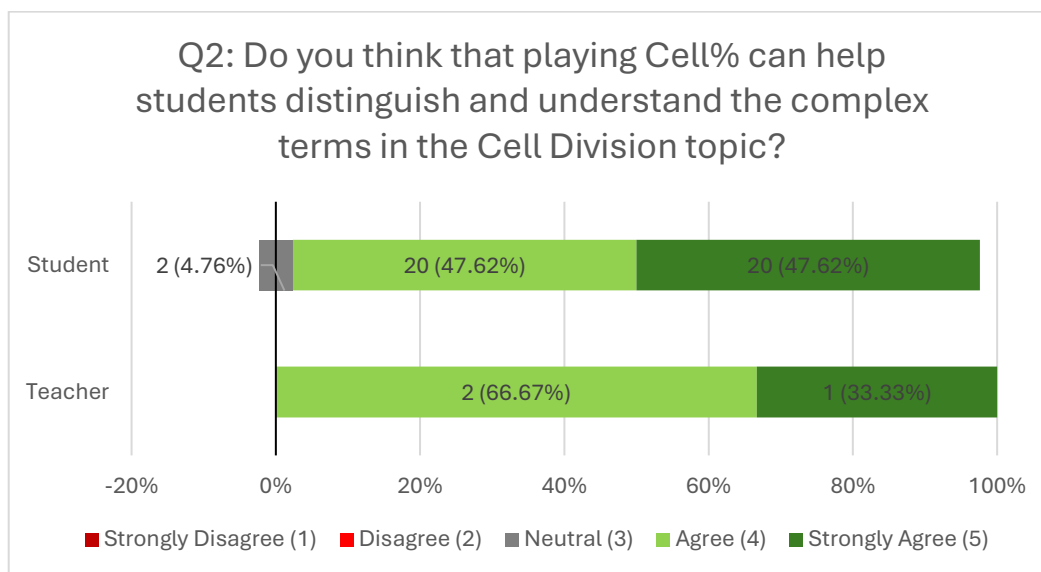


Figure 6.3: Responses for Q2

Figure 6.3 shows the responses of students and teachers regarding whether playing Cell% helps students distinguish and understand complex terms in the Cell Division topic. Among students, 47.62% agreed and 47.62% strongly agreed, with only 4.76% being neutral, resulting in a mean score of 4.43. For teachers, 66.67% agreed and 33.33% strongly agreed, resulting in a mean score of 4.33. No teachers expressed negative or neutral views. Overall, both groups found the game effective in clarifying complex terms, with students showing slightly higher agreement.

Table 6.4: Feedback for Q2

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Highlighted Keywords	“The highlighted keywords help me differentiate, memorize, and understand the terms used in the cell division process” (S22)	19
		Clarity	“Because the game explains it well” (S38)	9
		Gamified Learning	“It makes the terms look easier in gaming” (S15)	6
		Visual Aids	“Because the game gives notes, videos, and pictures to make the topics easier to understand” (S6)	4
		Quiz	“Putting almost similar looking or sounding terms on the answer is a good way to help students differentiate those terms” (S20)	4
	Total			42
	Neutral	Uncertain	“Not sure” (S14)	1
		Partial Understanding	“The keyword was helpful, but I'm still confuse with the terms” (S34)	1
		Total		
	Teacher	Positive	Highlighted Keywords	“The highlighted keywords stated clearly” (Teacher E)
Pre-Assessment Learning			“The meaning of the terms are given earlier and tested in the game” (Teacher D)	1
Quiz			“Quiz with similar terms” (Teacher F)	1
Total			3	

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.4 summarizes the feedback from both students and teachers on whether playing Cell% helps students distinguish and understand the complex terms in the Cell Division topic.

From the students' perspective, the majority of feedback was positive (42 mentions), strongly suggesting that Cell% aids in distinguishing and understanding complex terms. The most common reason (19 mentions) was the use of highlighted keywords in the notes, which helped students remember and differentiate terms, as noted by S22. This reason aligns with the signalling principle in CTML, which suggests that highlighting key information can reduce cognitive overload and facilitate the learner's working memory (Mayer, 2002a). Clarity of the content was the second most common reason (9 mentions), with students appreciating the game's explanation of terms, as noted by S38. Gamified learning (6 mentions) and visual aids (4 mentions) also stood out, as they made the terms more understandable, as noted by S15 and S6. These findings can be explained by the design of the notes in the game, where each picture was labelled with relevant terms, helping students link the picture with the term, thus easing their understanding. Additionally, the quiz feature (4 mentions) was valued for helping students practice distinguishing similar terms, as noted by S20.

On the other hand, neutral feedback from students was limited. One student (S14) was unsure about the game's effectiveness, while another student (S34) found the highlighted keywords helpful but still struggled to fully understand them. This suggests that while the game was generally helpful, a small number of students might still find the terms challenging.

From the teachers' perspective, the feedback was entirely positive. Teacher E highlighted the importance of the highlighted keywords in clarifying complex terms, while Teacher D appreciated the pre-assessment and quiz features. Teacher F valued the quiz for testing students on similar terms, aiding their understanding.

In summary, the feedback indicates that Cell% effectively helps students distinguish and understand complex terms in the Cell Division topic, with highlighted keywords, clarity, gamified learning, visual aids and the quiz feature being key factors. Although a few students expressed uncertainty or partial understanding, the overall positive feedback suggests the game is a useful tool.

6.4.2.3 The Concept Is Hard to Understand

The effectiveness of Cell% in addressing the problem of “The concept is hard to understand” was evaluated by asking the question, “Do you think that playing Cell% can help students understand the concept of Cell Division topic more easily?” in the questionnaire. The results are presented below.

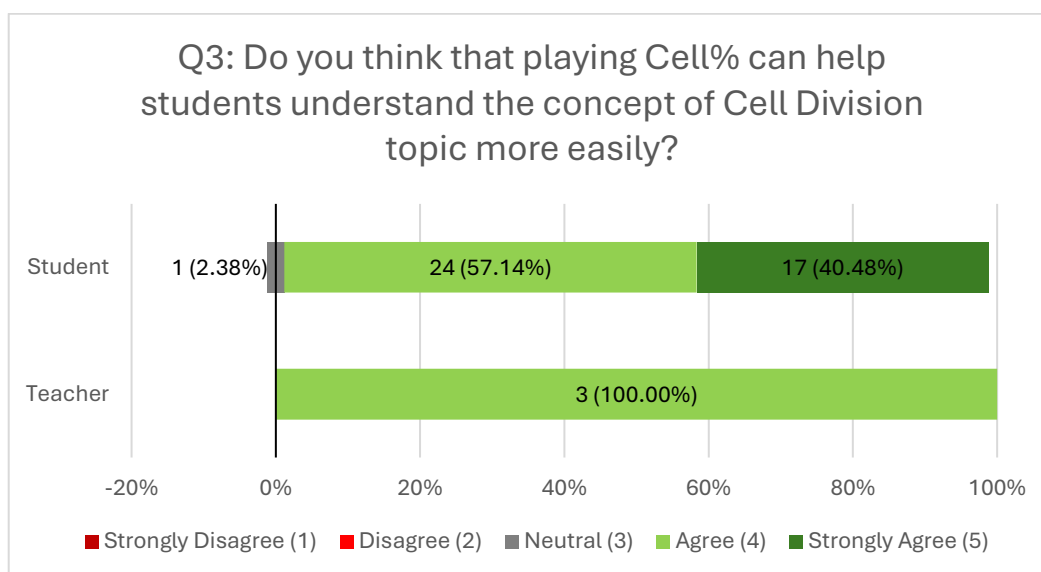


Figure 6.4: Responses for Q3

Figure 6.4 shows the responses of students and teachers regarding whether playing Cell% aids in understanding the concept of Cell Division topic more easily. Among students, 57.14% agreed and 40.48% strongly agreed, with only 2.38% neutral, resulting in a mean score of 4.38 and indicating general approval. For teachers, 100% agreed, with a mean score

of 4.00. Overall, both groups viewed the game as helpful for understanding Cell Division, with students expressing stronger agreement.

Table 6.5: Feedback for Q3

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Visual Aids	“The video helps the understanding cell” (S14)	16
		Clarity	“Because the content in the game is simple” (S25)	9
		Gamified Learning	“Because it's easy to understand via gaming” (S15)	6
		Notes	“Pictures and text in notes can help students understand the process of cell division” (S17)	6
		Memory Retention	“The game requires students to memorize the pictures and key words to pass each level” (S6)	4
		Repetition	“Because the game is repeated to remind about the content of cell division” (S29)	2
		Practical Application	“Apply to practice” (S31)	1
		Multimodal Learning	“Students can easily understand through multiple methods of learning” (S22)	1
	Total			45
	Neutral	Partial Understanding	“Because I can't understand a little bit of the concept” (S36)	1
Total				1
Teacher	Positive	Clarity	“The explanations are clear and understandable” (Teacher D)	2
		Visual Aids	“... and videos” (Teacher F)	1
		Notes	“Simple and easy notes...” (Teacher F)	1
	Total			4

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.5 presents the feedback from both students and teachers on whether playing the game Cell% can help students understand the concept of Cell Division topic more easily.

From the students' perspective, the majority of feedback was positive (45 mentions), indicating that Cell% aids understanding of the topic. Visual aids were the most frequently cited reason (16 mentions), with S14 noting that the videos and images helped them grasp the cell division process. This finding aligns with a study conducted by Kalimuthu (2017), which found that animations can enhance learners' understanding of meiosis. Students tend to pay more attention and learn better with videos compared to traditional teaching methods (Baharudin et al., 2019). Clarity of content (9 mentions) was another key factor, with S25 appreciating how the game simplified complex concepts, as supported by Chang and colleagues (2018), who claimed that appropriate presentations of information or media can reduce extraneous cognitive load, thereby improving learning. Gamified learning (6 mentions) also stood out, as the interactive game engaged students and made content more accessible, as stated by S15. This finding was supported by Mayer (2014), who mentioned that the highly visual nature of digital games reduces learners' cognitive load by presenting content in multimedia form, allowing visual and verbal representations to be stored in working memory and linked to prior knowledge. Additionally, notes combining text and pictures were helpful for understanding (6 mentions), supported by the contiguity principle in CTML (Mayer, 2002a). Moreover, the game was seen as beneficial for memory retention (4 mentions), as students were required to memorize visual and textual information to progress through the levels, as mentioned by S6.

Repetition, practical application, and multimodal learning were mentioned by fewer students but still reflect key aspects of the game. Repetition (2 mentions) reinforced learning,

as noted by S29. Practical application (1 mention) allowed S31 to apply their knowledge, and multimodal learning (1 mention) offered various ways to engage, as appreciated by S22. On the other hand, neutral feedback was minimal, with only one student (S36) indicating partial understanding.

From the teachers' perspective, feedback was entirely positive. Teacher D praised the clarity of explanations, while Teacher F highlighted the value of visual aids and notes in reinforcing content.

In summary, the feedback suggests that playing Cell% effectively aids students' understanding of Cell Division topic, with visual aids, clarity, gamified learning, note and memory retention being key factors. Despite a small fraction of students struggling, the overall feedback from both groups indicates the game is a valuable tool for learning the topic.

6.4.2.4 Misconceptions

The effectiveness of Cell% in addressing the problem of "Misconceptions" was evaluated by asking the question, "Do you think that playing Cell% can help prevent students from being confused when learning the Cell Division topic?" in the questionnaire. The results are presented below.

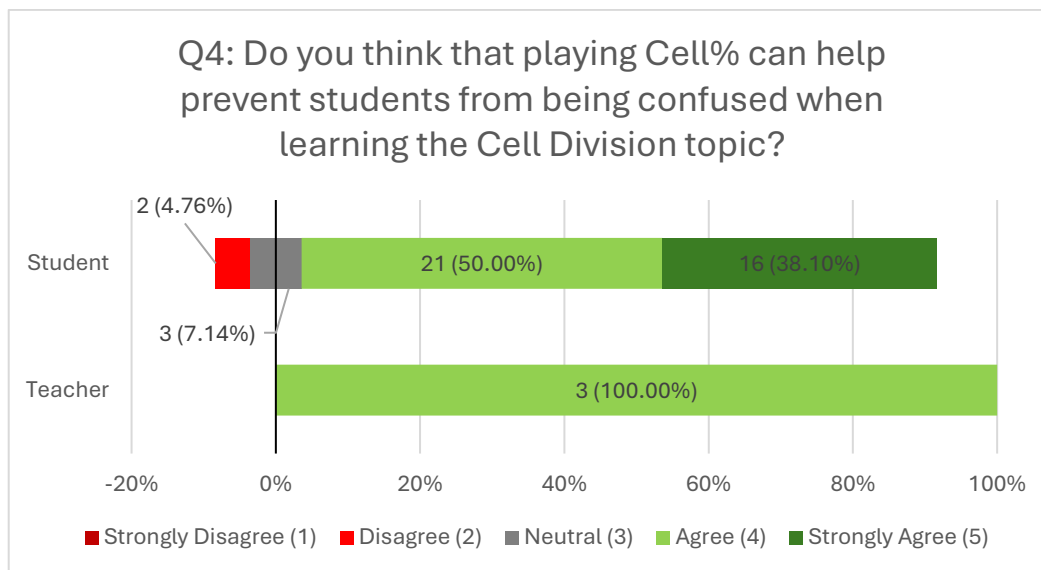


Figure 6.5: Responses for Q4

Figure 6.5 shows the responses of students and teachers regarding on whether playing Cell% can help prevent confusion when learning the Cell Division topic. Among students, 50% agreed and 38.10% strongly agreed, with 7.14% neutral and 4.76% disagreeing, resulting in a mean score of 4.21. This suggests that most students found the game effective in clarifying the material, though a few still experienced confusions. For teachers, all respondents (100%) agreed, with no strong agreements or disagreements, resulting in a mean score of 4.00. Overall, both groups generally agreed that Cell% helps prevent confusion, though a small portion of students felt it did not fully resolve their confusion.

Table 6.6: Feedback for Q4

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Visual Aids	“The pictures and videos show the process happening in the cell and help students compare each process easily” (S24)	12
		Clarity	“Because the explanation in the game is very clear” (S37)	11

Table 6.6 continued

	Game Level Design	“The game explains the concepts one by one according to the level. Every level has different concepts” (S11)	8
	Notes	“There are free notes after each level completed to compare and differentiate each phase in cell division” (S6)	7
	Feedback Mechanism	“Because when I’m wrong, I can read the notes again and correct my mistake” (S1)	2
Total			40
Negative	Confusion	“Sometimes it causes misunderstandings” (S14)	1
	Insufficient Assessment	“Not enough questions to show students the difference between topics like Mitosis vs. Meiosis I vs Meiosis II” (S20)	1
	Total		2
Neutral	Confusion	“Not really, because the words are almost similar, it’s not because of the game anyway” (S35)	2
	Uncertain	“Not sure” (S12)	1
	Total		3
Teacher	Clarity	“The comparisons are shown clearly” (Teacher E)	1
	Game Level Design	“The processes are given step by step based on game levels” (Teacher D)	1
	Notes	“There are notes in collection feature to do revision” (Teacher F)	1
	Total		3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.6 presents feedback from both students and teachers on whether playing the game Cell% can help prevent confusion when learning the Cell Division topic.

From the students' perspective, most feedback was positive (40 mentions). Visual aids (12 mentions) were the most cited, with students noting that the pictures and videos clarified the cell division processes. For example, S24 mentioned that visuals helped them compare stages more easily, thus reducing confusion. This statement aligns with Dikmenli (2010), who found that visual tools can eliminate misconceptions in learning cell division. Clarity (11 mentions) was another common reason, with S37 stating that clear explanations simplified complex concepts. The game's level design (8 mentions) was also appreciated for explaining each concept step-by-step, as noted by S11. Other positive aspects included the availability of notes (7 mentions) to compare cell division phases, and the feedback mechanism (2 mentions), which helped students correct mistakes, as mentioned by S1.

In contrast, there were a few negative responses (2 mentions). S14 expressed confusion (1 mention) about the game, and S20 highlighted insufficient assessment (1 mention), noting that more questions were needed to differentiate between similar topics like mitosis and meiosis. These criticisms suggest areas for improvement.

On the other hand, neutral feedback was minimal (3 mentions). Some students experienced confusion (2 mentions), with S35 noting that term similarities caused misunderstandings. S12 expressed uncertainty (1 mention) about whether the game reduced confusion.

From the teachers' perspective, all feedback was positive (3 mentions). Teachers praised the game's clarity (1 mention), level design (1 mention), and the availability of notes (1 mention), with Teacher F noting that the collection feature helped students with revision.

These findings indicate that teachers believe the game effectively prevents confusion by organizing the learning material in a clear and structured way.

In summary, the feedback suggests that Cell% is generally effective in preventing misconceptions in learning Cell Division, particularly through visual aids, clarity, and structured game level design. While a few students pointed out areas of confusion or a lack of assessment, the overall response indicates that the game successfully presents the content in a clear and organized manner.

6.4.2.5 Abstract Nature of the Topic

The effectiveness of Cell% in addressing the problem of “The topic is too abstract” was evaluated by asking the question, “Do you think that playing Cell% can help students learn the abstract topic of Cell Division better?” in the questionnaire. The results are presented below.

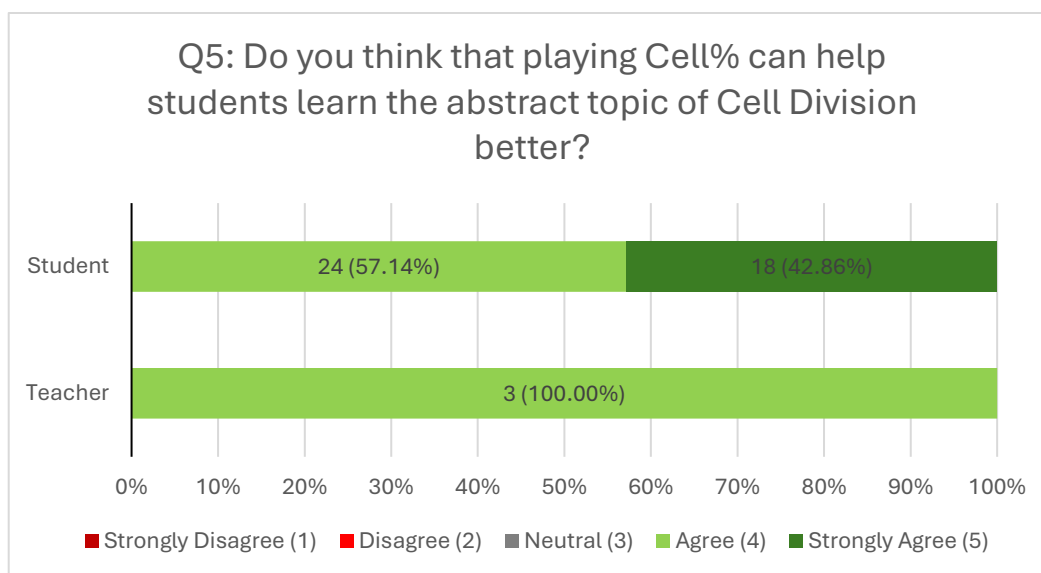


Figure 6.6: Responses for Q5

Figure 6.6 shows the responses of students and teachers regarding whether playing Cell% can help students learn the abstract topic of Cell Division better. Among students,

57.14% agreed and 42.86% strongly agreed, with no students neutral or disagreeing, resulting in a mean score of 4.43. This indicates a strong belief in the game's effectiveness. For teachers, all respondents (100%) agreed, resulting in a mean score of 4.00. Overall, both groups expressed a high level of agreement that Cell% helps students better grasp the abstract concept of cell division, with students showing slightly stronger support.

Table 6.7: Feedback for Q5

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Visual Aids	“Pictures and videos of cell division really help me visualize the process for each stage” (S22)	19
		Clarity	“Agree because it's easy to understand” (S8)	12
		Gamified Learning	“Playing the game allows students to quickly understand the general content and key points of the topic” (S9)	6
		Notes	“There are very detailed notes to help me answer the question” (S16)	3
		Repetition	“Because the game will help players review the topic again and again through video and games” (S5)	2
		Memorization	“Students can memorize the information while playing the game” (S36)	2
	Total			44
Teacher	Positive	Visual Aids	“The diagrams and videos are very helpful” (Teacher D)	2
		Clarity	“Explained well” (Teacher E)	1
	Total			3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.7 presents feedback from both students and teachers on whether playing the game Cell% can help students learn the abstract topic of Cell Division more effectively.

From the students' perspective, all feedback was positive (44 mentions). Visual aids (19 mentions) were the most cited reason, with students noting that the pictures and videos helped them visualize the stages of cell division. S22 highlighted that these visuals made the abstract topic clearer. This statement aligns with Basri and Abdullah (2020), who found that visualizing abstract concepts enhances learning. Clarity (12 mentions) was another key factor, with S8 noting that the game's clear explanations made the content easier to grasp, helping students master complex concepts. Students also appreciated the gamified learning aspect (6 mentions), with S9 noting that the game helped them quickly understand key points. Notes (3 mentions) were valued, with S16 mentioning that detailed notes reinforced their understanding. Repetition (2 mentions) allowed students to review the topic through gameplay, strengthening their knowledge, as noted by S5. Memorization (2 mentions) was also seen as a benefit, with S36 saying the game helped them memorize key cell division facts.

From the teachers' perspective, all feedback was similarly positive (3 mentions). Visual aids (2 mentions) were praised by Teacher D, who found the diagrams and videos helpful for conveying abstract concepts. Clarity (1 mention) was also appreciated by Teacher E, who noted that the game simplified complex topics effectively.

In summary, the feedback suggests that Cell% is highly effective in helping students learn Cell Division topic. Visual aids, clarity, and gamified learning were key reasons for improved understanding, with both students and teachers agreeing on the game's value in teaching abstract topics like cell division.

6.4.3 Motivational Perspective

6.4.3.1 Lack of Interest in the Learning Content

The effectiveness of Cell% in addressing the problem of “Not interested in the learning content” was evaluated by asking the question, “Do you think that playing Cell% can increase students’ interest on the learning content of Cell Division topic?” in the questionnaire. The results are presented below.

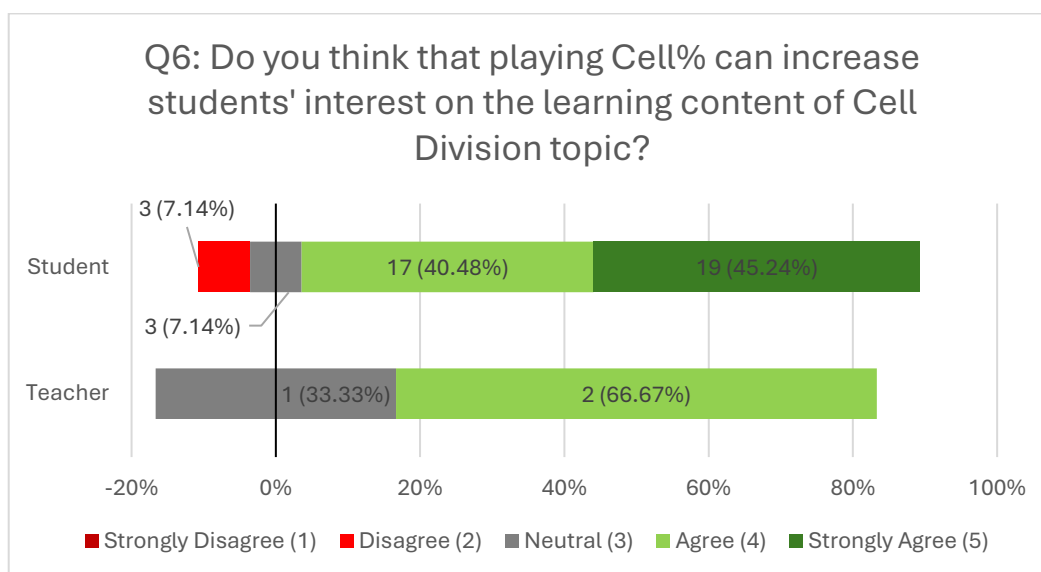


Figure 6.7: Responses for Q6

Figure 6.7 presents the responses of students and teachers regarding whether playing Cell% can increase students' interest in the learning content of the Cell Division topic. Among students, 45.24% strongly agreed and 40.48% agreed, with 7.14% neutral and 7.14% disagreeing, resulting in a mean score of 4.29. This suggests a strong positive impact on students’ interest. For teachers, 66.67% agreed and 33.33% were neutral, resulting in a mean score of 3.67. Overall, both groups felt that Cell% helps increase interest, though a Teacher Dnd a small portion of students did not find it as effective.

Table 6.8: Feedback for Q6

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Game Engagement	“Being a game itself can encourage students to play and learn” (S22)	27
		Competitiveness	“Students can compete with their friends in the game” (S24)	4
		Puzzle Game Elements	“Yes, because the students get tasks or puzzles to solve” (S10)	3
		Badges	“Yes, badges are interesting” (S18)	2
		Mobile Learning Preference	“Because students like learning with phones more than studying in class or using textbooks” (S41)	2
		Visual Aids	“The game explains the topic in animated way” (S6)	1
	Total			39
	Negative	Lack of Game Engagement	“It's boring” (S13)	1
		Nature of Topic	“No matter how fun the game is, this topic is still boring due to its nature...” (S20)	1
		Technical Issues	“The game is laggy and the camera sensitivity is too slow” (S35)	1
	Total			3
	Neutral	Lack of Game Engagement	“In my experience, it doesn't” (S14)	1
	Total			1
Teacher	Positive	Game Engagement	“The game is fun” (Teacher E)	2
	Total			2
	Neutral	Uncertain	“Not sure, I think students should draw or make models to show the cell division processes to encourage them to learn” (Teacher D)	1
	Total			1

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.8 presents feedback from both students and teachers on whether playing the game Cell% can increase students' interest in the learning content of the Cell Division topic.

From the students' perspective, most feedback was positive (39 mentions). The main reason was game engagement (27 mentions), with students noting that the game's format made learning more engaging than traditional methods. S22 highlighted that the game format enhanced their learning experience, aligning with studies showing the positive effects of game-based learning on motivation (Shamsudin et al., 2020; Sumandal, 2023). Competitiveness (4 mentions) was another factor, with S24 stating that competing with friends motivated them to learn. This finding aligns with Plass and colleagues' (2013) study, which shows that competition and collaboration make learning more interesting and enjoyable while encouraging students to focus on improving and mastering skills. Puzzle game elements (3 mentions) also contributed to engagement, as S10 noted that solving tasks made learning more dynamic. Other reasons included the appeal of badges (2 mentions), a preference for mobile learning (2 mentions), and visual aids (1 mention).

However, there were a few negative responses (3 mentions), including lack of engagement (1 mention) from S13, who found the game "boring", the inherent difficulty of the topic (1 mention) noted by S20, and technical issues (1 mention) reported by S35, which affected the gameplay experience. Neutral feedback (1 mention) came from S14, who felt the game did not necessarily increase interest.

From the teachers' perspective, the feedback was generally positive (2 mentions). Teacher E praised the game's fun aspect, which contributed to engagement. However, Teacher D expressed neutral feedback (1 mention), suggesting that additional activities like drawing or making models could further enhance student interest.

In summary, feedback suggests that Cell% generally increases interest in the Cell Division topic, primarily through engagement, competitiveness, and puzzle game elements. While some students found the game less engaging or encountered technical issues, most feedback indicates a positive impact on motivation and interest, with teachers suggesting that supplementary activities could further enhance learning.

6.4.3.2 Lack of Motivation Due to the Topic's Difficulty

The effectiveness of Cell% in addressing the problem of “Lack of motivation due to the topic's difficulty” was evaluated by asking the question, “Do you think that playing Cell% motivates students to learn the Cell Division topic, regardless of its difficulty?” in the questionnaire. The results are presented below.

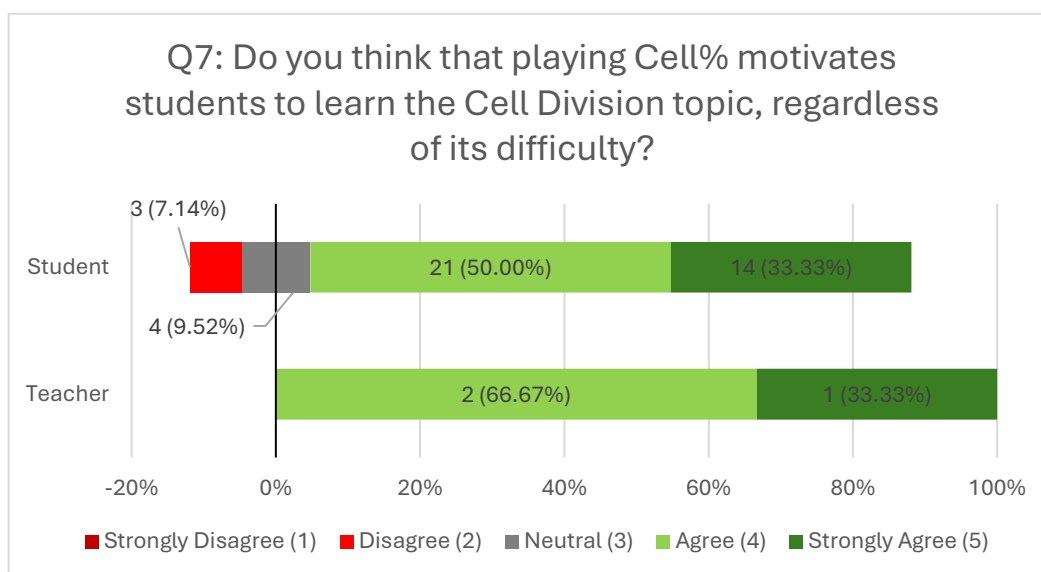


Figure 6.8: Responses for Q7

Figure 6.8 illustrates the responses of students and teachers regarding whether playing Cell% motivates students to learn the Cell Division topic, despite its difficulty. Among students, 50% agreed and 33.33% strongly agreed, while 7.14% disagreed and 9.52% were neutral, resulting in a mean score of 4.10. For teachers, 66.67% agreed and 33.33%

strongly agreed, with no neutrality or disagreement, resulting in a mean score of 4.33. Overall, both groups believed Cell% motivates learning, though a small portion of students did not find it motivating.

Table 6.9: Feedback for Q7

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Game Engagement	“Because it motivates us, making us feel like it's not that hard if we learn and enjoy it through playing game” (S34)	16
		Competitiveness	“I was really motivated to study the topic because I want to be number 1 in the game” (S28)	13
		Badges	“I agree because the badges can motivate students to play the game” (S24)	4
		Task-Based Oriented	“Because it has missions to complete” (S19)	1
		Study Aids	“Because it has a collection feature where I can easily review the basic concepts of cell division” (S25)	1
		Social Engagement	“While playing with friends in a clan” (S7)	1
		Guided Learning	“This game teaches us step by step” (S12)	1
	Total			37
	Negative	Lack of Engagement	“Sure, it can probably motivate students to learn this topic a little, but this game lacks the activities to fully motivate students to learn this topic” (S20)	2
		Learning Challenges	“Disagree because it's still difficult to remember” (S8)	1
Total			3	

Table 6.9 continued

	Neutral	Uncertain	“Well, maybe. It depends” (S35)	2
		Partial Game Engagement	“I agree, by playing game, but it didn't motivate me very much actually” (S3)	1
		Learning Challenges	“Still difficult” (S17)	1
	Total			4
Teacher	Positive	Badges	“Reward system with badges” (Teacher E)	1
		Game Engagement	“Learn by playing game is a suitable technique for the students nowadays” (Teacher D)	1
		Competitiveness	“Leaderboard” (Teacher F)	1
	Total			3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.9 presents feedback from both students and teachers on whether playing the game Cell% motivates students to learn the Cell Division topic, regardless of its difficulty.

From the students' perspective, most feedback was positive (37 mentions). Game engagement (16 mentions) was the most cited reason, with students noting that the game made learning more enjoyable and less challenging. S34 highlighted that the game's fun aspect increased motivation, making it easier to engage with the complex topic. Competitiveness (13 mentions) was another key motivator, with S28 stating that striving for higher scores pushed them to study harder, supporting findings by Plass and colleagues (2013) that competitive elements in the game can drive students to engage more deeply with the learning content. Additional positive feedback included badges (4 mentions), task orientation (1 mention), study aids (1 mention), social engagement (1 mention), and guided learning (1 mention).

Negative feedback was minimal (3 mentions). S20 noted a lack of engagement, while S8 mentioned that the game didn't fully address the difficulty of the topic. This suggests that although the game motivates many students, some may still struggle with the content. On the other hand, neutral feedback was also limited (2 mentions). One student (S35) expressed uncertainty, while another (S3) felt the game partially engaged them but not fully. S17 mentioned that the content remained difficult despite the game's efforts.

From the teachers' perspective, all feedback was positive (3 mentions). Teachers praised badges (1 mention), game engagement (1 mention), and competitiveness (1 mention), with Teacher E noting that the reward system helped maintain student interest. This finding is supported by Ismail and colleagues (2018), who mentioned that the use of gamification, such as badges as rewards, can encourage learners' extrinsic motivation. Additionally, Teacher F mentioned the leaderboard as an effective tool for encouraging students to learn. This aligns with the students' feedback, where competitiveness was also a strong motivator.

In summary, feedback indicates that Cell% effectively motivates students to learn the Cell Division topic, particularly through game engagement and competitiveness. While most students found it motivating, a small number still struggled to fully engage, suggesting that Cell% is beneficial for many but may not meet every learner's needs.

6.4.3.3 Students' Passivity in Class

The effectiveness of Cell% in addressing the problem of "Students are passive in class" was evaluated by asking the question, "Do you think that playing Cell% make students more active when learning the Cell Division topic?" in the questionnaire. The results are presented below.

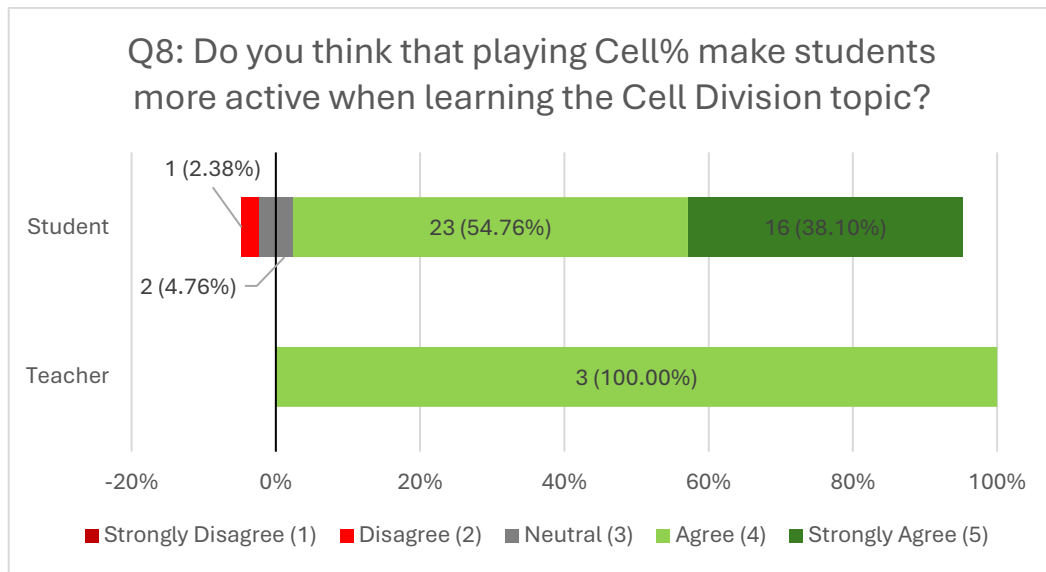


Figure 6.9: Responses for Q8

Figure 6.9 illustrates the responses of students and teachers regarding whether playing Cell% makes students more active when learning the Cell Division topic. Among students, 54.76% agreed and 38.10% strongly agreed, with 2.38% disagreeing and 4.76% neutral, resulting in a mean score of 4.29. For teachers, 100% agreed, resulting in a mean score of 4.00. Overall, both groups recognized the game’s potential to boost student engagement, though a small portion of students did not find it effective.

Table 6.10: Feedback for Q8

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Game Engagement	“The students become very active by playing game” (S39)	20
		Clarity	“It is more understandable” (S7)	8
		Competitiveness	“To be on top of the leaderboard, students must be active while playing this game” (S26)	5
		Study Aids	“It's helpful as it has notes and other features” (S34)	3
		Social Engagement	“Yes, you can play together with your friends” (S39)	3

Table 6.10 continued

Total	Badges	“Because after playing all the games, we will get a badge” (S32)	1	
			40	
Negative	Lack of Long-Term Engagement	“Sure, it can make students more active, but after finishing the game, there's nothing left to do, so students may forget the game and not reopen it” (S20)	1	
Total			1	
Neutral	Uncertain	“Not sure, but I can learn with the others indirectly” (S25)	1	
	Technical Issues	“The game has a crucial bug; I had to play the same level five times because it crashed and went black screen” (S35)	1	
Total			2	
Teacher	Positive	Gamification	“Gamification elements” (Teacher F)	1
		Self-Exploration	“Can self-explore” (Teacher E)	1
		Pre-learning Support	“They can get the knowledge while playing the game before learn the topic in the class.” (Teacher D)	1
	Total			3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.10 presents feedback from both students and teachers on whether playing the game Cell% makes students more active when learning the Cell Division topic.

From the students' perspective, most feedback was positive (40 mentions). Game engagement (20 mentions) was the most cited reason, with students noting that the interactive nature of the game encouraged active participation. For example, S39 highlighted that the game fostered a dynamic learning environment. Clarity (8 mentions) also played a significant role, with S7 noting that the game made the material more understandable.

Competitiveness (5 mentions) motivated students, as S26 explained that staying active helped them remain on the leaderboard. Other positive factors included study aids (3 mentions), social engagement (3 mentions), and badges (1 mention).

Negative feedback was minimal (1 mention), with S20 stating that while the game promoted initial activity, it lacked long-term engagement after completion. Neutral feedback (2 mentions) was also limited. S25 expressed uncertainty about the long-term impact of the game, aligning with Nørgård and colleagues (2017), who noted that extrinsic motivators may not foster sustained engagement. S35 mentioned technical issues, such as game crashes, which disrupted the learning experience.

From the teachers' perspective, all feedback was positive (3 mentions). Teachers highlighted gamification (1 mention), self-exploration (1 mention), and pre-learning support (1 mention) as factors contributing to student activity. Teacher F praised the gamified elements, while Teacher E noted that the game encouraged independent exploration. Teacher D emphasized that the game helped students gain foundational knowledge before class, supporting active learning both inside and outside the classroom.

In summary, feedback suggests that Cell% is effective in increasing student activity in learning the Cell Division topic, with game engagement, clarity, and competitiveness frequently mentioned by students. Teachers also recognized the game's gamification and self-exploration elements. While some students expressed concerns about long-term engagement and technical issues, the overall response indicates that Cell% effectively promotes active learning.

6.4.4 Affective Perspective

6.4.4.1 Learning Process Is Not Enjoyable

The effectiveness of Cell% in addressing the problem of “Learning process is not enjoyable” was evaluated by asking the question, “Do you think that playing Cell% make learning of the Cell Division topic more enjoyable?” in the questionnaire. The results are presented below.

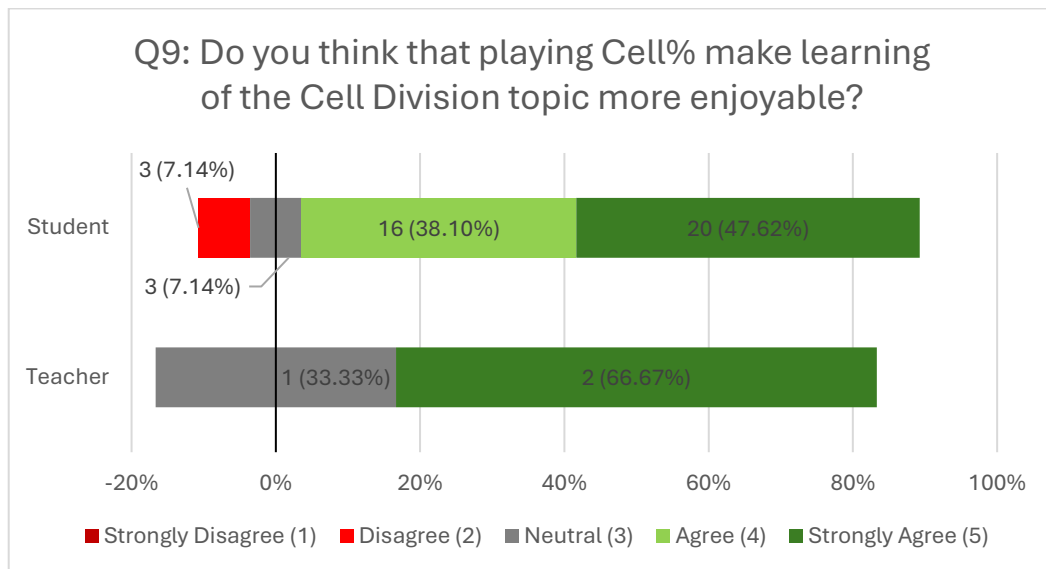


Figure 6.10: Responses for Q9

Figure 6.10 presents the responses of students and teachers regarding whether playing Cell% makes learning the Cell Division topic more enjoyable. Among students, 38.10% agreed and 47.62% strongly agreed, with 7.14% disagreeing and 7.14% neutral, resulting in a mean score of 4.26. For teachers, 66.67% strongly agreed and 33.33% were neutral, resulting in a mean score of 4.33. Overall, both groups felt the game made learning more enjoyable, though a small portion of students expressed reservations.

Table 6.11: Feedback for Q9

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Game Engagement	“Yes, it makes learning this topic more enjoyable compared to just learning by textbook” (S20)	29
		Visual Appeal	“Because the animation content in the game is very interesting” (S37)	2
		Clarity	“The notes in this game are easier to understand” (S16)	2
		Relaxation	“Can let my hair down” (S3)	2
		Convenience	“It's an interesting way to understand and very convenient to learn by phone” (S6)	1
	Total	Badges	“Because when I got badges, I feel more enjoyable” (S1)	1
				37
	Negative	Technical Issues	“The slow sensitivity of the game makes it hard to enjoy” (S14)	2
		Lack of Interest	“I feel bored because I don't like to play games” (S13)	1
	Total			3
Teacher	Neutral	Neutral	“Not enjoyable nor boring” (S17)	1
		Uncertain	“I don't know” (S8)	1
	Total	Technical Issues	“The graphics are less interesting, but it reduces the pressure of learning cell division if the game doesn't lag” (S25)	1
				3
	Positive	Game Engagement	“The game is fun and adventurous” (Teacher E)	2
	Total			2
Teacher	Neutral	Uncertain	“Not sure, I think the students still need explanation from the teacher to learn, even though they enjoy the game” (Teacher D)	1
	Total			1

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.11 presents feedback from both students and teachers regarding whether playing Cell% makes learning about the Cell Division topic more enjoyable.

From the students' perspective, the overwhelmingly positive feedback (37 mentions) indicates that Cell% makes learning about cell division more enjoyable. The most cited reason was "Game Engagement" (29 mentions), with students noting that the game makes learning more enjoyable than traditional methods, as S20 pointed out. This reason supported by Kanyapasit and Srisawasdi (2014), who found that digital games promote better engagement. Students also appreciated the game's visual appeal (2 mentions), clarity (2 mentions), and relaxing nature (2 mentions), with some enjoying the mobile learning convenience (1 mention) and the badges system (1 mention).

Negative feedback was minimal (3 mentions), with a few students mentioning technical issues, such as slow sensitivity which hindered enjoyment, as stated by S14. S13 also expressed a lack of interest, suggesting that not all students enjoy gamified learning. If students are not prepared for gamified learning, their motivation may be lower during the learning process (Aldemir et al., 2018). However, these concerns were infrequent and did not significantly impact the overall positive feedback.

Neutral feedback was also minimal (3 mentions). S17 found the game neither enjoyable nor boring, while S8 was unsure about its impact on their learning enjoyment. S25 noted that although the graphics were unimpressive, the game reduced the pressure of learning Cell Division when there were no technical issues. This suggests that, despite mixed feelings, the game still offered benefits.

From the teachers' perspective, feedback was generally positive (2 mentions), with Teacher E praising the game's engaging nature. However, Teacher D gave neutral feedback,

expressing uncertainty and noting that students might need additional explanations to fully understand the content. This suggests that while Cell% enhances enjoyment, traditional teaching methods may still be necessary.

In summary, feedback shows that Cell% significantly increases enjoyment of learning the Cell Division topic, with key factors being game engagement, visual appeal, clarity, and a relaxing nature. While some students noted technical issues or a lack of interest, the overall response was positive. Teachers recognize the game’s benefits but suggest it could be complemented by other teaching methods for optimal learning outcomes.

6.4.4.2 Negative Feelings Towards the Topic

The effectiveness of Cell% in addressing the problem of “Have negative feelings towards the topic” was evaluated by asking the question, “Do you think that playing Cell% makes students feel more positive toward the Cell Division topic?” in the questionnaire. The results are presented below.

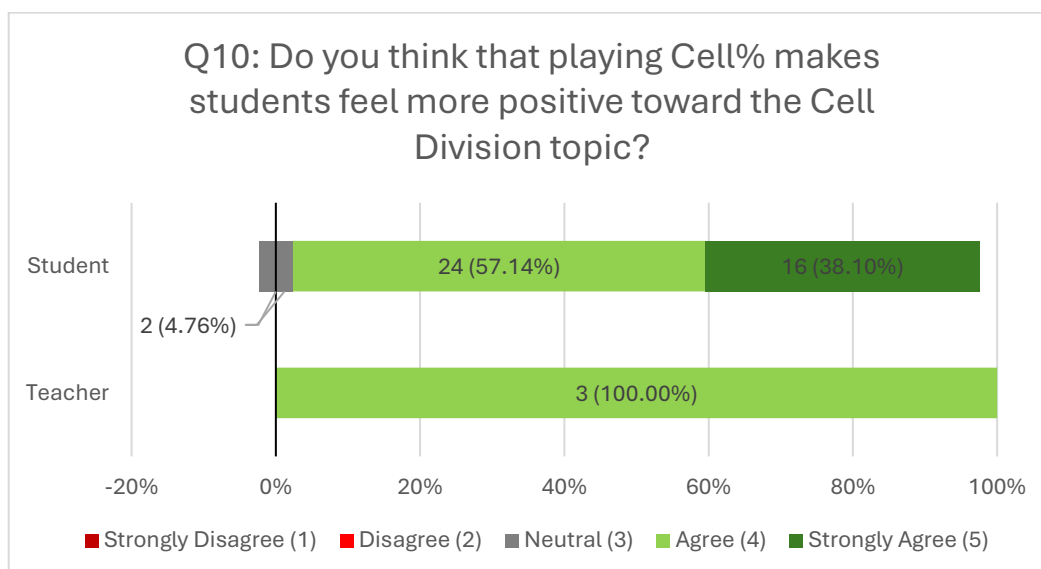


Figure 6.11: Responses for Q10

Figure 6.11 illustrates the responses of students and teachers regarding whether playing Cell% makes students feel more positive toward the cell division topic. Among students, 57.14% agreed and 38.10% strongly agreed, with 4.76% neutral, resulting in a mean score of 4.33. For teachers, 100% agreed, with no neutrality or disagreement, resulting in a mean score of 4.00. Overall, both groups believed the game positively influenced students' attitudes, though students showed a slightly broader range of responses.

Table 6.12: Feedback for Q10

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Positive Attitude	“After playing the game, my point of view toward the topic has surprisingly changed to a more positive one” (S28)	16
		Clarity	“Because the game has simple content and is easier to understand” (S25)	7
		Game Engagement	“The vibe of the game is the best” (S36)	5
		Motivation	“More willing to learn” (S17)	3
		Improved Confidence	“I think this game will help me a lot in preparing for exams and increase my confidence” (S26)	2
		Social Engagement	“Helps to build better teammates” (S21)	2
		Study Aids	“Because I can study notes that are given before answering the questions” (S4)	2
		Relaxation	“I agree because the game can help students ease their stress” (S24)	2
		User-Friendly Interface	“The game screen is simple and easy to use” (S30)	1
		Memory Retention	“Because students can easily memorize by learning through the game” (S29)	1
Total			41	

Table 6.12 continued

Teacher	Neutral	Uncertain	“I don't really have any opinion. Some may feel more positive while others may feel no changes and still be frustrated...” (S20)	2
	Total			2
	Positive	Game Engagement	“Students like to play game and the game is quite challenging as well” (Teacher D)	1
		Badges	“Reward system like badges” (Teacher E)	1
		Gamification	“Gamification element” (Teacher F)	1
	Total			3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.12 presents feedback from both students and teachers regarding whether playing Cell% makes students feel more positive toward the Cell Division topic.

From the students’ perspective, the feedback was overwhelmingly positive (41 mentions), with “Positive Attitude” (16 mentions) being the most common reason. S28 noted that their perspective toward the topic improved after playing the game, supporting Sung and Hwang’s (2013) finding that digital games foster positive attitudes. Clarity (7 mentions) was another key factor, with students like S25 finding the material easier to understand. Game engagement (5 mentions) also contributed to a positive experience, with students like S36 enjoying the game’s interactive nature. Additionally, students reported increased motivation (3 mentions) and confidence (2 mentions), with S26 noting that the game helped with exam preparation. Social engagement (2 mentions) and study aids (2 mentions) were also appreciated, aligning with Eseryel and colleagues (2014), who found that collaboration

and competition enhance engagement. Some students found the game relaxing (2 mentions), helping reduce stress during learning, as noted by S24.

Neutral feedback was minimal (2 mentions). For instance, S20 expressed uncertainty, stating that while some may feel more positive, others may not experience any changes and could still feel frustrated. This suggests that while most students benefit from the game, a small portion may not experience the same level of positivity or engagement, possibly due to varying learning preferences or expectations.

From the teachers' perspective, the feedback was similarly positive. Teachers recognized the game's engaging and challenging nature, as described by Teacher D, who mentioned that students enjoyed playing the game and found it stimulating. Additionally, Teacher E appreciated the reward system, such as badges, which enhanced student motivation. Teacher F also acknowledged the gamification element, which likely contributes to making learning more enjoyable and rewarding for students.

In summary, feedback shows that Cell% significantly enhances students' attitudes toward learning the Cell Division topic. The students' positive attitudes, along with the game's clarity, engagement, and motivational features, foster a positive learning environment, although a few students may remain indifferent. Overall, both students and teachers highlight the game's potential to foster a positive learning environment.

6.4.5 Social Perspective

6.4.5.1 Lack of Social Interaction in Class

The effectiveness of Cell% in addressing the problem of “Lack of social interaction in class” was evaluated by asking the question, “Do you think that playing Cell% can increase students’ social interaction with others when learning the Cell Division topic?” in the questionnaire. The results are presented below.

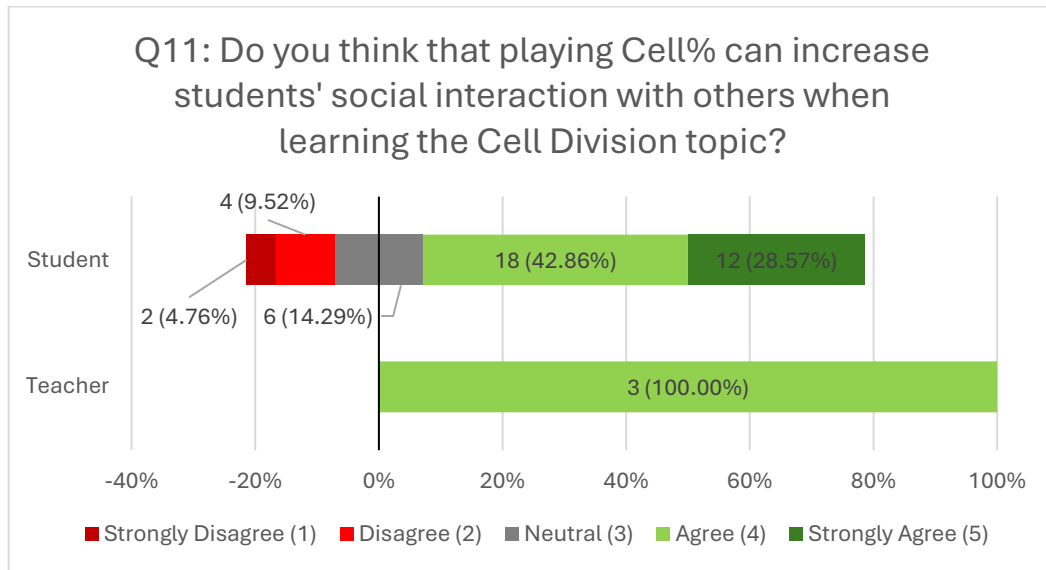


Figure 6.12: Responses for Q11

Figure 6.12 shows the responses of students and teachers regarding whether playing Cell% can increase students’ social interaction while learning the Cell Division topic. Among students, 42.86% agreed and 28.57% strongly agreed, with 4.76% strongly disagreeing, 9.52% disagreeing, and 14.29% neutral, resulting in a mean score of 3.81. For teachers, 100% agreed, resulting in a mean score of 4.00. Overall, both groups believed the game can encourage social interaction, though students showed a wider range of opinions compared to teachers.

Table 6.13: Feedback for Q11

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Forum Feature	“The forum platform helps increase student interaction with peers and teachers by asking or answering questions.” (S22)	16
		Social Engagement	“I agree because I can interact with my friend and teacher to ask questions about things I don't understand” (S24)	15
		Clan Feature	“Because of the clan option” (S15)	3
	Total			34
	Negative	Lack of Interaction	“Sometimes people won't answer, maybe once someone answers they will get some rewards” (S5)	4
		Shyness	“Students are probably shy to ask questions, and the forum should allow anonymous posts” (S20)	2
	Total			6
	Neutral	Shyness	“I don't have the courage to ask” (S23)	4
		Lack of Interaction	“Not many use this feature” (S42)	2
Total			6	
Teacher	Positive	Social Engagement	“They can play the game together and share the contents with their friends” (Teacher D)	2
		Forum Feature	“There are discussion platform” (Teacher E)	1
	Total			3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.13 presents feedback from both students and teachers on whether playing the game Cell% can enhance students' social interaction during the learning of the Cell Division topic.

From the students' perspective, most feedback was positive (34 mentions). The forum feature was the most cited reason (16 mentions), with students noting that it encouraged interaction between peers and teachers. For example, S22 highlighted that the platform promoted collaborative learning. Social engagement (15 mentions) was also frequently mentioned, with S24 explaining how the game facilitated discussions with both friends and teachers. The clan feature (3 mentions) was praised by S15, who found it made the learning experience more collaborative. These findings align with Chen and colleagues (2015b), who noted that collaboration features in digital games foster interaction toward common goals.

Despite the overall positive feedback, some students provided negative responses (6 mentions). A lack of interaction (4 mentions) was one reason, with S5 noting that some students only responded in the forum if there were rewards. Shyness (2 mentions) was another issue, with S20 suggesting that anonymity in forum posts might encourage more participation. Moreover, neutral feedback (6 mentions) also emerged, with S23 stating a lack of courage to participate in discussions, and S42 observing that the forum was underused.

From the teachers' perspective, feedback was entirely positive. Teacher D highlighted the value of peer collaboration through gameplay, and Teacher E praised the forum feature as a useful tool for student interaction.

In summary, feedback suggests that Cell% can enhance social interaction in learning Cell Division, particularly through the forum and peer engagement. While shyness and inconsistent interaction were noted as barriers, both students and teachers agreed that the game effectively promotes social learning.

6.4.5.2 Feeling of Isolation When Studying the Topic

The effectiveness of Cell% in addressing the problem of “Feeling of isolation during topic study” was evaluated by asking the question, “Do you think that playing Cell% makes students feel they are learning with others when studying the Cell Division topic?” in the questionnaire. The results are presented below.

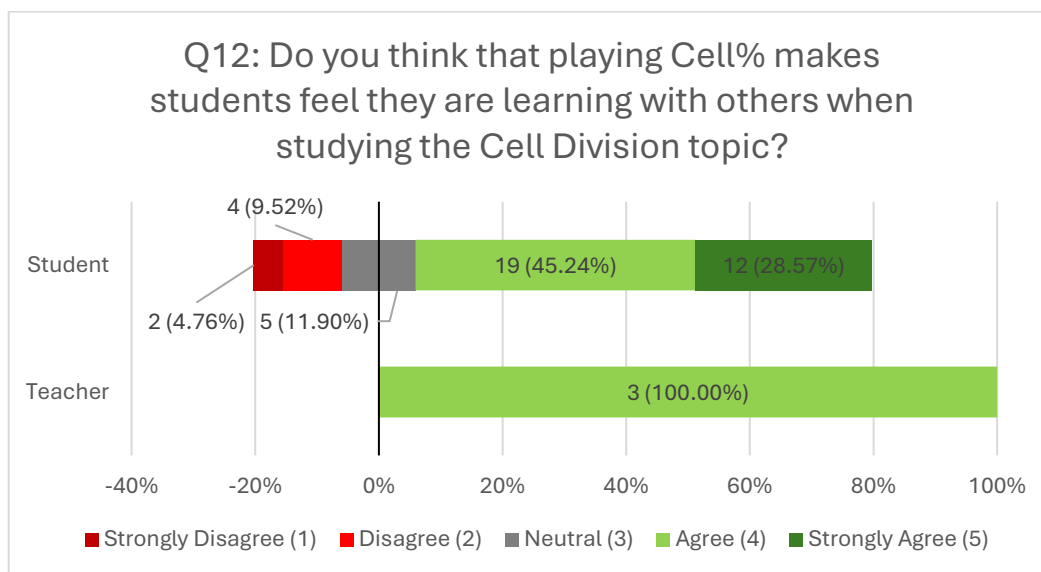


Figure 6.13: Responses for Q12

Figure 6.13 illustrates the responses of students and teachers regarding whether playing Cell% helps students feel they are learning with others while studying the Cell Division topic. Among students, 45.24% agreed and 28.57% strongly agreed, with 4.76% strongly disagreeing, 9.52% disagreeing, and 11.90% neutral, resulting in a mean score of 3.83. For teachers, 100% agreed, resulting in a mean score of 4.00. Overall, both groups felt that Cell% promotes a collaborative learning environment, though teachers showed more uniform agreement than students.

Table 6.14: Feedback for Q12

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Peer Collaboration	“Agree because we can play with friends” (S8)	13
		Clan Feature	“I agree because I can team up with my friend and we can collect points together and compete with other clans” (S24)	11
		Leaderboard	“The leaderboard shows everyone the level and the points of other students” (S11)	7
		Forum Feature	“You can communicate with others in forum” (S14)	7
		Competitiveness	“Yes, and we can compete with others” (S10)	3
	Total			41
	Negative	Loneliness	“In my opinion, no. I felt lonely when playing the game. There should be an option to play multiplayer.” (S20)	5
		Uncertain	“I don’t know” (S41)	1
	Total			6
	Neutral	Uncertain	“I’m not sure” (S36)	2
		Neutral	“The forum feature can be a big help if students use it” (S26)	2
		Lack of Real-Time Interaction	“It’s because we can’t interact while playing the game” (S33)	1
	Total			5
Teacher	Positive	Peer Collaboration	“They can play the game and share the contents with their friends while playing” (Teacher D)	2
		Leaderboard	“Player ranking in leaderboard” (Teacher F)	1
	Total			3

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.14 presents feedback from students and teachers on whether playing Cell% fosters a sense of collaborative learning when studying the topic of Cell Division.

From the students' perspective, most feedback was positive (41 mentions). Peer collaboration (13 mentions) was the most common reason, with students noting how the game supported interaction with friends during learning. For example, S8 felt that playing with friends enhanced collaboration. This aligns with Serrano (2019), who highlighted collaboration as a key feature in digital GBL. The clan feature (11 mentions) was also praised, with S24 describing how teaming up with friends added to the shared learning experience. This finding shows that the clan feature supports enable group learning, by creating group setting that allow learners collaborate one another to achieve optimal learning outcomes under the same goals (Zhong, 2019). The leaderboard (7 mentions) allowed students to track their progress relative to peers, which S11 appreciated. This is supported by Mohamad and colleagues (2017), who argued that the leaderboard showcases each player's rank for easy recognition and encourages competition among students. Forum engagement (7 mentions) and competitiveness (3 mentions) were also seen as promoting collaborative learning.

There were some negative responses (6 mentions), with loneliness (5 mentions) being a concern. S20 felt isolated during gameplay and suggested multiplayer options to address this. One student (S41) also expressed uncertainty about the game's collaborative aspects. On the other hand, neutral feedback (5 mentions) included S36, who was unsure about the game's collaborative features, and S26, who found the forum useful only if students participated. S33 noted the lack of real-time interaction, which reduced the collaborative feel of the game.

From the teachers' perspective, feedback was entirely positive (3 mentions). Teacher D noted that the game supported peer collaboration, while Teacher F appreciated the leaderboard for enhancing engagement and competition.

In summary, feedback indicates that Cell% fosters collaborative learning through features like peer collaboration, clans, and leaderboards. However, some students noted feelings of loneliness and uncertainty, suggesting the game could benefit from additional real-time interaction features. Teachers generally agreed on the game's positive impact on collaborative learning.

6.4.5.3 Lack of Opportunities for Group Learning

The effectiveness of Cell% in addressing the problem of "Lack of opportunities for group learning" was evaluated by asking the question, "Do you think that playing Cell% gives students more opportunities for group learning when studying the Cell Division topic?" in the questionnaire. The results are presented below.

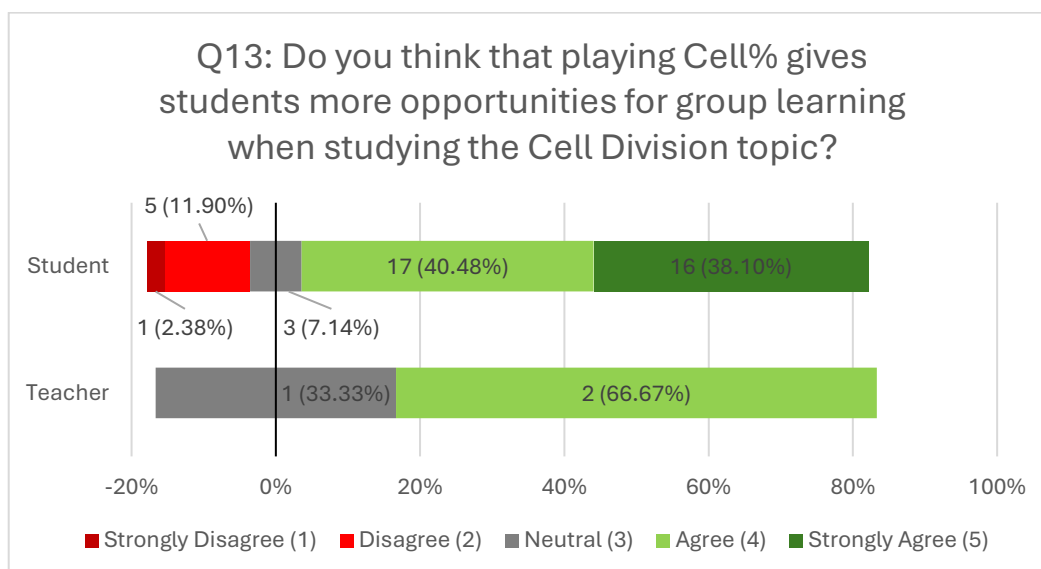


Figure 6.14: Responses for Q13

Figure 6.14 illustrates the responses of students and teachers regarding whether playing Cell% provides more opportunities for group learning when studying the Cell Division topic. Among students, 40.48% agreed and 38.10% strongly agreed, with 2.38% strongly disagreeing, 11.90% disagreeing, and 7.14% neutral, resulting in a mean score of 4.00. For teachers, 66.67% agreed and 33.33% were neutral, resulting in a mean score of 3.67. Overall, both groups viewed Cell% as promoting group learning, with students showing stronger agreement than teachers.

Table 6.15: Feedback for Q13

Group	Feedback	Reason	Sample Excerpts	Frequency
Student	Positive	Clan Feature	“Because it has a clan feature that allows students to play together” (S25)	11
		Forum Feature	“With the forum platform, students can ask questions, and friends and teachers can help, opening many opportunities for group learning” (S22)	11
		Group Learning Opportunity	“Yes, students have more opportunities to learn together” (S2)	8
		Peer Collaboration	“I agree because I can learn together with my friends and help each other with understanding the topic” (S24)	4
	Total			34
	Negative	Loneliness	“I don't think this is a cooperative game; everyone can complete the tasks alone” (S9)	3
		Limited Group Learning	“No, I don't think so. There are just not enough opportunities for group learning” (S20)	2
		Competitive Focus	“For me, the clan only makes students compete against each other to be at the top of the clan, but not really play together” (S26)	1
	Total			6

Table 6.15 continued

	Neutral	Uncertain	“I don't know” (S10)	2
		Limited Group Learning	“Only 3 people are not enough for a clan” (S5)	1
	Total			3
Teacher	Positive	Peer Collaboration	“Can learn collaboratively with others” (Teacher E)	1
		Clan Feature	“Students can form clan” (Teacher F)	1
	Total			2
	Neutral	Uncertain	“Not sure, but as the students already gain the knowledge from the game, they and can share it in the class by using learning walk process.” (Teacher D)	1
Total				1

Note. The total frequency of reasons is not equal to the total number of participants because a participant can give multiple reasons for their rating

Table 6.15 presents student and teacher feedback on whether playing Cell% provides more opportunities for group learning when studying the topic of Cell Division.

From the students' perspective, positive feedback focused on the clan (11 mentions) and forum features (11 mentions), with many students noting that these features facilitated group learning. S25 highlighted how the clan feature enabled collaboration, while S22 emphasized the forum's role in promoting interaction with peers and teachers. These findings align with Serrano (2019), who noted that digital game features support collaborative learning. Additionally, group learning opportunities (8 mentions) and peer collaboration (4 mentions) were often cited, with students like S2 and S24 appreciating the chance to work together and help each other understand the topic.

However, some negative feedback was also provided. Loneliness (3 mentions) was a concern, with S9 feeling the game lacked cooperative elements, as tasks in the game could be done alone. Limited group learning opportunities (2 mentions) were noted by S20, who felt the game didn't facilitate enough collaboration. S26 also criticized the clan feature for fostering competition over teamwork. On the other hand, neutral feedback (3 mentions) included uncertainties about the game's effectiveness for group learning, with S10 and S5 questioning its collaborative potential.

From the teachers' perspective, feedback was generally positive (2 mentions), with Teacher E highlighting peer collaboration and Teacher F praising the clan feature for fostering teamwork. However, Teacher D provided neutral feedback and expressed uncertainty, suggesting the game's contribution to group learning was unclear.

In summary, feedback suggests that Cell% supports group learning through features like clans and forums but could improve by offering more collaborative opportunities. While many students appreciated these features, some noted the game's solo play options and lack of interaction features. Teachers agreed the game promotes peer collaboration but called for further development to optimize its group learning potential in class.

6.4.6 Overall

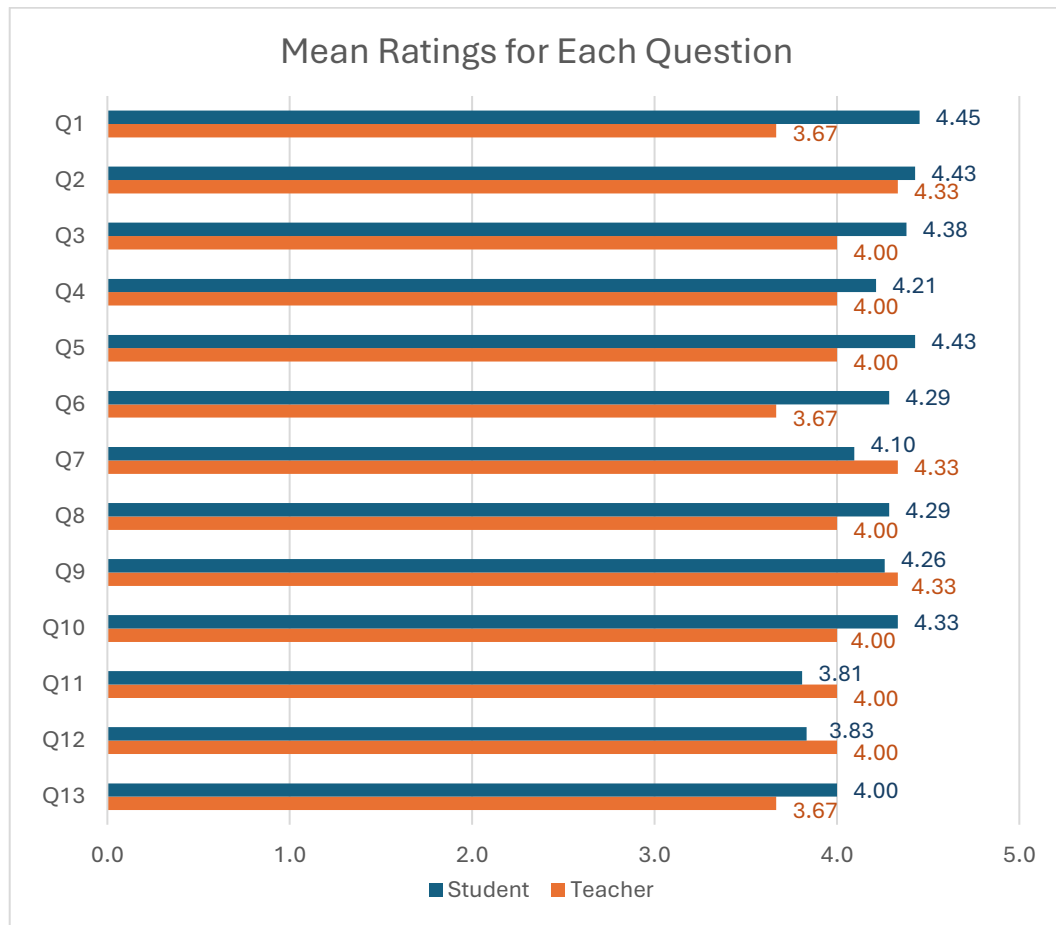


Figure 6.15: Mean Ratings for Each Question

Figure 6.15 illustrates the mean ratings for each question from students and teachers, providing insights into how the Cell% was perceived in addressing learning problems. Overall, both students and teachers view the game positively, with students typically rating it higher than teachers. It's important to note that the teachers' responses came from a small group of only three individuals, meaning their ratings could be heavily influenced by just one person's opinion.

From the cognitive perspective, both groups viewed the game positively, but students rated it higher for aiding memory retention, understanding, and distinguishing complex terms. For example, students rated memory retention (Q1) at 4.45, while teachers rated it at

3.67. Similarly, students rated handling complex terms (Q2) and understanding (Q3) higher than teachers. Both groups agreed that the game helps reduce confusion (Q4) and aids in abstract learning (Q5), with students again rating these aspects slightly higher.

From the motivational perspective, students felt the game had a stronger impact on interest, motivation, and participation than teachers. Students rated the game's ability to increase interest (Q6) at 4.29, while teachers rated it lower at 3.67. The same trend was observed for motivation (Q7) and active participation (Q8), suggesting students feel more engaged by the game.

From the affective perspective, both students and teachers agreed the game improved these aspects, with ratings for enjoyment (Q9) at 4.26 for students and 4.33 for teachers, and a similar trend for positivity toward learning (Q10).

From the social perspective, the ratings were slightly lower compared to other perspectives. Students rated social interaction (Q11) at 3.81, while teachers rated it at 4.00. Both groups gave similar ratings for feeling like they are learning with others (Q12), and group learning opportunities (Q13) received lower scores from students compared to teachers. These findings indicate room for improvement in the game's collaborative features.

Overall, the results show that Cell% effectively addresses identified learning challenges in Cell Division topic, particularly in cognitive and affective perspectives. However, the lower ratings in the social perspective highlight areas where further development could enhance the learning experience. Based on the Brace's (2004) classification criteria, as suggested by Shiratuddin and Zaibon (2011), if the rating exceeds 3.40, it can be classified as "high" or "highly high". With overall ratings ranging from 3.67 to 4.45, Cell% received high effectiveness ratings across all perspectives, demonstrating its

success in addressing the identified learning challenges. In conclusion, Cell% fulfilled the research objective of the study, which was to design and develop an mGBL application that would address the challenges identified in the learning of the Cell Division topic.

6.5 Suggestions on Improving Cell%

An open-ended question was included in the questionnaire to give participants an opportunity to provide comments or suggestions about Cell%, so that the researcher can improve the game in the future.

The data collected from the question were reviewed and divided into student and teacher groups to enable comparison between the two groups for data analysis. The data were coded into sub-categories of suggestion based on keywords from the responses, then further classified into different categories of suggestion, which were derived from recurring themes in the sub-categories. Categories, sub-categories, and their frequencies were then presented. Each sub-category was accompanied by a sample quotation from a participant to provide insights into their suggestion. All data were tabulated and discussed in the report, as presented below.

Table 6.16: The Suggestions From Students and Teachers on Improving Cell%

Group	Category	Sub-category	Samples Excerpts	Frequency
Student	No Changes Needed	Positive comments	“The game is amazing. Nothing to do to improve the game because it's really good” (S1)	9
		No suggestions	“No” (S4)	8
	Total			17
	Bug Fixes	General bug	“The game has some bugs. Hope it can improve” (S16)	4

Table 6.16 continued

	Screen black-out bug	“Bugs like black screen after talking to NPC” (S35)	2
	Wall stuck bug	“Bugs when falling off a moving bridge, get stuck in the wall and can't get out” (S23)	1
	Leaderboard bug	“Problem displaying leaderboard info” (S25)	1
	Level completion bug	“Bugs in levels not showing as completed” (S22)	1
Total			9
Screen Sensitivity Improvement	Increase screen sensitivity	“Increase the sensitivity of the game” (S14)	5
	Add screen sensitivity setting	“Can make setting for screen sensitivity” (S2)	1
Total			6
Multiplayer Request	Add multiplayer functionality	“I think you can make it multiplayer so I can join my friends to play together” (S19)	4
Total			4
Graphics Improvement	General graphics improvement	“I think you can improve the graphics...” (S24)	2
	Lighting enhancement	“I think if the game's lighting is brighter, it will make the game easier to see when playing in low brightness” (S6)	1
	Colour enhancement	“The colour could be brighter and more comfortable” (S40)	1
Total			4
Game Performance Improvement	Increase game responsiveness	“Enhance the responsiveness for smoother gameplay” (S3)	2
	Game crashing issue	“The game performance should improve. It keeps crashing...” (S20)	1
Total			3

Table 6.16 continued

	Locomotion	Increase walking speed	“...walking speed a little faster” (S37)	1
	Control			
	Improvement	Control responsiveness issue	“The control movement is hard for me. Sometimes I can control it, sometimes I cannot” (S10)	1
Total				2
	Gameplay	Add more challenges and quests	“... add more challenges. Include extra quests” (S28)	1
	Design			
	Improvement	Difficult to get on bridge issue	“The bridge is so hard to get on...Please make the bridge bigger” (S5)	1
Total				2
	Character	Increase character options	“I think you could add more characters and allow customization” (S33)	1
	Customization			
Total				1
		No suggestions	- (Teacher E and Teacher F)	2
Teacher	No Changes Needed	Positive comments	“The game is interesting and entertaining. It helps the students to understand the concept of cell division” (Teacher D)	1
	Total			3

Note. The total frequency of suggestions is not equal to the total number of participants because a participant can give multiple suggestions

Table 6.16 shows feedback and suggestions from both students and teachers on ways to improve the Cell% game. A wide variety of ideas were shared, highlighting areas where the game could be refined to enhance the user experience.

From the students’ perspective, many students expressed satisfaction with the game as it is, with 17 mentions of no changes being necessary. From it, nine students provided positive comments, with S1 stating that there was “nothing to do to improve the game

because it's really good". However, while many were pleased with the game, there were still areas where some students felt improvements could be made.

Common feedback from students included bug fixes (9 mentions), such as general bugs (16 mentions), screen blackouts (S35), getting stuck in walls (S3), and leaderboard issues (S22). According to Perttula and colleagues (2017), even minor technical problems, such as interaction or audiovisual issues, can affect the flow and experience of gameplay. Addressing these problems would likely enhance the overall experience for many students. Students also requested better screen sensitivity (6 mentions), with S14 suggesting an increase in sensitivity and S2 recommending adjustable settings for customization. Multiplayer functionality was requested by four students, including S19, who emphasized a desire for more social interaction.

Beyond these technical aspects, students suggested improvements to the game's visual and aesthetic elements. Four students requested graphics improvements, such as general upgrades (S24), better lighting for low-light environments (S6), and more comfortable colours (S40). Game performance was also discussed, with students suggesting better responsiveness (S3) and fixes for game crashes (S20). Movement control was another area for improvement, with requests for faster walking speeds (S37) and more responsive controls (S10). In terms of game content, two students suggested gameplay improvements, including adding extra challenges (S28) and addressing issues with bridges, which were difficult to cross (S5). Finally, character customization was another point of interest, with S33 asking for more options to personalize characters, which could make the game more engaging.

From the teachers' perspective, all expressed overall satisfaction with the game, with no suggestions for improvement. Teacher D praised the game for its usefulness in understanding cell division concepts.

In conclusion, while students appreciated the game, they offered suggestions primarily related to bug fixes, gameplay, and added features. Teachers were generally satisfied, reinforcing the game's value as a learning tool.

6.6 Chapter Summary

In summary, this chapter discussed the evaluation findings of Cell% by students and Biology teachers regarding its playability and effectiveness in addressing learning challenges identified in the preliminary study. The results indicate that Cell% achieves high playability, with a playability score of 4.33. Additionally, Cell% received high ratings for effectiveness in addressing learning challenges across all perspectives, with scores ranging from 3.67 to 4.45, demonstrating its success in meeting these challenges. However, slightly lower ratings in the social dimension highlight areas for potential improvement to enhance the collaborative learning experience. While students expressed satisfaction with the game, they provided valuable feedback for future updates, particularly on bug fixes and feature enhancements. Teachers also responded positively, affirming the game's potential as a valuable learning tool.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This study can be divided into two parts, the preliminary study aimed at identifying the learning challenges faced by secondary school students in learning the Cell Division topic, and the study to evaluate the effectiveness of the mGBL application developed by the researcher in addressing those challenges.

From the preliminary study, various learning challenges were identified from different perspectives, such as cognitive, motivational, affective, social, and others, based on both students' and teachers' views. Cognitive challenges were the most prominent, with students struggling to memorize content, differentiate between similar terms and grasp abstract concepts. Additionally, strategies suggested by students and teachers to improve learning the Cell Division topic included the use of games, visual learning materials, memory aids, and collaborative learning techniques.

Based on the findings from the preliminary study, an mGBL called Cell% was developed by the researcher to address these challenges. To ensure quality and user experience, the playability of Cell% was considered in terms of Game Usability, Game Mobility, Gameplay, and Learning Content during the design and development process of Cell%. As a result, an evaluation of Cell% in terms of playability and its effectiveness in addressing the identified learning challenges was conducted from the views of students and teachers.

The findings showed that Cell% had high playability and effectively addressed all learning challenges identified in the preliminary study, with overall ratings ranging from 3.67 to 4.45, particularly in the cognitive and affective aspects. However, its effectiveness in addressing social challenges was lower compared to other areas. This indicates that there is room for improvement in enhancing Cell% in the social aspect, such as increasing social interaction and group learning opportunities in the game. Additionally, the study collected comments and suggestions from students and teachers, revealing that most of them were satisfied with Cell%, but some suggested technical improvements, particularly in terms of bug fixes, gameplay enhancements, and additional features.

Overall, this study successfully fulfilled both research objectives, which are identifying the learning challenges faced by secondary school students in learning the Cell Division topic from both students' and teachers' views, and developing an mGBL application to address the challenges identified in the learning of the Cell Division topic.

7.2 Significance of Study

This study provides an alternative for secondary school students in Malaysia to learn the Cell Division topic by offering an online mGBL application or mobile game, called as Cell%. The game is available for download on Google Play (<https://play.google.com/store/apps/details?id=com.SweatingOrangeProduction.CellDivisionApp>). Since the features of the game were specifically designed and developed to address the learning challenges in Cell Division topic, and have demonstrated successful effectiveness in this study, the mobile game is suitable for Biology teachers to use as a teaching tool for their teaching in the topic. Furthermore, students can play the game at their

own pace at home for self-learning, due to the advantages of mobile learning, which allows learners to study through mobile phones without time or geographical constraints.

From instructional design perspective, this study provides an example of how to design and develop an mGBL that addresses learning challenges from multiple perspectives. While previous studies on GBL in learning Cell Division topic have focused on students' understanding (Kanyapasit & Srisawasdi, 2014; Shamsudin et al., 2020; Wilson et al., 2018), learning performance (Nasharuddin et al., 2021), and motivation (Shamsudin et al., 2020; Sumandal, 2023), this study uses a design-based research approach, which develops an mGBL application aimed at addressing identified learning challenges in the Cell Division topic, rather than solely focusing on learning outcomes or motivation. Furthermore, the mGBL application was designed from different perspectives, including cognitive, motivational, affective, and social aspects. As noted by Plass and colleagues (2015), the combination of cognitive, motivational, affective, and sociocultural dimensions should be considered in game design to fully unlock the potential of GBL for learning. This study exemplifies the use of multi-perspective and problem-based game design in GBL, which introduces a novel approach in GBL studies related to Cell Division learning.

Furthermore, the study highlights the methodological significance of adapting DBR approach. By following an iterative cycle of problem analysis, design, implementation, and reflection, the study ensured that the development of the Cell% application was grounded in authentic classroom challenges, informed by multiple learning theories, and refined through collaboration with teachers and students. This cyclical and collaborative process not only enhanced the practical relevance of the intervention but also contributes to methodological

knowledge by demonstrating how DBR can effectively guide the design and evaluation of mGBL in Biology education.

In addition, the study contributes to the theoretical foundations underpinning its design. The findings support the application of CLT and CTML, showing that features such as highlighted notes, signalling, and multimodal presentation effectively reduced extraneous load and improved memorization. The positive responses toward challenge–skill balanced gameplay further validate Flow Theory, emphasizing how structured progression and feedback sustain player engagement. Similarly, the inclusion of role-playing and problem-solving elements illustrates how PBL can be embedded in mGBL to promote contextual understanding. Finally, the collaborative features, such as forums and clans, align with Collaborative Learning theory, highlighting the value of peer interaction in reinforcing knowledge. Together, these findings extend theoretical understanding by demonstrating how multiple learning theories can be integrated in a unified game-based learning environment.

7.3 Limitation of Study

The mGBL application developed in this study focuses on the Cell Division topic. Therefore, the learning content is limited to the Cell Division chapter, which is the Chapter 6 of the Form 4 Biology textbook. Additionally, since the mGBL application is an online game, it is only available to the users who have access to the internet or mobile data. As indicated in the findings of the preliminary study, one teacher mentioned that students might face internet coverage issues due to the geographical areas where they live. Thus, this mGBL application may not be suitable for students with internet connectivity problems. However, fortunately, none of the students experienced such issues during the data collection phase of this study. Although none of the students experienced such issues during data collection,

poor connectivity could have influenced engagement and performance if it had occurred. In future, offline or hybrid modes of the game could help mitigate this limitation.

Based on the suggestions of participants collected from the study, it was found that some participants encountered technical problems such as bugs, when playing the game. Although the reported issues were minor bugs, but they could still affect the overall user experience. While these issues were small, they may have affected usability scores and players' overall experience, possibly lowering motivation or focus. Future research should address these by conducting more rigorous testing and updates to ensure smoother gameplay. Therefore, improvements should be made to address these technical limitations. Furthermore, the mGBL application in this study was designed for mobile phones or tablets with the Android operating system, making it incompatible with other portable devices that use different operating systems. This limits accessibility and may have excluded potential participants. Expanding compatibility to multiple operating systems in future versions could broaden participation and increase the generalizability of findings. Lastly, the number of participants in this study, particularly the teachers (only 3 teachers) was limited, which may have impacted the robustness of statistical analysis and reduced the variety of teacher perspectives. Future research should involve a larger and more diverse sample of teachers and students to validate the findings and strengthen their generalizability.

7.4 Recommendation for Future Research

As reported by the participants in this study, there are still some minor technical problems in the mGBL application, and some participants also suggested making gameplay improvements. Therefore, the mGBL application requires further refinement, particularly in fixing technical issues for future studies. Although this study demonstrated successful

effectiveness in addressing the identified learning challenges in the Cell Division topic, the effectiveness from social perspective was lower compared to other aspects. This may be due to the game's social features, such as the forum, clan feature, and leaderboard, not being strong enough. Thus, improvements should be made to foster stronger collaborative learning and provide more opportunities for group interaction within the game. As suggested by students in the study, a real-time multiplayer feature should be considered in the game design to enhance the sense of collaboration among players during gameplay. Additionally, it was noted that some participants mentioned a lack of forum use in the game. To encourage greater participation, more motivators should be implemented, such as awarding game points for each post or comment made by players.

From the study's context, since this research focuses on the development of an mGBL application to address learning challenges specifically in the Cell Division topic, future research could explore the impact of the mGBL application on students' learning performance. This would help to reveal how a problem-based mGBL design affects learning outcomes. Lastly, the scope of this study could be expanded to other topics or even the entire Biology syllabus, rather than just the Cell Division topic, so that the problem-based design in multiple perspectives approach of this study can be investigated on a broader scale.

7.5 Chapter Summary

In conclusion, this study successfully met its objectives by developing an mGBL application that both addresses students' learning challenges and demonstrates its potential as an effective educational resource. This study not only highlights the effectiveness of mGBL in addressing the learning challenges of the Cell Division topic but also paves the way for future innovations in educational game design. By combining cognitive,

motivational, affective and social dimensions in GBL, this study offers valuable insights into creating a more engaging and holistic learning experience. The findings provide a foundation for expanding the application of mGBL to other educational topics and contexts, further contributing to the evolution of digital learning tools that can better meet the diverse needs of students.

REFERENCES

- Abd Elsattar, H. K. H. (2017, May). Designing for Game-based Learning Model: The Effective Integration of Flow Experience and Game Elements to Support Learning. In *2017 14th International Conference on Computer Graphics, Imaging and Visualization* (pp. 34-43). IEEE. <https://doi.org/10.1109/CGiV.2017.31>.
- Acharya, A. (2017, June 4). *Mobile Game Development Process*. Gamasutra. <https://www.gamedeveloper.com/business/mobile-game-development-process>
- Admiraal, W., Huizenga, J., Akkerman, S., & Ten Dam, G. (2011). The concept of flow in collaborative game-based learning. *Computers in human behavior*, 27(3), 1185-1194. <https://doi.org/10.1016/j.chb.2010.12.013>
- Agboghoroma, T. E., & Oyovwi, E. O. (2015). *Evaluating Effect of Students' Academic Achievement on Identified Difficult Concepts in Senior Secondary School Biology in Delta State* (EJ1081378). ERIC. <https://files.eric.ed.gov/fulltext/EJ1081378.pdf>
- Ahmad, S. A. ., Yoke, S. K. ., Yunos, R. M. ., & Amin, J. M. . (2020). Exploring Lecturers' Readiness for 21st Century Education in Malaysian Higher Learning Institutions. *European Journal of Teaching and Education*, 1(1), 15–29. <https://doi.org/10.33422/EJTE.2019.10.27>
- Ahmed, I., & Ishtiaq, S. (2021). Reliability and Validity: Importance in medical research. *Methods*, 12(1), 2401-2406. <https://doi.org/10.47391/jpma.06-861>
- Aldemir, T., Celik, B., & Kaplan, G. (2018). A qualitative investigation of student perceptions of game elements in a gamified course. *Computers in human Behavior*, 78, 235-254. <https://doi.org/10.1016/j.chb.2017.10.001>

- Alkhalifah, T., de Vries, D., & Rampersad, G. (2017). *Mobile Learning Adoption in Developing Countries*. 89-93. Paper presented at 9th International Conference on Education Technology and Computers (ICETC 2017). <https://doi.org/10.1145/3175536.3175583>
- Arslan, K., & Ari, A. G. (2022). The Effect of Teaching Science with Digital Games on Students' Cognitive Structures and Conceptual Changes. *IBAD Sosyal Bilimler Dergisi*, (14), 174-203. <https://doi.org/10.21733/ibad.1189330>
- Arthur, F., & Akwetey, F. A. (2021). Cognitive challenges to effective teaching and learning: Perspectives of senior high school teachers. *International Journal of Innovative Research and Development*, 10(6), 104-110. <http://dx.doi.org/10.13140/RG.2.2.11379.86560>
- Aspin, S. H., Ali, M., & Bunyamin, M. A. H. (2022). STEM education in Malaysia: A review. *Learning Science and Mathematics*, 17(1), 125–139. http://www.recsam.edu.my/sub_LSMJournal/index.php/lsm-journal/journal-2021-2025/issue-17-2022/2-uncategorised/63-2022-1-rza-127
- Azahar, N. S. H. (2024, September 13). *Strengthening STEM foundations in primary education to achieve the 60:40 goal*. Khazanah Research Institute. https://www.krinstitute.org/assets/contentMS/img/template/editor/KRI%20Views_STEM%20-%20Nur%20Sofea%20Hasmira%20Azahar-final.pdf
- Azhar, M. S., Shamsudin, O., Abdul Rasid, J., & Radhiah, R. S. (2020). Penggunaan Frog VLE dalam pengajaran penulisan karangan Bahasa Melayu murid-murid sekolah menengah. *International Journal of Education and Training*, 6(2), 1-8.

http://www.injet.upm.edu.my/images/volume/isunov6_2020/Penggunaan%20Frog%20VLE%20dalam%20Pengajaran%20Penulisan%20Karangan%20Bahasa%20Melayu%20Murid-Murid%20Sekolah%20Menengah.pdf

Baharudin, S. N., Zulkiflei, K., & Yunus, M. M. (2019). Using Multimedia to Promote Students' Learning and Understanding of English Literature in Secondary School. *International Journal of Academic Research in Business and Social Sciences*, 9(2). <https://doi.org/10.6007/ijarbss/v9-i2/5525>

Baluška, F., Menzel, D., & Barlow, P. W. (2006). Cytokinesis in plant and animal cells: endosomes 'shut the door'. *Developmental biology*, 294(1), 1-10. <https://doi.org/10.1016/j.ydbio.2006.02.047>

Basri, S., & Abdullah, M. S. (2020). Level of Understanding and Alternative Frameworks in Genetics Fundamental Concepts among Form Four Biology Students in Sabah, Malaysia. *International Journal of Academic Research in Business and Social Sciences*, 10(9). <http://dx.doi.org/10.6007/IJARBSS/v10-i9/7830>

Bell, D. (2016). The reality of STEM education, design and technology teachers' perceptions: A phenomenographic study. *International journal of technology and design education*, 26, 61-79. <https://doi.org/10.1007/s10798-015-9300-9>

Black, S. E., Muller, C., Spitz-Oener, A., He, Z., Hung, K., & Warren, J. R. (2021). The importance of STEM: High school knowledge, skills and occupations in an era of growing inequality. *Research policy*, 50(7), 104249. <http://dx.doi.org/10.1016/j.respol.2021.104249>

- Bounajim, D., Rachmatullah, A., Boulden, D., Mott, B., Lester, J., Lord, T., Reichsman, F., Horwitz, P., Dorsey, C., & Wiebe, E. (2020). Utilizing Cognitive Load Theory and Evidence-Centered Design to Inform the Design of Game-Based Learning Environments. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 64(1), 826–830. <https://doi.org/10.1177/1071181320641192>
- Bounthavong, M. (2019, May 16). Communicating data effectively with data visualization – Part 15 (Diverging Stacked Bar Chart for Likert scales). *Mark Bounthavong*. <https://mbounthavong.com/blog/tag/Diverging+stacked+bar+chart>
- Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., ... & Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, 94, 178-192. <https://doi.org/10.1016/j.compedu.2015.11.003>
- Brace, I. (2004). *Questionnaire design*. Kogan Page.
- Breech, R. (2022). Recent Trends in Educational Technology: Implications for Teaching and Learning. *International Journal of Open Publication and Exploration*, ISSN: 3006-2853, 10(2), 6-12. <https://ijope.com/index.php/home/article/view/71>
- Cahyana, U., Paristiowati, M., Savitri, D. A., & Hasyrin, S. N. (2017). Developing and Application of Mobile Game Based Learning (M-GBL) for High School Students Performance in Chemistry. *EURASIA Journal of Mathematics, Science and Technology Education*, 13(10). <https://doi.org/10.12973/ejmste/78728>
- Chan, K., Wan, K., & King, V. (2021). Performance Over Enjoyment? Effect of Game-Based Learning on Learning Outcome and Flow Experience. *Frontiers in Education*, 6. <https://doi.org/10.3389/feduc.2021.660376>

- Chang, C. C., Warden, C. A., Liang, C., & Lin, G. Y. (2018). Effects of digital game-based learning on achievement, flow and overall cognitive load. *Australasian Journal of Educational Technology*, 34(4). <https://doi.org/10.14742/ajet.2961>
- Chang, C. C., Warden, C. A., Liang, C., & Lin, G. Y. (2018). Effects of digital game-based learning on achievement, flow and overall cognitive load. *Australasian Journal of Educational Technology*, 34(4). <https://doi.org/10.14742/ajet.2961>
- Chang, C. S., Chen, J. F., & Chen, F. L. (2015). Development and Design of Problem Based Learning Game-Based Courseware (ED562503). ERIC. <https://files.eric.ed.gov/fulltext/ED562503.pdf>
- Chang, C. S., Chung, C. H., & Chang, J. A. (2020). Influence of problem-based learning games on effective computer programming learning in higher education. *Educational Technology Research and Development*, 68(5), 2615–2634. <https://doi.org/10.1007/s11423-020-09784-3>
- Chang, W. C., Wang, T. H., Lin, F. H., & Yang, H. C. (2009). Game-Based Learning with Ubiquitous Technologies. *IEEE Internet Computing*, 13(4), 26–33. <https://doi.org/10.1109/mic.2009.81>
- Chatfield, T. (2010). *Fun Inc.: Why games are the 21st Century's most serious business*. Random House. https://books.google.com.my/books?hl=en&lr=&id=36Xb_27e9pEC&oi=fnd&pg=PR9&ots=ErjPClooMu&sig=YCXBtOPTn3RJSM637gQv8T9AJnc&redir_esc=y#v=onepage&q&f=false
- Chattopadhyay, A. (2012). Understanding of mitosis and meiosis in higher secondary students of Northeast India and the implications for genetics education. *Education*, 2(3), 41-47. <http://dx.doi.org/10.5923/j.edu.20120203.04>

- Chen, C. H., Liu, G. Z., & Hwang, G. J. (2015a). Interaction between gaming and multistage guiding strategies on students' field trip mobile learning performance and motivation. *British Journal of Educational Technology*, 47(6), 1032–1050. <https://doi.org/10.1111/bjet.12270>
- Chen, C. H., Wang, K. C., & Lin, Y. H. (2015b). The comparison of solitary and collaborative modes of game-based learning on students' science learning and motivation. *Journal of Educational Technology & Society*, 18(2), 237-248. <http://www.jstor.org/stable/jeductechsoci.18.2.237>
- Chew, S. L., & Cerbin, W. J. (2021). The cognitive challenges of effective teaching. *The Journal of Economic Education*, 52(1), 17-40. <https://doi.org/10.1080/00220485.2020.1845266>
- Christopoulos, A., Mystakidis, S., Cachafeiro, E., & Laakso, M. J. (2022). Escaping the cell: virtual reality escape rooms in biology education. *Behaviour & Information Technology*, 42(9), 1434–1451. <https://doi.org/10.1080/0144929X.2022.2079560>
- Chun, T. C., & Abdullah, M. N. L. Y. (2022). Contemporary Practices in Teaching 21st Century Skills at Malaysian Primary Schools: Do Environmental Factors and Teacher's Attitudes Matter. *Asia Pacific Journal of Educators and Education*, 37(1), 61-85. <http://dx.doi.org/10.21315/apjee2022.37.1.4>
- Cimer, A. (2012). What makes biology learning difficult and effective: Students' views. *Educational Research and Reviews*, 7(3), 61-71. <https://doi.org/10.5897/ERR11.205>

- Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & education*, 59(2), 661-686. <https://doi.org/10.1016/j.compedu.2012.03.004>
- Corredor, J. A. (2011). Bio-gaming: videogames as tool to teach cell biology. In *Proceedings of the 7th international conference on Games+ Learning+ Society Conference* (pp. 65-71). <https://dl.acm.org/doi/abs/10.5555/2206376.2206384>
- Csikszentmihalyi, M. (1990). Flow: the psychology of optimal experience. *Choice Reviews Online*, 28(01), 28–0597. <https://doi.org/10.5860/choice.28-0597>
- Csikszentmihalyi, M. (2000). *Beyond boredom and anxiety*. Jossey-bass.
- Davis, J. S. (2020). Game Framework Analysis and Cognitive Learning Theory Providing a Theoretical Foundation for Efficacy in Learning in Educational Gaming. *International Journal of Learning, Teaching and Educational Research*, 19(7), 159–175. <https://doi.org/10.26803/ijlter.19.7.9>
- de Araujo Guerra Grangeia, T., de Jorge, B., Franci, D., Martins Santos, T., Vellutini Setubal, M. S., Schweller, M., & de Carvalho-Filho, M. A. (2016). Cognitive Load and Self-Determination Theories Applied to E-Learning: Impact on Students' Participation and Academic Performance. *PLOS ONE*, 11(3), e0152462. <https://doi.org/10.1371/journal.pone.0152462>
- de Jong, T. (2010). Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science*, 38(2), 105–134. <https://doi.org/10.1007/s11251-009-9110-0>
- Department of Statistics Malaysia (DOSM). (2024, April 22). *ICT Use and Access by Individuals and Households Survey Report, 2023*. <https://www.dosm.gov.my/portal->

main/release-content/ict-use-and-access-by-individuals-and-households-survey-report-2023

- Dikmenli, M. (2010). Misconceptions of cell division held by student teachers in biology: A drawing analysis. *Scientific Research and Essay*, 5(2), 235-247. <https://hdl.handle.net/20.500.12395/25072>
- Doğru, M. S., & Özsevgeç, L. C. (2018). Biology subjects which the teacher candidates have difficulties in learning and leading reasons. *European Journal of Education Studies*. <http://dx.doi.org/10.46827/ejes.v0i0.2059>
- Dolcos, F., LaBar, K. S., & Cabeza, R. (2004). Interaction between the Amygdala and the Medial Temporal Lobe Memory System Predicts Better Memory for Emotional Events. *Neuron*, 42(5), 855–863. [https://doi.org/10.1016/s0896-6273\(04\)00289-2](https://doi.org/10.1016/s0896-6273(04)00289-2)
- Dolmans, D. H. J. M., Loyens, S. M. M., Marcq, H., & Gijbels, D. (2016). Deep and surface learning in problem-based learning: a review of the literature. *Advances in Health Sciences Education*, 21(5), 1087–1112. <https://doi.org/10.1007/s10459-015-9645-6>
- Duchowski, A. T. (2017). *Eye Tracking Methodology: Theory and Practice* (3rd ed. 2017 ed.). Springer. <https://link.springer.com/content/pdf/10.1007/978-3-319-57883-5.pdf>
- Dulskiy, I. (2015, October 20). *9 Stages In Mobile Game Development*. Art driver. <https://artdriver.com/blog/9-stages-in-mobile-game-development>
- Eccles, J. S., Wigfield, A., & Schiefele, U. (1998). Motivation to succeed. In W. Damon & N. Eisenberg (Ed.), *Handbook of child psychology: Social, emotional, and personality development* (pp. 1017–1095). John Wiley & Sons, Inc.. <https://psycnet.apa.org/record/2005-03132-015>

- Elangovan, T., & Ismail, Z. (2013). The effects of realistic simulation and non-realistic simulation on biology students' achievement. *Education*, 3(4), 231-241. <http://article.sapub.org/10.5923.j.edu.20130304.03.html>
- Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Computers & Education*, 67, 156–167. <https://doi.org/10.1016/j.compedu.2013.02.019>
- Eseryel, D., Law, V., Ifenthaler, D., Ge, X., & Miller, R. (2014). An investigation of the interrelationships between motivation, engagement, and complex problem solving in game-based learning. *Journal of Educational Technology & Society*, 17(1), 42-53. <https://www.jstor.org/stable/jeductechsoci.17.1.42>
- Es-Sajjade, A., & Paas, F. (2020). Educational theories and computer game design: lessons from an experiment in elementary mathematics education. *Educational Technology Research and Development*, 68(5), 2685–2703. <https://doi.org/10.1007/s11423-020-09799-w>
- Etobro, A. B., & Fabinu, O. E. (2017). Students' perceptions of difficult concepts in biology in senior secondary schools in Lagos state. *Global Journal of Educational Research*, 16(2), 139. <https://doi.org/10.4314/gjedr.v16i2.8>
- Fauzi, A., & Mitalistiani, M. (2018). High school biology topics that perceived difficult by undergraduate students. *Didaktika Biologi: Jurnal Penelitian Pendidikan Biologi*, 2(2), 73-84. <https://doi.org/10.32502/dikbio.v2i2.1242>
- Ferry, I., Kuzan-Fischer, C. M., Ernoult, E., & Rutka, J. T. (2018). Targeting Cell Cycle Proteins in Brain Cancer. In *Handbook of Brain Tumor Chemotherapy, Molecular Therapeutics, and Immunotherapy* (pp. 271-290). Academic Press. <https://doi.org/10.1016/B978-0-12-812100-9.00019-X>

- Finneran, C. M., & Zhang, P. (2003). A person–artefact–task (PAT) model of flow antecedents in computer-mediated environments. *International Journal of Human-Computer Studies*, 59(4), 475-496. [https://doi.org/10.1016/S1071-5819\(03\)00112-5](https://doi.org/10.1016/S1071-5819(03)00112-5)
- Fletcher, J. D., & Tobias, S. (2006, February). Using computer games and simulations for instruction: A research review. In *Proceedings of the Society for Advanced Learning Technology Meeting* (Vol. 108). https://www.researchgate.net/profile/J-D-Fletcher/publication/228511464_Using_computer_games_and_simulations_for_instruction_A_research_review/links/02e7e5232290531f49000000/Using-computer-games-and-simulations-for-instruction-A-research-review.pdf
- Foss, B., Løkken, A., Leland, A., Stordalen, J., Mordt, P., & Oftedal, B. F. (2014). Digital game-based learning: A supplement for medication calculation drills in nurse education. *E-learning and Digital Media*, 11(4), 342-349. <https://doi.org/10.2304/elea.2014.11.4.342>
- Frederick-Jonah, T. M., & Tobi, T. (2022). Areas and causes of students' difficulties in learning the concept of cell in secondary school biology curriculum. *International Journal of Advanced Academic Research*, 8(3), 16-27. <https://www.ijaar.org/articles/v8n3/ahe/ijaar-v8n3-Mar22-p8322.pdf>
- Gan, W. Y., Abd. Aziz, N. A. B., Mohd. Yusof, Y. B., & Ibrahim, N. H. B. (2019). *Biology Form 4 textbook KSSM (Dual language programme)*. Mustread Sdn Bhd. https://fliphtml5.com/ffzny/oipi/TEXTBOOK_KSSM_Biology_Form_4_%28DLP%29/
- Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment*, 1(1), 20. <https://doi.org/10.1145/950566.950595>

- Giannakas, F., Kambourakis, G., Papasalouros, A., & Gritzalis, S. (2017). A critical review of 13 years of mobile game-based learning. *Educational Technology Research and Development*, 66(2), 341–384. <https://doi.org/10.1007/s11423-017-9552-z>
- Hadiprayitno, G., Muhlis, & Kusmiyati. (2019). Problems in learning biology for senior high schools in Lombok Island. *Journal of Physics: Conference Series*, 1241, 012054. <https://doi.org/10.1088/1742-6596/1241/1/012054>
- Halim, L., & Meerah, T. S. M. (2016). Science education research and practice in Malaysia. In *Science education research and practice in Asia* (pp. 71-93). Springer, Singapore. https://doi.org/10.1007/978-981-10-0847-4_5
- Hawlitsek, A., & Joeckel, S. (2017). Increasing the effectiveness of digital educational games: The effects of a learning instruction on students' learning, motivation and cognitive load. *Computers in Human Behavior*, 72, 79–86. <https://doi.org/10.1016/j.chb.2017.01.040>
- Helppi, V. (2015, January 14). *The Agile Process for Mobile Game Development and Testing*. Bitbar. <https://bitbar.com/blog/the-agile-process-for-mobile-game-development-and-testing/>
- Heng, L. C., & Said, M. N. H. M. (2020). Effects of digital game-based learning apps based on Mayer's cognitive theory of multimedia learning in mathematics for primary school students. *Innovative Teaching and Learning Journal (ITLJ)*, 4(1), 65-78. <http://161.139.21.34/itlj/index.php/itlj/article/view/54>
- Hoffman, B., & Nadelson, L. (2009). Motivational engagement and video gaming: a mixed methods study. *Educational Technology Research and Development*, 58(3), 245–270. <https://doi.org/10.1007/s11423-009-9134-9>

- Hu, H., & Sperling, R. A. (2022). Pre-service teachers' perceptions of adopting digital games in education: A mixed methods investigation. *Teaching and Teacher Education*, 120, 103876. <https://doi.org/10.1016/j.tate.2022.103876>
- Huang, W. D., & Johnson, T. (2009). Instructional game design using cognitive load theory. In *Handbook of research on effective electronic gaming in education* (pp. 1143-1165). IGI Global.
- Huang, Y. L., Chang, D. F., & Wu, B. (2017). Mobile game-based learning with a Mobile app: Motivational effects and learning performance. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, 21(6), 963-970. <https://doi.org/10.20965/jaciii.2017.p0963>
- Huizenga, J., Admiraal, W., Akkerman, S., & Dam, G. T. (2009). Mobile game-based learning in secondary education: engagement, motivation and learning in a mobile city game. *Journal of Computer Assisted Learning*, 25(4), 332-344. <https://doi.org/10.1111/j.1365-2729.2009.00316.x>
- Hung, W. (2013). Problem-Based Learning: A Learning Environment for Enhancing Learning Transfer. *New Directions for Adult and Continuing Education*, 2013(137), 27-38. <https://doi.org/10.1002/ace.20042>
- Idris, R., Govindasamy, P., & Nachiappan, S. (2023). Challenge and obstacles of STEM education in Malaysia. *International Journal of Academic Research in Business and Social Sciences*, 13(4), 820-828. <http://dx.doi.org/10.6007/IJARBSS/v13-i4/16676>
- Imboy, D. H. E., Salic-Hairulla, M. A., Bagaloyos, J. B., Bazzar, S. C., & Malayao, S. O. (2025). Development of Digital Interactive Comics for Grade 8 Learners in Cell

- Division. *International Journal of Research and Innovation in Social Science*, 9(1), 1063-1074. <https://dx.doi.org/10.47772/IJRISS.2025.9010088>
- Indah, R. N., & Rohmah, G. N. (2020). The communicativeness and critical thinking devices of language supplementary materials for primary school. *RETORIKA: Jurnal Ilmu Bahasa*, 6(2), 165–172. <https://doi.org/10.22225/jr.6.2.2300.165-172>
- Ismail, M. E., Sa'adan, N., Samsudin, M. A., Hamzah, N., Razali, N., & Mahazir, I. I. (2018). Implementation of The Gamification Concept Using KAHOOT! Among TVET Students: An Observation. *Journal of Physics: Conference Series*, 1140, 012013. <https://doi.org/10.1088/1742-6596/1140/1/012013>
- Ismail, M. H. B., Salleh, M. F. M., & Nasir, N. A. M. (2019). The Issues and Challenges in Empowering STEM on Science Teachers in Malaysian Secondary Schools. *International Journal of Academic Research in Business and Social Sciences*, 9(13). <https://doi.org/10.6007/ijarbss/v9-i13/6869>
- Jääskä, E., & Aaltonen, K. (2022). Teachers' experiences of using game-based learning methods in project management higher education. *Project Leadership and Society*, 3, 100041. <https://doi.org/10.1016/j.plas.2022.100041>
- Jeu, N. P., Ali, M. F., & Yapp, A. (2015). Application of Cognitive Theory in Multimedia Technology-Based Learning: Concentration on Malaysian Cultural and Heritage. In *Proceedings of the International Symposium on Research of Arts, Design and Humanities (ISRADH 2014)* (pp. 405-412). Springer, Singapore. https://doi.org/10.1007/978-981-287-530-3_41

- Jin, J., & Bridges, S. M. (2014). Educational Technologies in Problem-Based Learning in Health Sciences Education: A Systematic Review. *Journal of Medical Internet Research*, 16(12), e251. <https://doi.org/10.2196/jmir.3240>
- Juhari, A. N., Hani, M., & Bakar, A. (2020). Popular Game Elements Used in Designing Game-Based Learning STEM Application for School Students-A Review. *Jurnal kejuruteraan*, 32(4), 559-568. [https://doi.org/10.17576/jkukm-2020-32\(4\)-01](https://doi.org/10.17576/jkukm-2020-32(4)-01)
- Kalimuthu, I. (2017). Improving understanding and reducing secondary school students' misconceptions about cell division using animation-based instruction. *Overcoming Students' Misconceptions in Science: Strategies and Perspectives from Malaysia*, 283-306. https://doi.org/10.1007/978-981-10-3437-4_15
- Kanyapasit, P., & Srisawasdi, N. (2014). Development of digital game-based biology learning experience on cell cycle through DSLM instructional approach. In *Proceedings of the 22nd International Conference on Computers in Education* (pp. 857-866). https://www.researchgate.net/profile/Niwat-Srisawasdi/publication/280318719_Development_of_Digital_Game-based_Biology_Learning_Experience_on_Cell_Cycle_through_DSLM_Instructional_Approach/links/55b26f9608aec0e5f431b1ce/Development-of-Digital-Game-based-Biology-Learning-Experience-on-Cell-Cycle-through-DSLM-Instructional-Approach.pdf
- Kapp, K. M. (2012). *The gamification of learning and instruction: Game-based methods and strategies for training and education*. Pfeiffer. <https://books.google.com.my/books?hl=en&lr=&id=GLr81qqtELcC&oi=fnd&pg=PR13&dq=Kapp,+Karl.+The+gamification+of+learning+and+instruction:+Game-based+methods+and+strategie>

s+for+training+and+education.+San+Francisco:+Pfeiffer,+2012.+ISBN+97811180
96345.&ots=C-OAc3yier&sig=5rqLy_pihmQYVNStaZGPYvLxZLA&redir_esc=
y#v=onepage&q&f=false

Kelly, J. (2012, September). The Learning Pyramid. The Peak Performance Center.
<https://thepeakperformancecenter.com/educational-learning/learning/principles-of-learning/learning-pyramid/>

Ketamo, H., & Kiili, K. (2010). Conceptual change takes time: Game based learning cannot be only supplementary amusement. *Journal of Educational Multimedia and Hypermedia*, 19(4), 399-419. <https://www.learntechlib.org/primary/p/33167/>

Khazanah Research Institute. (2024). *Shifting tides: Charting career progression of Malaysia's skilled talents*. Khazanah Research Institute.
[https://www.krinstitute.org/assets/contentMS/img/template/editor/KRI%20Report%20-%20Shifting%20Tides%20\(1\).pdf](https://www.krinstitute.org/assets/contentMS/img/template/editor/KRI%20Report%20-%20Shifting%20Tides%20(1).pdf)

Khoo, A., Gentile, K. A., & Tan, O. (2005). Problem-based learning in the world of digital games. *Problem-based learning in eLearning Breakthroughs*, 97-129.

Kiili, K. (2005). *On educational game design: Building blocks of flow experience*. Tampere University of Technology. <https://trepo.tuni.fi/bitstream/handle/10024/114249/kiili.pdf?sequence=1&isAllowed=y>

Kiili, K., de Freitas, S., Arnab, S., & Lainema, T. (2012). The Design Principles for Flow Experience in Educational Games. *Procedia Computer Science*, 15, 78–91.
<https://doi.org/10.1016/j.procs.2012.10.060>

- Kiili, K., Lainema, T., de Freitas, S., & Arnab, S. (2014). Flow framework for analyzing the quality of educational games. *Entertainment Computing*, 5(4), 367–377. <https://doi.org/10.1016/j.entcom.2014.08.002>
- Kılıç, D., Taber, K. S., & Winterbottom, M. (2016). A cross-national study of students' understanding of genetics concepts: Implications from similarities and differences in England and Turkey. *Education Research International*, 2016. <https://doi.org/10.1155/2016/6539626>
- Kong, L. N., Qin, B., Zhou, Y. Q., Mou, S. Y., & Gao, H. M. (2014). The effectiveness of problem-based learning on development of nursing students' critical thinking: A systematic review and meta-analysis. *International Journal of Nursing Studies*, 51(3), 458–469. <https://doi.org/10.1016/j.ijnurstu.2013.06.009>
- Kongvitayanont, V., Pipitrat, P., Sathong, K., & Tangsripairoj, S. (2017, May). Bloody buddy: A biology game-based learning application. In *2017 6th ICT International Student Project Conference (ICT-ISPC)* (pp. 1-4). IEEE. <https://doi.org/10.1109/ICT-ISPC.2017.8075297>.
- Korhonen, H. (2016). Evaluating playability of mobile games with the expert review method. *University of Tampere*. <https://trepo.tuni.fi/bitstream/handle/10024/99584/978-952-03-0205-4.pdf>
- Korhonen, H., & Koivisto, E. M. (2006, September). Playability heuristics for mobile games. In *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services* (pp. 9-16). <http://dx.doi.org/10.1145/1152215.1152218>
- Kubai, E. (2019). Reliability and validity of research instruments. In *Conference: NMK conference. Project: Critical Analysis of policies on Special Education in Kenya*.

kubaiedwin@yahoo.com. https://www.researchgate.net/publication/335827941_Reliability_and_Validity_of_Research_Instruments_Correspondence_to_kubaiedwinyahoocom

- Kuk, K., Jovanovic, D., Jokanovic, D., Spalevic, P., Caric, M., & Panic, S. (2012). Using a game-based learning model as a new teaching strategy for computer engineering. *Turkish Journal of Electrical Engineering & Computer Sciences*, 20(2), 1312-1331. <https://dergipark.org.tr/en/pub/tbtkelektrik/issue/12058/144171>
- Lai, C. H., Chu, C. M., Liu, H. H., Yang, S. B., & Chen, W. H. (2013). An Examination of Game-Based Learning from Theories of Flow Experience and Cognitive Load. *International Journal of Distance Education Technologies*, 11(4), 17-29. <https://doi.org/10.4018/ijdet.2013100102>
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.
- Lavi, R., Tal, M., & Dori, Y. J. (2021). Perceptions of STEM alumni and students on developing 21st century skills through methods of teaching and learning. *Studies in Educational Evaluation*, 70, 101002. <https://doi.org/10.1016/j.stueduc.2021.101002>.
- Lee, J. (2022). Problem-based gaming via an augmented reality mobile game and a printed game in foreign language education. *Education and Information Technologies*, 27(1), 743-771. <https://doi.org/10.1007/s10639-020-10391-1>
- Lenhard, W., & Lenhard, A. (2013). Learning difficulties. *Learning Disabilities*, 25, 33-45. https://www.researchgate.net/publication/260695699_Learning_Difficulties

- Li, M. C., & Tsai, C. C. (2013). Game-Based Learning in Science Education: A Review of Relevant Research. *Journal of Science Education and Technology*, 22(6), 877–898. <https://doi.org/10.1007/s10956-013-9436-x>
- Lin, W. C., Ho, J. Y., Lai, C. H., & Jong, B. S. (2014, April). Mobile game-based learning to inspire students learning motivation. In *2014 International Conference on Information Science, Electronics and Electrical Engineering* (Vol. 2, pp. 810-813). IEEE. <https://doi.org/10.1109/InfoSEEE.2014.6947779>.
- Lindgren, B. (2018). WHAT MAKES A GAME'EDUCATIONAL'? An interview study about teachers' perceptions of educational games and game based learning. <http://hdl.handle.net/2077/58011>
- Lipponen, L. (2002). Exploring foundations for computer-supported collaborative learning. *Proceedings of the Conference on Computer Support for Collaborative Learning Foundations for a CSCL Community - CSCL '02*. <https://doi.org/10.3115/1658616.1658627>
- Liu, Y. C., Wang, W. T., & Huang, W. H. (2023). The effects of game quality and cognitive loads on students' learning performance in mobile game-based learning contexts: The case of system analysis education. *Education and Information Technologies*, 28(12), 16285-16310. <https://doi.org/10.1007/s10639-023-11856-9>
- Lo, S. M., Gardner, G. E., Reid, J., Napoleon-Fanis, V., Carroll, P., Smith, E., & Sato, B. K. (2019). Prevailing questions and methodologies in biology education research: A longitudinal analysis of research in CBE—Life Sciences Education and at the Society

- for the Advancement of Biology Education Research. *CBE—Life Sciences Education*, 18(1), ar9. <https://doi.org/10.1187/cbe.18-08-0164>
- Loyens, S. M., Jones, S. H., Mikkers, J., & van Gog, T. (2015). Problem-based learning as a facilitator of conceptual change. *Learning and Instruction*, 38, 34–42. <https://doi.org/10.1016/j.learninstruc.2015.03.002>
- Mandryk, R. L., Inkpen, K. M., & Calvert, T. W. (2006). Using psychophysiological techniques to measure user experience with entertainment technologies. *Behaviour & Information Technology*, 25(2), 141–158. <https://doi.org/10.1080/01449290500331156>
- Martin, E., & Hine, R. (Eds.). (2015). *A dictionary of biology*. Oxford university press, USA. <https://www.oxfordreference.com/display/10.1093/acref/9780198714378.001.0001/acref-9780198714378>
- Matawali, A., Bakri, S. N. S., Jumat, N. R., Ismail, I. H., Arshad, S. E., & Din, W. A. (2019). The preliminary study on inverted problem-based learning in biology among science foundation students. *International Journal of Evaluation and Research in Education (IJERE)*, 8(4), 713. <https://doi.org/10.11591/ijere.v8i4.20294>
- Mayer, R. E. (1999). *The promise of educational psychology: Learning in the content areas* (Vol. 1). Pearson Educación.
- Mayer, R. E. (2002a). Cognitive Theory and the Design of Multimedia Instruction: An Example of the Two-Way Street Between Cognition and Instruction. *New Directions for Teaching and Learning*, 2002(89), 55–71. <https://doi.org/10.1002/tl.47>
- Mayer, R. E. (2002b). Multimedia learning. In *Psychology of learning and motivation* (Vol. 41, pp. 85-139). Academic Press. [https://doi.org/10.1016/S0079-7421\(02\)80005-6](https://doi.org/10.1016/S0079-7421(02)80005-6)

- Mayer, R. E. (2010). Applying the science of learning to medical education. *Medical Education*, 44(6), 543–549. <https://doi.org/10.1111/j.1365-2923.2010.03624.x>
- Mayer, R. E. (2014). *Computer games for learning. An evidence-based approach*. MIT Press.
- Mayer, R. E., & Moreno, R. (2003). Nine Ways to Reduce Cognitive Load in Multimedia Learning. *Educational Psychologist*, 38(1), 43–52. https://doi.org/10.1207/s15326985ep3801_6
- Merritt, J., Lee, M. Y., Rillero, P., & Kinach, B. M. (2017). Problem-based learning in K–8 mathematics and science education: A literature review. *Interdisciplinary Journal of Problem-Based Learning*, 11(2). <https://doi.org/10.7771/1541-5015.1674>
- Mohamad, A., Sulaiman, T., & Mohd, A. F. (2023). Factors Influencing 21st Century Teaching among Secondary School Teachers in Selangor, Malaysia. *International Journal of Academic Research in Business and Social Sciences*, 13(12). <http://dx.doi.org/10.6007/IJARBSS/v13-i12/19805>
- Mohamad, N. H., & Mustapha, R. (2022). Relationship between 21st century learning understanding toward teaching practice among Teachers Trainee in Eastern Zone: The IPGM trainee perspectives. *Journal of Contemporary Social Science and Education Studies (JOCSESSES)* E-ISSN-2785-8774, 2(1), 52-59. <https://doi.org/10.5281/zenodo.10277159>
- Mohamad, S. N. M., Salam, S., & Bakar, N. (2017, April). An analysis of gamification elements in online learning to enhance learning engagement. In *International Conference of Computing and Informatics* (pp. 452-460). <https://repo.uum.edu.my/id/eprint/22890/>

- Murtonen, M., Nokkala, C., & Södervik, I. (2020). Challenges in understanding meiosis: fostering metaconceptual awareness among university biology students. *Journal of Biological Education*, 54(1), 3-16. <https://doi.org/10.1080/00219266.2018.1538016>
- Mussard, J., & Reiss, M. J. (2022). Why is genetics so hard to learn? Insights from examiner reports for 16-to 18-year-olds in England. *School Science Review*, 103(384), 32-40. <https://www.ase.org.uk/resources/school-science-review/issue-384/why-genetics-so-hard-learn-insights-examiner-reports-16-18>
- Nakamura, J., & Csikszentmihalyi, M. (2014). The concept of flow. In *Flow and the foundations of positive psychology* (pp. 239-263). Springer, Dordrecht. https://doi.org/10.1007/978-94-017-9088-8_16
- Nasharuddin, N. A., Khalid, N. A., & Hussin, M. (2021). InCell VR: A Virtual Reality-based Application on Human Cell Division for Mobile Learning. *International Journal of Interactive Mobile Technologies (iJIM)*, 15(02), pp. 55–71. <https://doi.org/10.3991/ijim.v15i02.18049>
- Ni, L. B., Chai, W. L., & Abdullah, S. (2021). Smart Learning Improves Student Participation. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, 6(4), 227-241. <https://doi.org/10.47405/mjssh.v6i4.738>
- Nørgård, R. T., Toft-Nielsen, C., & Whitton, N. (2017). Playful learning in higher education: developing a signature pedagogy. *International Journal of Play*, 6(3), 272-282. <https://doi.org/10.1080/21594937.2017.1382997>
- Nursetyo, K. I., Ariani, D., Wibawa, B., & Siregar, E. (2024, November). Game Based Learning-Enabled 21st Century Skills: A Bibliometric Analysis. In *7th International*

- Conference on Learning Innovation and Quality Education (ICLIQE 2023)* (pp. 69-77). Atlantis Press. https://doi.org/10.2991/978-2-38476-301-6_8
- Özbudak, Z., & Özkan, M. (2014). An analysis of teacher's views on the unit regarding cell division and heredity. *Procedia-Social and Behavioral Sciences*, 152, 714-719. <https://doi.org/10.1016/j.sbspro.2014.09.309>
- Ozcan, T., Ozgur, S., Kat, A., & Elgun, S. (2014). Identifying and Comparing the Degree of Difficulties Biology Subjects by Adjusting it is Reasons in Elementary and Secondary Education. *Procedia - Social and Behavioral Sciences*, 116, 113–122. <https://doi.org/10.1016/j.sbspro.2014.01.177>
- Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive Load Theory: Instructional Implications of the Interaction between Information Structures and Cognitive Architecture. *Instructional Science*, 32(1/2), 1–8. <https://doi.org/10.1023/b:truc.0000021806.17516.d0>
- Paavilainen, J. (2020). Defining playability of games: Functionality, usability, and gameplay. In *23rd International Academic Mindtrek Conference, AcademicMindtrek 2020* (pp. 55-64). ACM. <https://doi.org/10.1145/3377290.3377309>
- Panzoli, D., Cussat-Blanc, S., Pascalie, J., Disset, J., O'Rourke, M., Bricchese, L., ... & Duthent, Y. (2017, September). Learning the cell cycle with a game: Virtual experiments in cell biology. In *2017 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)* (pp. 47-54). IEEE. <https://doi.org/10.1109/VS-GAMES.2017.8055810>
- Perkins, D., & Salomon, G. (1989). Are Cognitive Skills Context-Bound? *Educational Researcher*, 18(1), 16–25. <https://doi.org/10.3102/0013189x018001016>

- Perttula, A., Kiili, K., Lindstedt, A., & Tuomi, P. (2017). Flow experience in game based learning – a systematic literature review. *International Journal of Serious Games*, 4(1). <https://doi.org/10.17083/ijsg.v4i1.151>
- Petko, D., Schmid, R., & Cantieni, A. (2020). Pacing in Serious Games: Exploring the Effects of Presentation Speed on Cognitive Load, Engagement and Learning Gains. *Simulation & Gaming*, 51(2), 258–279. <https://doi.org/10.1177/1046878120902502>
- Piaget, J. (1962). *Play, Dreams and Imitation in Childhood*. W. W. Norton & Company.
- Plass, J. L., Heidig, S., Hayward, E. O., Homer, B. D., & Um, E. (2014). Emotional design in multimedia learning: Effects of shape and color on affect and learning. *Learning and Instruction*, 29, 128–140. <https://doi.org/10.1016/j.learninstruc.2013.02.006>
- Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of Game-Based Learning. *Educational Psychologist*, 50(4), 258–283. <https://doi.org/10.1080/00461520.2015.1122533>
- Plass, J. L., O'Keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., & Perlin, K. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of educational psychology*, 105(4), 1050. <http://dx.doi.org/10.1037/a0032688>
- Qian, M., & Clark, K. R. (2016). Game-based Learning and 21st century skills: A review of recent research. *Computers in Human Behavior*, 63, 50–58. <https://doi.org/10.1016/j.chb.2016.05.023>
- Quílez-Robres, A., Moyano, N., & Cortés-Pascual, A. (2021). Motivational, emotional, and social factors explain academic achievement in children aged 6–12 years: A meta-analysis. *Education Sciences*, 11(9), 513. <https://doi.org/10.3390/educsci11090513>

- Rabbany, R., Elatia, S., Takaffoli, M., & Zaïane, O. R. (2014). Collaborative learning of students in online discussion forums: A social network analysis perspective. In *Educational data mining* (pp. 441-466). Springer, Cham. https://doi.org/10.1007/978-3-319-02738-8_16
- Rafat, F., & Ali, M. (2023). A Study on Misconceptions in Cell Division and Reproduction among Secondary School Students in Relation to Their Preferred Teaching Styles. *International Journal of Applied Social Science*, 10(5-6), 335-340. http://scientificresearchjournal.com/wp-content/uploads/2023/07/Social-Science-10_A-335-340.pdf
- Rahmat, A. M., Mohd, I. H., Omar, M. K., Kamalludeen, R., Zahari, W. M. Z. W., Azmy, N., & Adnan, A. H. M. (2022). Integrating Socio-Digital Skills in the Industry 4.0 era for graduates' employability: An employers' perspective. *Journal of Positive School Psychology*, 6(3), 8493-8507. <https://www.journalppw.com/index.php/jpsp/article/view/5115>
- Ramírez-Donoso, L., Rojas-Riethmuller, J. S., Pérez-Sanagustín, M., & Neyem, A. (2017, April). Enhancing collaborative learning in higher education online courses through a mobile game app. In *2017 IEEE 21st International Conference on Computer Supported Cooperative Work in Design (CSCWD)* (pp. 103-108). IEEE. <https://doi.org/10.1109/CSCWD.2017.8066678>
- Reeves, T. (2006). Design research from a technology perspective. In *Educational design research* (pp. 64-78). Routledge. <https://www.taylorfrancis.com/chapters/>

edit/10.4324/9780203088364-13/design-research-technology-perspective-thomas-reeves

- Rozaidi, S., & Ismail, I. (2018). Enjoyment of learning biology through mobile game based learning for form 5 students: Kidney Rush. In *Information, Communication and Multimedia Technology Colloq.(ICMMTC)* (pp. 163-170).
https://www.researchgate.net/profile/Ismassabah-Ismail/publication/335755919_ENJOYMENT_OF_LEARNING_BIOLOGY_THROUGH_MOBILE_GAME_BASED_LEARNING_FOR_FORM_5_STUDENTS_KIDNEY_RUSH/links/5d79cabda6fdcc9961c12b8b/ENJOYMENT-OF-LEARNING-BIOLOGY-THROUGH-MOBILE-GAME-BASED-LEARNING-FOR-FORM-5-STUDENTS-KIDNEY-RUSH.pdf
- Ruhi, U. (2015). Level Up Your Strategy: Towards a Descriptive Framework for Meaningful Enterprise Gamification. *Technology Innovation Management Review*, 5(8), 5–16.
<https://doi.org/10.22215/timreview/918>
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68–78. <https://doi.org/10.1037/0003-066x.55.1.68>
- Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The Motivational Pull of Video Games: A Self-Determination Theory Approach. *Motivation and Emotion*, 30(4), 344–360.
<https://doi.org/10.1007/s11031-006-9051-8>
- Saleh, S. (2014). Malaysian students' motivation towards Physics learning. *European Journal of Science and Mathematics Education*, 2(4), 223–232.
<https://doi.org/10.30935/scimath/9414>
- Salen, K., & Zimmerman, E. (2004). *Rules of play* [Kindle]. MITPress.

- Salleh, W. N. W. M., Ahmad, C. N. C., & Setyaningsih, E. (2021). Difficult topics in Biology from the view point of students and teachers based on KBSM implementation. *EDUCATUM Journal of Science, Mathematics and Technology*, 8(1), 49-56. <https://doi.org/10.37134/ejsmt.vol8.1.6.2021>
- Sánchez, J. L. G., Vela, F. L. G., Simarro, F. M., & Padilla-Zea, N. (2012). Playability: analysing user experience in video games. *Behaviour & Information Technology*, 31(10), 1033-1054. <https://doi.org/10.1080/0144929X.2012.710648>
- Šćepanović, S. N. E. Ž. A. N. A., Vujičić, T. I. J. A. N. A., Matijević, T. R. I. P. O., & Radunović, P. E. T. A. R. (2015, September). Game based mobile learning—application development and evaluation. In *The Sixth International Conference on e-Learning (eLearning-2015)* (pp. 24-25). <https://elearning.metropolitan.ac.rs/files/pdf/2015/22-Snezana-Scepanovoc-Tijana-Vujicic-Tripo-Matijevic-Petar-Radunovic-Game-based-mobile-learning-application-development-and-evaluation.pdf>
- Schrader, P. G., & Rapp, E. E. (2016). Does multimedia theory apply to all students? The impact of multimedia presentations on science learning. *Journal of Learning and Teaching in Digital Age*, 1(1), 32-46. <https://dergipark.org.tr/en/pub/joltida/issue/55462/760056>
- Scott, E. E., Wenderoth, M. P., & Doherty, J. H. (2020). Design-based research: A methodology to extend and enrich biology education research. *CBE—Life Sciences Education*, 19(2), es11. <https://doi.org/10.1187/cbe.19-11-0245>

- Serrano, K. (2019). The effect of digital game-based learning on student learning: A literature review. <https://scholarworks.uni.edu/grp/943/>
- Shaffer, D. W., Halverson, R., Squire, K. R., & Gee, J. P. (2005). Video Games and the Future of Learning. WCER Working Paper No. 2005-4. *Wisconsin Center for Education Research (NJI)*. <https://eric.ed.gov/?id=ED497016>
- Shamim, M. (2018). Application of Cognitive Theory of Multimedia Learning in Undergraduate Surgery Course. *International Journal of Surgery Research and Practice*, 5(1). <https://doi.org/10.23937/2378-3397/1410065>
- Shamsudin, N. H., Balasuntram, R., Jeram, E. H., & Devadas, L. (2020). Interactive Courseware: Untangle the Misconceptions in Cell Division. *Journal of Management & Science*, 18(2), 9-9. <https://doi.org/10.57002/jms.v18i2.247>
- Shelden, E. A., Offerdahl, E. G., & Johnson, G. T. (2019). A virtual laboratory on cell division using a publicly-available image database. *CourseSource*, 6. <https://doi.org/10.24918/cs.2019.15>
- Shen, C. Y., & Chu, H. P. (2014, June). The relations between interface design of digital game-based learning systems and flow experience and cognitive load of learners with different levels of prior knowledge. In International Conference on Cross-Cultural Design (pp. 574-584). Springer, Cham. https://doi.org/10.1007/978-3-319-07308-8_55
- Shippee, M., & Keengwe, J. (2012). mLearning: Anytime, anywhere learning transcending the boundaries of the educational box. *Education and Information Technologies*, 19(1), 103–113. <https://doi.org/10.1007/s10639-012-9211-2>
- Shiratuddin, N., & Zaibon, S. B. (2011, November). Designing user experience for mobile game-based learning. In 2011 International Conference on User Science and

- Engineering (i-USer)* (pp. 89-94). IEEE.
<https://doi.org/10.1109/iUSER.2011.6150543>.
- Shonola, S. A., Joy, M. S., Oyelere, S. S., & Suhonen, J. (2016). The Impact of Mobile Devices for Learning in Higher Education Institutions: Nigerian Universities Case Study. *International Journal of Modern Education and Computer Science*, 8(8), 43–50. <https://doi.org/10.5815/ijmecs.2016.08.06>
- Staff, Z. (2021, August 12). *The Process of Android Game Development*. Zco Corporation. <https://www.zco.com/blog/the-process-of-android-game-development/>
- Stenerson, M., Schneller, W., & Wurtele, E. S. (2011, June). Enabling educators to customize the game environment. In *Proceedings of the 7th international conference on Games+ Learning+ Society Conference* (pp. 230-236). <https://dl.acm.org/doi/pdf/10.5555/2206376.2206404>
- Stenros, J. (2022). Game Definition. In Grabarczyk, P. (ed.), *Encyclopedia of Ludic Terms* (Spring 2022 Edition). <https://eolt.org/articles/game-definition>
- Storksdieck, M. (2016). Critical information literacy as core skill for lifelong STEM learning in the 21st century: reflections on the desirability and feasibility for widespread science media education. *Cultural Studies of Science Education*, 11(1), 167–182. <https://doi.org/10.1007/s11422-015-9714-4>
- Subscribed.fyi. (2024, July 25). *Android vs iOS: Mobile Operating System market share statistics (Updated 2024)*. Subscribed.fyi. <https://subscribed.fyi/blog/navigating-os-trends-the-most-common-mobile-operating-systems/>
- Sumandal, A. H. (2023). Development and Evaluation of Educational Games Using Lumi Education in General Biology 1 for STEM Students: Basis for Recommended

- Supplementary Teaching Materials. *American Journal of Education and Technology*, 1(4), 13-23. <https://doi.org/10.54536/ajet.v1i4.1089>
- Sung, H. Y., & Hwang, G. J. (2013). A collaborative game-based learning approach to improving students' learning performance in science courses. *Computers & Education*, 63, 43–51. <https://doi.org/10.1016/j.compedu.2012.11.019>
- Swann, C., Keegan, R. J., Piggott, D., & Crust, L. (2012). A systematic review of the experience, occurrence, and controllability of flow states in elite sport. *Psychology of Sport and Exercise*, 13(6), 807–819. <https://doi.org/10.1016/j.psychsport.2012.05.006>
- Sweetser, P., & Wyeth, P. (2005). GameFlow: a model for evaluating player enjoyment in games. *Computers in Entertainment (CIE)*, 3(3), 3-3. <https://doi.org/10.1145/1077246.1077253>
- Sweller, J. (2010). Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load. *Educational Psychology Review*, 22(2), 123–138. <https://doi.org/10.1007/s10648-010-9128-5>
- Sweller, J., Van Merriënboer, J. J., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational psychology review*, 31, 261-292. <https://doi.org/10.1007/s10648-019-09465-5>
- Tan, P. H., Ling, S. W., & Ting, C. Y. (2007, September). Adaptive digital game-based learning framework. In *Proceedings of the 2nd international conference on Digital interactive media in entertainment and arts* (pp. 142-146). <https://doi.org/10.1145/1306813.1306844>

- Tee, P. K., Wong, L. C., Dada, M., Song, B. L., & Ng, C. P. (2024). Demand for digital skills, skill gaps and graduate employability: Evidence from employers in Malaysia. *F1000Research*, 13, 389. <https://doi.org/10.12688/f1000research.148514.1>
- Teo, N.C. (2021, January 19). When will the 150,000 laptops promised in Budget 2021 be ready for students? *DAP Malaysia*. <https://dapmalaysia.org/en/42546/when-will-the-150000-laptops-promised-in-budget-2021-be-ready-for-students/>
- Terzidou, T., & Tsiatsos, T. (2011, October). Designing a 3D Collaborative Game to Support Game Based Learning. In *European Conference on Games Based Learning* (p. 573). Academic Conferences International Limited. http://users.auth.gr/users/4/7/043774/public_html/CD-Papers/5_Papers/C55.pdf
- Thelma, C. C. (2023). Social challenges and learners' academic performance: A case of selected primary schools in Lusaka District, Zambia. *International Journal of Novel Research in Humanity and Social Sciences*, 10(5), 38–49. <https://doi.org/10.5281/zenodo.8351325>
- Tran, T. M. (2023). Integrating 21st century skills into translation classroom from students' perspective. *International Journal of TESOL & Education*, 3(1), 64-78. <https://doi.org/10.54855/ijte.23315>
- Tsiligiris, V., & Bowyer, D. (2021). Exploring the impact of 4IR on skills and personal qualities for future accountants: a proposed conceptual framework for university accounting education. *Accounting Education*, 30(6), 621-649. <https://doi.org/10.1080/09639284.2021.1938616>

- Um, E., Plass, J. L., Hayward, E. O., & Homer, B. D. (2012). Emotional design in multimedia learning. *Journal of educational psychology*, 104(2), 485. <https://doi.org/10.1037/a0026609>
- Vaishnavi, V. K., & Kuechler, W. (2015). *Design Science Research Methods and Patterns: Innovating Information and Communication Technology, 2nd Edition* (2nd ed.). CRC Press.
- Vijaindren, A. (2018, August 13). *Malaysia needs 500,000 scientists and engineers by 2020*. New Straits Times. <https://www.nst.com.my/news/politics/2018/08/400909/malaysia-needs-500000-scientists-and-engineers-2020>
- Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard university press.
- Wahid, N. T. A., & Talib, O. (2017). Stem integration in classroom practices among biology teachers in Mara Junior Science College (MJSC). *International Journal of Academic Research in Business and Social Sciences*, 7(4), 2222-6990. <http://dx.doi.org/10.6007/IJARBSS/v7-i4/2912>
- Wang, C., Fang, T., & Miao, R. (2018). Learning performance and cognitive load in mobile learning: Impact of interaction complexity. *Journal of Computer Assisted Learning*, 34(6), 917-927. <https://doi.org/10.1111/jcal.12300>
- Wilson, C. D., Reichsman, F., Mutch-Jones, K., Gardner, A., Marchi, L., Kowalski, S., ... & Dorsey, C. (2018). Teacher implementation and the impact of game-based science curriculum materials. *Journal of Science Education and Technology*, 27, 285-305. <https://doi.org/10.1007/s10956-017-9724-y>

- Wommer, F. G. B., Sepel, L. M. N., & Loreto, E. L. S. (2023). Insects GO: a gaming activity for entomology teaching in middle school. *Research in Science & Technological Education*, 41(2), 581-595. <https://doi.org/10.1080/02635143.2021.1921724>
- Wu, W. H., Hsiao, H. C., Wu, P. L., Lin, C. H., & Huang, S. H. (2012). Investigating the learning-theory foundations of game-based learning: a meta-analysis. *Journal of Computer Assisted Learning*, 28(3), 265-279. <https://doi.org/10.1111/j.1365-2729.2011.00437.x>
- Wulandari, R. (2021). Characteristics and learning models of the 21st century. In *Social, Humanities, and Educational Studies (SHEs): Conference Series* (Vol. 4, No. 3, pp. 8-16). <https://doi.org/10.20961/shes.v4i3.49958>
- Xie, H., Mayer, R. E., Wang, F., & Zhou, Z. (2019). Coordinating visual and auditory cueing in multimedia learning. *Journal of Educational Psychology*, 111(2), 235–255. <https://doi.org/10.1037/edu0000285>
- Xu, P. (2016). *Solutions to cognitive (over) load in game-based learning using learning experience design for K-12 education: a review of the literature* (Doctoral dissertation). <https://core.ac.uk/download/pdf/211340918.pdf>
- Yaman, H., Sousa, C., Neves, P. P., & Luz, F. (2024). Implementation of Game-Based Learning in Educational Contexts: Challenges and Intervention Strategies. *Electronic Journal of e-Learning*, 22(10), 19-36. <https://doi.org/10.34190/ejel.22.10.3480>
- Yang, W. Y., Chow, S. K. K., & Yuan, X. J. (2018, May). The Structural Design Computer Model-based Games for Assisting Mathematics Classroom Learning. In *Proceedings*

- of the 2018 International Conference on Distance Education and Learning (pp. 54-58). <https://doi.org/10.1145/3231848.3231853>
- Zaibon, S. B., & Shiratuddin, N. (2010). Mobile Game-Based Learning (mGBL): Application Development and Heuristics Evaluation Strategy. *Malaysian Journal of Learning and Instruction*. Published. <https://doi.org/10.32890/mjli.7.2010.7619>
- Zakaria, N. Y. K., Zaini, H., Hamdan, F., & Norman, H. (2018). Mobile game-based learning for online assessment in collaborative learning. *International Journal of Engineering & Technology*, 7(4.21), 80-85. <https://doi.org/10.14419/ijet.v7i4.21.21620>
- Zeng, Y., & Zhang, L. X. (2012). Implementing a cooperative learning model in universities. *Educational Studies*, 38(2), 165–173. <https://doi.org/10.1080/03055698.2011.598687>
- Zhong, Q. (2019). Design of game-based collaborative learning model. *Open Journal of Social Sciences*, 7(7), 488-496. <https://doi.org/10.4236/jss.2019.77039>
- Zin, N. A. M., Jaafar, A., & Yue, W. S. (2009). Digital game-based learning (DGBL) model and development methodology for teaching history. *WSEAS transactions on computers*, 8(2), 322-333. <https://api.semanticscholar.org/CorpusID:13203466>
- Zohrabi, M. (2013). Mixed method research: Instruments, validity, reliability and reporting findings. *Theory and practice in language studies*, 3(2), 254. <http://dx.doi.org/10.4304/tpls.3.2.254-262>
- Zusho, A., Anthony, J. S., Hashimoto, N., & Robertson, G. (2014). Do video games provide motivation to learn? In F. C. Blumberg (Ed.), *Learning by playing: Video gaming in education* (pp. 69–86). Oxford University Press. <https://doi.org/10.1093/acprof:osobl/9780199896646.003.0006>

APPENDICES

Appendix A: Teacher Interview Protocol with Informed Consent Form (Preliminary Study)

https://drive.google.com/file/d/1pKdZeBkGm2JVMkO_nyd2wsw8Br6JaW0N/view

Appendix B: Student's Self-Administered Questionnaire with Informed Consent Form (Preliminary Study)

https://drive.google.com/file/d/19F5qUO4Q5Eiz_Dyo4k-_4jM_dWhuMaLl/view

Appendix C: Teacher Informed Consent Form

<https://drive.google.com/file/d/1nP1s2lBnz1BNcMh-nLDqq5vSs7cg6B1u/view>

Appendix D: Student Informed Consent Form

<https://drive.google.com/file/d/1WAiey-QiFQC1Gbx1PuNN7PE45hxEuZtx/view>

Appendix E: mGBL Evaluation Instrument

https://drive.google.com/file/d/1umAbdrwdrMUD-o_mlgIT10JIG_Hz6Kuz/view

Appendix F: Approval Letters for Preliminary Study

<https://drive.google.com/file/d/1VeH483rvjnEYmykAf8hhVUphsSnvtuv9/view>

Appendix G: Approval Letters for Study

<https://drive.google.com/file/d/1RQstFT6mrGVJsS2JkPLSQ3o8HlctvAYy/view>

Appendix H: Transcripts of Teacher Interviews

https://drive.google.com/file/d/1mWCOMmJtmIkuduuiVirvA5ss42rUh_Nv/view

Appendix I: Screenshots of Game Features in Cell%

<https://drive.google.com/file/d/1gJlQltjXZrkTuD1lIDuXNIda8K0cD2gZ/view>