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Circuit Smart: Understanding Electricity through Collaborative Learning and Gamification

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ABSTRACT

This paper explores the use of gamification in providing solutions to overcome learning problems related to electricity on series and parallel circuits in Science for Primary Year 5. The two primary schools involved were in the rural districts of Betong and Lubok Antu in Sarawak. The use of game design thinking as a learning approach was utilised to facilitate the creation of educational games. Modern and traditional games inspired the games produced. Several modifications were re-designed for the game elements to suit the learning context and logistics. The games consisted of online and physical means of conduct where participants could collaborate between two schools and among themselves as a group. The findings obtained by the participants as the players of the games revealed the effectiveness of the games with the combination of computer-supported and collaborative learning in helping them understand the Science topic through play. Online communication, collaborative activities, and knowledge sharing were implemented between the two schools via the internet. The intricacies of the games encourage cooperative and collaborative skills to promote frequent play by adjusting the degree of difficulty of the game mechanics. Future research should enhance students' conceptual understanding with appropriate teaching and learning resources since electricity is a science subject closely related to learners' daily lives.

Keywords: game design thinking, Science, electricity, collaborative learning, gamification

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1 INTRODUCTION

Science education is an essential component of primary school curricula worldwide. Science education in primary schools aims to develop learners' understanding of the world around them by providing a basic understanding of scientific concepts, principles, and procedures. However, learners may face additional challenges regarding the specific topic of learning Science. The mental comprehension of learning Science still demonstrates a barrier to learners at primary school levels. Teaching Science to primary learners can be challenging, especially when concepts are not apparent (Preston et al., 2022, p. 950). Electricity in the Science Year 5 primary school syllabus of the Malaysian National Curriculum teaches the learners about sources of electrical energy as the introduction to the topic. The learners will be introduced to the type of circuits: a series circuit and a parallel circuit. As learners become more familiar with the circuit type, they are introduced to the electrical symbols representing the components in an electric circuit, such as dry cell, switch, bulb, and wire. Learners also must know the function of each component and the symbols of the component. The most crucial part is that the learners must know how to build series and parallel circuits and be able to identify the advantages and disadvantages of the types of circuits used. Identify the factors that affect the brightness of bulbs in each different type of circuit by doing hands-on activities. Learners will also be exposed to factors affecting electrical energy usage and the mishandling of electrical appliances.

The study aims to create a game prototype that could aid learners in overcoming the learning problems of Science subjects in primary Year 5. The two chosen primary schools were School A in Betong and School B in Lubok Antu. Both schools are in Betong and Lubok Antu districts in Sarawak, respectively. One Science teacher from each school participated in a brief interview to provide some feedback to investigate further the learning challenges faced by educators in hopes of delivering the desired learning outcomes of the subject to the learners. According to the needs analysis, the target group of Year 5 learners found the chapter on Electricity to be the most challenging to comprehend. The focus of the Electricity topic lies within the understanding of learners about series and parallel circuits.

The team members had collaboratively undergone the Design Thinking Process to produce a game prototype known as Circuit Smart or *Bijak Litar*. Circuit Smart is a Year 5 Science game created by the team members, comprising two phases. The two games used the ideas of both online and physical creativity, where the inspirations of both games transpired from activities such as treasure hunts and a traditional game called *Galah Panjang*, also known as Long Pole. Game 1 is an online treasure hunt activity using quizzes, whereas Game 2 is a physical activity played using Long Pole. Collaboration and gamification learning aspects were incorporated into both Circuit Smart games. Gamification offers a platform for experimentation for students and is dynamic and entertaining (Brull & Finlayson, 2016, p. 372). With gamification, learners can learn and progress at their own pace. Additionally, various learners can benefit from using it irrespective of age, gender, background, location, space, and time.

The notion of gamification drives the practice of bringing game-like elements, such as interactivity and principles, to non-game activities or applications (Buckley & Doyle, 2016, p. 1163). Games were introduced into learning to stimulate and increase the levels of engagement. The approach is

a shift from conventional instructional strategies used at these schools. Learners participate in physical, mental, and emotional interactions using game dynamics. As the learners share expected academic learning outcomes, they are encouraged to work collaboratively in groups by taking part in activities assigned to them by their instructors. Learners taking responsibility to collaborate with their peers may achieve more meaningful results through shared learning, such as group discussions and critical thinking. According to Meske et al. (2017), the phenomenon known as "social facilitation," which happens when groups outperform individuals, is another benefit of collaboration in gamified information systems (p. 97). The study incorporates a frugal approach in its design. It considers using traditional games to extend familiar cues for learning tasks.

1.1 Traditional Games

Traditional games incorporated into learning activities boost motivation across all instructional design components. The traditional game encourages all learners to actively participate in the events by engaging in solid physical activity (Adnan et al., 2020, p. 486). In addition to bolstering the learners' self-assurance, the laid-back setting gave them complete control over the activities of the traditional game. In addition to the motivational feature described earlier, the traditional game provides a pattern of good social development that might be seen when team members communicate directly and work together to achieve the assigned job within the allotted time. These attitudes can be included in physical education lessons that focus on character development and are based on traditional games played in primary schools (Masyhuri & Suherman, 2020, p. 10). *Galah Panjang* may enhance motor fitness capabilities, such as agility, reaction time, speed, and balance (Ghipit et al., 2017, p. 165). The *Galah Panjang* game is a traditional game that crosses barrier lines. One of the purposes of this game is to test the player's ability to run across human obstacles made by their friends as opponents. The game is played by children aged 7 to 14 years. Both boys and girls can play the game. It is played on open, wide, and flat ground. *Galah Panjang* does not require any specific equipment.

1.2 Frugal Education

A frugal agent is capable of living as well as a less frugal one with fewer material resources. Living frugally can be misinterpreted as eliminating certain aspects of life to save resources out of force and thus resulting in less quality of life. Zwarthoed (2015) defines frugality as a combination of knowledge, value orientations, preferences, emotional susceptibility, practical skills, and habits. This combination disposes the agent to behave frugally. Zwarthoed's definition points out a determining quality of frugality as a deliberate choice to choose carefully and still live a life with quality. While in education, the frugal concept aims to empower educators to create new educational interventions that respond creatively to adverse social, cultural, and environmental changes (Arnab et al., 2021). The goal is a mindful educational practice that costs less but provides a high-quality educational experience. Besides that, frugal education also aims to foster resilience and creativity in problem-solving that utilises available materials, sustainable resources, and trailing-edge technologies. With frugal education, educators will be able to plan and create quality educational inventions even when they are in a situation where they lack materials and resources. White (2021) elaborates on motivations for frugal education, where frugal living is willingly adopted for intrinsic or extrinsic reasons. In history, frugal living has been forced on humans by

war or pandemics, but nowadays, some prefer to embrace frugal living despite having no obligation to do so. These are considered intrinsic reasons for frugal living, but in education, intrinsic reasons alone are not enough to motivate the practice of frugal concepts. Education should include understanding and acting on the effects of, and ways of combating, climate change in general, and not least in developing countries such as their own, where droughts, storms, floods, deforestation, and rising temperatures are already causing disaster (White, 2021, p. 11). Educating for frugality looks further than the current demand or situation. White's argument draws attention towards the long-term effects of frugality concepts in education. Frugal education will be the bridge that brings closer the gap between the more privileged and the less privileged children while also teaching them that frugal living is not an option anymore, especially with the growing concern about climate change.

1.3 Gamification

'Gamification refers to using game-based mechanics, aesthetics, and game thinking to engage with people, encourage action, increase learning, and solve problems (Kapp, 2012, p. 10, as cited in Buckley & Doyle, 2016, p. 1163). Over the past several years, there has been much excitement and interest in gamification's potential applications in marketing and the workplace (Surendeleg et al., 2014, p. 1610). The topic of gamification in education has a significant amount of flair because, as humans, we constantly want to learn, regardless of age. Thus, it is crucial to acknowledge this matter. As mentioned by Meske et al. (2017), gamification is the process of applying game-specific aspects, such as achievements, badges, or virtual goods, to situations that are often reserved for games (such as learning and work) (p. 94). New and innovative ways to engage students in learning and address the expanding requirements of education are constantly being created by technological developments and their rapid development (Kalogiannakis et al., 2021, p. 1). Technology integration in educational systems has long been vital to improving teaching and learning (Estriegana et al., 2021, p. 2032). The use of collaborative learning as a teaching strategy can be successful both in traditional and online learning contexts such that it can be set up in a variety of ways, including to supplement more conventional activities (Estriegana et al., 2021, p. 2034).

2 METHODOLOGY

The study involved 12 participants aged 11 years old from two primary schools: School A and School B. The two teachers involved were also members of the study. Each teacher represented their school respectively and collected responses from their learners. When deciding on the participants, both schools agreed to choose average-performance learners and a small group of participants to play the games. Hence, each school's focus group comprised six students, respectively. They were also easily accessible to the teachers who implemented the study. After being selected according to the criteria above, they all agreed to participate in this study. Consent was obtained from both participants and their parents. As part of the necessary ethical considerations, privacy was maintained for all participants, where their identities and personal information were changed to anonymous. The setting of this study utilised both online and physical means for the activities to be carried out. Due to the collaboration between the two schools, participants and teachers liaised to schedule any intended meetings online or for physical activities.

The sampling method used was non-probability sampling which entails non-random selection based on convenience or other criteria, facilitating data collection (McCombes, 2019). Reading and writing proficiency was the most important criterion for selecting participants for the sample. They should be able to comprehend the instructions by listening or reading quickly. The capability enables them to participate in the activities efficiently. The participants were also selected based on their apparent digital literacy skills. It was essential to assist them in completing the collaborative games.

Data collection is the process of acquiring and quantifying information on variables of interest in a systematic manner that allows one to answer specific research questions, test hypotheses, and assess outcomes (Kabir, 2016, p. 202). The study's primary qualitative data-gathering techniques were semi-structured interviews, focus groups, observations, and game-playing to evaluate the learners' achievement of the predetermined learning objectives. The abovementioned techniques enabled the study implementers to capture data linked with words, feelings, emotions, and other intangible factors (Dudovskiy, 2022). Another mode of data collection was observation. The observational notes focused on the participants' behaviour and responses to online and physical activities. With the participants' permission, video recordings were incorporated to aid the observations. According to the data collected, the information obtained from observation and semi-structured interviews provided personal insights. The structure of the analysis was developed and arranged in an orderly manner. Data tabulation or relevant diagrams were generated and labelled accordingly. The inputs and feedback gathered by the participants and teachers were then used to analyse the learning problem for the design of game prototypes. The demographic profile of the participants and teachers were depicted in tables. The findings of the study were gathered through subjective interpretations. The game design thinking was the steps taken in designing and creating the game prototypes of the study, where a more in-depth discussion took place via the process for the creation of the games.

2.1 Game Design Thinking

Minoi et al. (2019) adopted the game design thinking process in this study. Figure 1 illustrates the five steps of the design thinking process inspired by play and games: empathise, define, ideate, prototype, and test (Minoi et al., 2019, p. 174). The subsequent sub-stages of the design thinking process focused on game design and the chance to incorporate cultural components (Chuah et al., 2021, p. 45). These steps were the guidelines for producing the game prototypes in this study. Contributors in design thinking study come from various disciplines rather than just designers. Design thinking employs a specific design methodology with tools and procedures that are clear to non-designers and readily available (Thoring & Müller, 2011, p. 138).

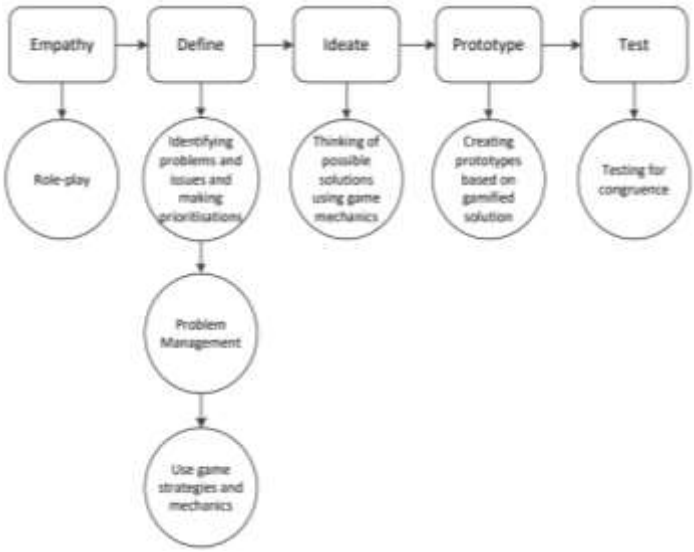

Figure 1. Game design thinking approach with play-based and game inspirations (Adopted from Minoi et al., 2019).

Empathy involves setting the stage to listen and understand the concerns of others without judgement or aspersion. In this study instance, the role-play aspect was included between teachers and learners to break the ice and pique interest, gain insights, and foster relationships. After compiling the ideas for the concerns, the team defined the problems by considering and prioritising the problems. This phase ensures that the game elements designed allow their shared academic goal to be achieved. Next, the ideate phase was brainstorming potential solutions by choosing several game elements and strategies. The following phase of the prototype encouraged the team to build the ideas into tangible results as the games. The final test phase of the prototype was then shared and tested with the participants involved.

2.1.1 Empathise

Developing empathy is the very first step in design thinking (Coleman, 2016, p. 65). The team concentrated on observing and interviewing the participants and gathering as much information as possible about them. The primary goal of this stage is for the design thinking team to observe, interact with, and immerse themselves in the user and their experiences (Kernbach & Nabergoj, 2018, p. 364). The study collected subjective inputs from participants about their learning problems. The collaboration between both schools was formed when the two teachers communicated with each other to discuss the learning problem. By narrowing down the learning problem, the same topic of Science electricity occurred in both schools. The discussion entailed how games would be beneficial for the participants in both schools through the means of collaboration. Then, the study was set out to introduce the participants from both schools through a written online platform in Padlet asynchronously. The follow-up introduction will be an online meeting of the participants from both schools, which will be done synchronously as scheduled.

Participants' Demographic and Profile

A total of 12 primary school learners participated in the study. The general demographic of the background of participants is described below (Table 1). Based on their profiles, each participant was labelled in alphabetical initials such as A, B, C, D, E, F, U, V, W, X, Y, and Z for learners.

Table 1. Demographic and profile of participants.

Participant	Age	School	Gender	Hobby	Ambition	Favourite Movie	About Myself
A	11	A	Female	Cooking	Teacher	No comment	No comment
B	11	A	Female	Badminton, netball	Teacher	Harry Potter, Kungfu Panda	No comment
C	11	A	Male	Badminton, hockey	Engineer	Harry Potter, KL Gangster, Mat Kilau	No comment
D	11	A	Male	Badminton, cycling	Fireman	No comment	I am brave and smart
E	11	A	Male	Badminton, reading, playing with a sibling	Pilot	No comment	An avid reader, but I am shy
F	11	A	Female	Reading storybooks, netball	Teacher	No comment	I like reading fairy tale books because it has moral values
U	11	B	Female	Drawing, handball, netball, athletics	Teacher	Annabelle, The Penthouse	No comment
V	11	B	Male	Badminton, volleyball. handball	Teacher	The Devil, Offering	I am smart and like to talk
W	11	B	Female	Badminton, athletics, netball	Teacher	Beauty and the Beast	No comment
X	11	B	Female	Reading, netball	Teacher	Keong Emas, Matilda	I am smart but shy
Y	11	B	Male	Reading, badminton	Teacher	Upin Ipin, Ejen Ali	I am a firm person
Z	11	B	Male	Badminton	Pilot	Harry Potter, Maze Runner	I am a responsible person

According to Table 1, all 12 participants were 11 years old and studying at the Year 5 level in primary school. Six participants represented two schools, School A and School B, respectively. Similarly, the six participants from each school comprised three male and three female learners. A brief idea of the students' characteristics showed they are intelligent, avid readers, responsible, firm, brave, and shy. The participants were described as active individuals who shared similar sports-related hobbies such as badminton, netball, handball, athletics, volleyball, cycling, and hockey. Some also enjoyed other interests like reading, cooking, drawing, and playing with their siblings. All participants stated their ambition: eight learners wanted to become a teacher; two wanted to become a pilot; one wanted to become a fireman and an engineer, respectively. Most participants (8 learners) enjoyed watching movies as entertainment, while the rest did not state their preference.

The team conducted a needs analysis to identify the learning problem among the participants. The interviewers (teachers) were moderators during the focus group interviews. The themes of the conversation revolved around the students' interests in learning Science, the topics they enjoy or dislike in their current curriculum, and the approaches they would like to recommend or attempt for learning the subject. The moderator also elicited their comments by asking them open-ended questions and encouraging them to justify their responses. Electricity is one of the Year 5 Science learning units listed in the Standard Curriculum and Assessment Document (DSKP) based on the Science Standard-based Curriculum for Primary School (Revised in 2017). It is under the theme of Physical Science. This topic is designed to stimulate and capture learners' interest in learning either in the classroom or independently. Hence, a mixture of reviews entailed a learning problem where some could comprehend the topic discussed while the majority may not. In this case, the majority said they could not understand the Electricity topic.

2.1.2 Define

The Define stage is where the participants are required and able to narrow down the focus to the main learning problem, they find to be the most challenging in their Science topic, Electricity. The teachers that moderated the session guided the participants with some questions that intrigued them. Unanimously, the majority agreed that the series and parallel circuits under the topic of Electricity were indeed difficult to understand. To further assist the participants' viewpoint, semi-structured interviews were conducted with one Science teacher from each school. The two teachers were labelled in numbers 1 and 2. The interviewers were the study implementers equipped with several questions about science education. The formal conversations covered their teaching experiences, the instructional approaches they had previously employed, their difficulties when teaching Science, and the incorporation of gamification components into their teaching activities. Despite having the interview outline, the interviewers obtained in-depth information by asking the Science teachers, as subject matter experts, relevant questions that prompted them to elaborate on their views. In addition to allowing interviewers to appear competent and eager to learn about Science teachers' perspectives, semi-structured interviews enabled teachers to express their opinions freely. The teachers from both schools gave their feedback as part of supporting evidence for the study.

Table 2. Demographic and profile of teachers.

Teacher	1	2
School	School A	School B
Gender	Female	Male
Education	IPG Kampus Tun Abdul Razak (IPGKTAR), Kota Samarahan	Universiti Pendidikan Sultan Idris, Perak
Subject	Major: Pengajian Bahasa Melayu Minor: Moral	Major: Physics Minor: -NIL-
Teaching Experience	Eight years	One year
Q1: Based on your experience, what are the challenges you encountered to ensure the learners understand concepts in Science?	Searching for interesting activities that suit learners' levels.	Every subject has their own requirement tools which I can say at my school, there's not enough Science equipment, and sometimes we don't have access to the internet to be used while delivering some concepts to the learners.
Q2: In your opinion, what are the factors that cause the learners to be slow to master or not master the skills or knowledge in Science?	Some learners have not mastered basic literacy and numeracy skills (asas 3M), science process skills (Kemahiran Proses Sains) and are not interested in Science.	The causes of slow learner students are illness and absence from school. Besides that, the environment factors also can contribute to their learning process such as family background.
Q3: Did you teach the learners about electric circuits (series circuit and parallel circuit)? Were the learners able to show that they understood the concept of the circuits?	Yes. Most of the learners who achieved TP5 could show their understanding about it.	Yes, I teach learners about electric circuits and their symbols. They seem to understand but when questions are asked they are clueless. Maybe my teaching process was boring, or the topic did not attract their interest.
Q4: Have you used any games in your lesson? What are they?	Yes. They are Quizizz, Liveworksheet, and Wordwall.	I have used online quizzes sometimes when I can get access to the Internet data. I used to divide them in groups and let them answer the online game quiz and compete among themselves. They seem to like it and are very excited. Wordwall.

In Table 2, Teacher 1 is a female from School A in Betong while Teacher 2 is a male from School B in Lubok Antu. Both teachers received their teaching education from public institutions. Teacher 1 attended the Institute of Teacher Education at *Institut Pendidikan Guru Kampus Tun Abdul Razak (IPGKTAR)*, whereas Teacher 2 graduated from *Universiti Pendidikan Sultan Idris*. The former majored in *Pengajian Bahasa Melayu* (Malay Language Studies), while the latter majored in Physics. Teacher 1 has been teaching for over eight years. Teacher 2 has only taught for one year. The first question directed to both teachers stated the challenges encountered to ensure the

learners understand the concepts in the Science subject. They both had different perspectives where; Teacher 1 was constantly searching for exciting activities that suited the level of her learners, while Teacher 2 highlighted the inadequate materials and poor Internet access to deliver Science concepts to the learners. The second question featured the opinion of the teachers on the factors that may cause learners to be slow in mastering or unable to master the skills or knowledge in Science. Teacher 1 mentioned that some factors include insufficient proficiency in their basic literacy and numeracy skills, science process skills, and disinterest in Science subjects. Teacher 2 stated that some possibilities were due to the absence from school and family background environment that may affect their learning process. The third question asked if the teachers taught the electric circuits (series and parallel circuits) and if the learners could understand the concepts. Both teachers revealed that the learners could understand the concepts, but Teacher 2 hinted that perhaps his teaching method was tedious, or the topic was not enjoyable; hence the learners were clueless when questions were asked. The final question sought whether the teachers used any games in their lessons and whether they could name them. Similarly, both teachers used Wordwall and other forms of online quizzes.

2.1.3 Ideate

Next, all the relevant ideas were presented in this ideation phase. Several brainstorming sessions were carried out to address the learning problem faced by the participants. Ideas were shared and discussed to open our minds to endless possibilities. The team members brainstormed by being creative and imaginative towards the potential solutions. Upon compiling data on learning gaps in simple circuits in electricity and looking through the learners' profiles, designing a gamified lesson should consider that both learner groups lack the materials needed and have limited access to the internet.

To overcome that, a cooperative game where learners must work in groups to complete the games is considered the most suitable because both schools do not have sufficient materials to build electric circuits. The Frugal Education Action Cards were utilised during the process of brainstorming. The team then decided on three major actions based on the cards: minimal, sustainable, and resilient.

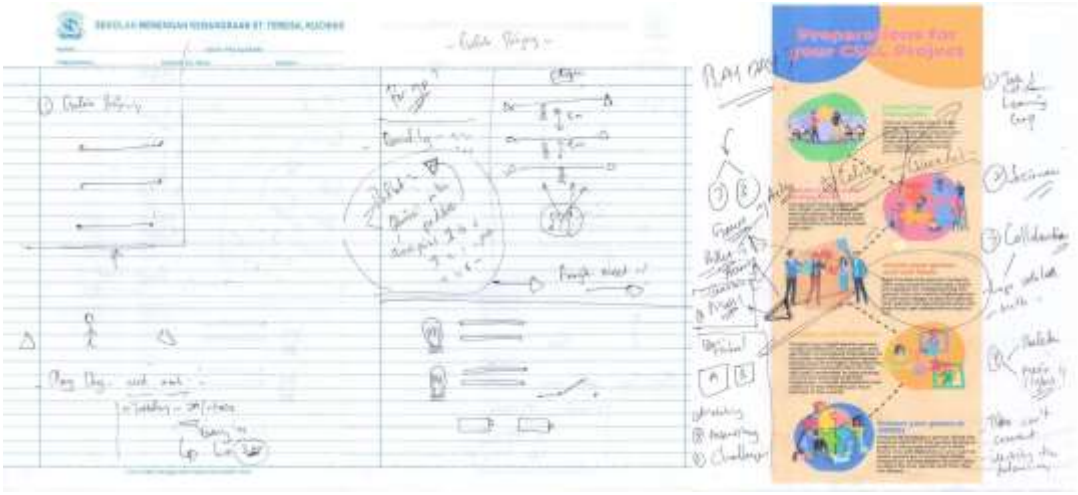

Figure 2. Example from one of the team member's sketches during brainstorming in the game design thinking process.

The game ideas and knowledge built during this process were collaboratively transformed into an actionable problem-solving plan. For instance, Figure 2 depicts the initial stage of ideas that one of the team members sketched. The team carried out a voting process to determine the types and number of games suitable for the study. A total of two games were decided and collaboratively conducted. The first game between both schools was conducted online before moving on to the second game, which will be played physically. A modified version of a conventional treasure hunt for Game 1 and *Galah Panjang* traditional game for Game 2 were the choices for the two games. The team members facilitated each other by designing the treasure hunt questions and traditional game outlines so it would be feasible. The instructions to play, winning criteria, game rules and mechanics were then implemented for both games. Upon consensus, the preferred language used for both games were Malay to ease the delivery of game instruction and content. The names for both games were also decided in this phase where Game 1 was named Circuit Smart Quiz and Game 2 was called Ready, Set, Circuit! Both games were designed to be completed in 1 hour, where the former would take approximately 20 minutes, whereas the latter required 40 minutes. The Circuit Smart Quiz is an online quiz game depicting a treasure hunt map with multiple-choice questions. Meanwhile, Ready, Set, Circuit! combines physical, mental, and emotional challenges to play the traditional *Galah Panjang* game incorporated with the modified version of getting from the starting point with items needed to the endpoint to assemble the given circuits.

2.1.4 Prototype

Game 2, a Galah Panjang-inspired physical game, is easy to play with few rules. The ideas were brought to life through the prototype phase, where the games were actionable, tangible, and testable by the participants. The Frugal Education Action Cards utilised in the game design thinking specified the three minimal actions (keep it simple), sustainable (economical), and resilient (universal). They were keeping the game simple with an online Padlet quiz which is lightweight and easy to navigate—moreover, being economical through minimising cost by using

fewer materials or reusing materials available in schools. As for universal, practical materials and resources, keep the game adaptable and easily accessible.

The treasure hunt online quiz is designed to be as easy and direct as possible. Several considerations were considered, such as the Internet connectivity and electronic devices available. The quiz was relatively minimal yet suitable as the participants could collaborate while competing against time. This approach geared the participants' minds before moving on to the next game, which is more physically and mentally challenging. Similarly, the *Galah Panjang*-inspired game was designed with frugal elements in mind. It was designed to be simple and minimal. Minimal in terms of fewer materials used and simple in terms of straightforward game rules. Ready, Set, Circuit! can be played anywhere if there is enough open space for the court to be made or drawn. Learners must work with their friends to build simple electric circuits to win. The goal was to build economic and sustainable games using materials available in most schools, especially rural schools such as Schools A and B. In doing so, the game did not use genuine electric kits; instead, they were replaced with pictures of circuit parts. This was done so that the game can be universal, hoping to make it accessible to learners from interior parts of Sarawak where it is difficult to find a simple circuit kit. Besides being a beginner, a simpler model of an electric circuit game should also be easy for teachers to make the materials themselves. The prototype was printed pictures of circuit parts, pasted on reusable cardboards to make it sturdy enough when players run around with them. The idea of an electric circuit was replaced with a puzzle in the hope that it could replicate the concept of an electric circuit.

Game 1: Circuit Smart Quiz

Figure 3 shows the Circuit Smart Quiz, a treasure hunt-themed online quiz game. This online quiz game assessed the participants' knowledge of series and parallel circuits. Padlet and Google Forms were the technology tools used to construct it. Each Google Form consisted of one question. Participants required laptops or other portable devices with a reliable internet connection to participate, and they were supposed to accurately answer all seven questions about Electricity to earn seven points.

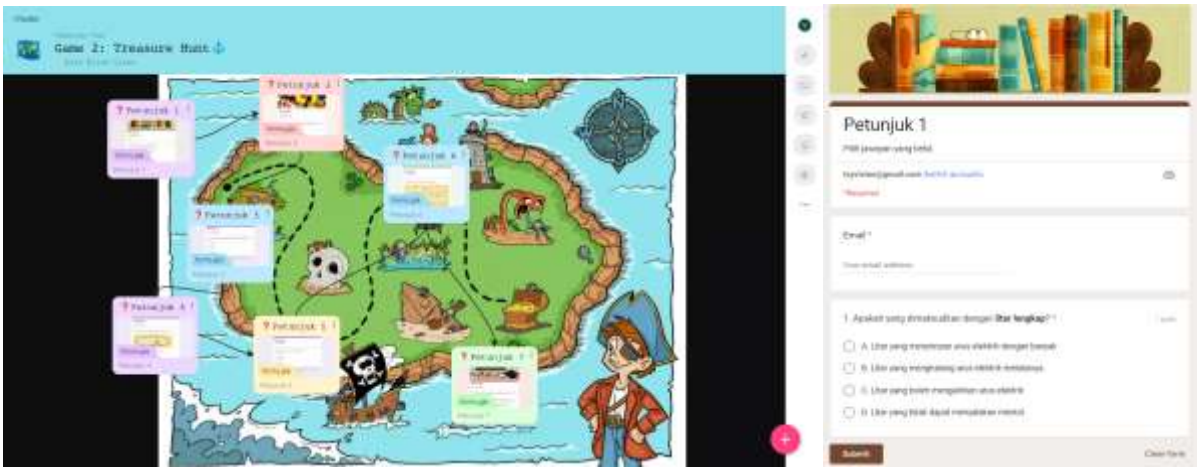

Figure 3. Game 1 (Circuit Smart Quiz) on Padlet incorporated with google forms.

As this online quiz game facilitated collaboration between School A and School B participants, they connected and communicated using Google Meet. The three-person groups got ready with a mobile device or a laptop, and they could join the online quiz game by clicking on the provided link or scanning the QR Code. Each team was required to sign into their school email account to track the responses for points calculation. The participants must attentively read the questions and swiftly select the proper responses. The winning team would be the one that completed the task the quickest and accumulated the most points. At the end of the Circuit Smart Quiz, the teachers revealed the winning team's final score and completion time. For a tiebreaker, in the case where teams have the same number of points, the team that completes the quiz in a shorter amount of time wins the game.

Game 2: Ready, Set, Circuit!

Ready, Set, Circuit! is a physical game inspired by the traditional *Galah Panjang* with an added electric twist. The primary objective was to select and collect the necessary electronic kits for assembling series and parallel circuits. The purpose assessment assessed the time the participants spent connecting the electronic components to build the electric circuits mentioned. Figure 4 shows an example of the Ready, Set, Circuit compilation! Game sketches, electric circuit components, and physical materials.

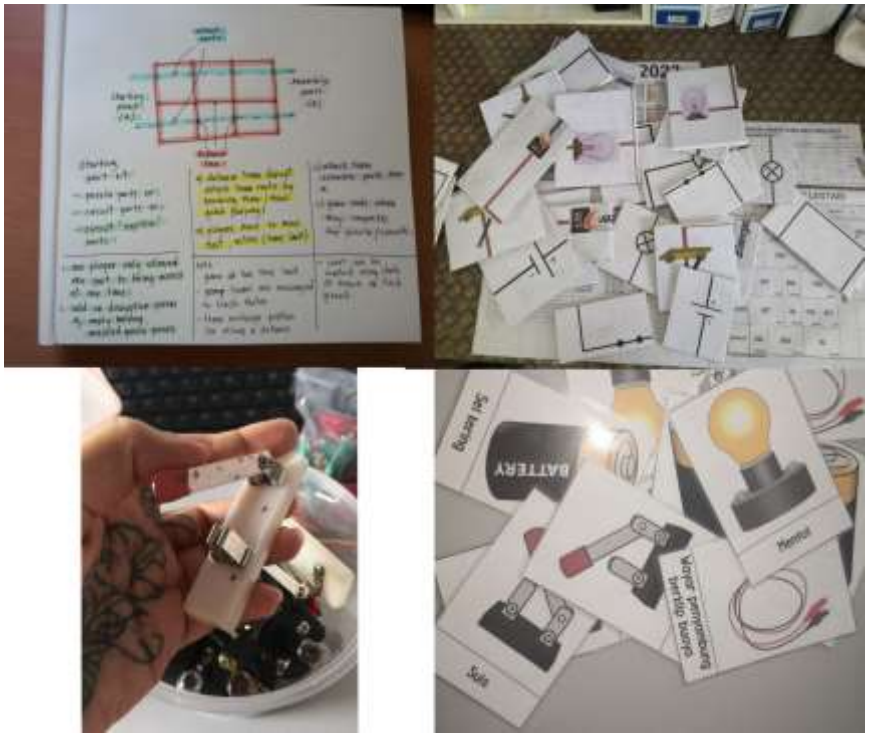

Figure 4. Game 2 (Ready, Set, Circuit!) compilation of sketches, components, and materials.

Each school's participants were divided into two groups of three. It was a competition between two groups of students from the same school. One team assumed the attacker position, while the other team assumed the role of defender. The attacking team prepared at the starting point, while the defending team positioned themselves at their respective defensive lines. The attacking team must decide beforehand which circuit they wish to form. The attacking team must dash to Table A at the sound of the whistle and select an electronic kit picture card for themselves. They brought the card and must run as quickly as possible beyond the defending lines. As students approached Table B, they swapped the electronic kit picture card for the actual electronic kits with their Science teachers. The attacking team could return to Table A to collect additional picture cards without going past the defenders if necessary.

After gathering enough electronic kits, they should assemble the circuit collaboratively. The round was complete when the attacking team correctly constructed their electronic kits, and the bulb lit up. Another electric circuit would consist of another game. After that, the attacking team switched roles with the defensive team. The time required by each playing group to finish each circuit was recorded. The groups that could build the electronic kits to form series and parallel circuits correctly within the shortest time were winners.

2.1.5 Test

The testing phase was conducted, and the input from the participants, teachers, or those involved was considered to bring vital alterations to the game prototypes. The feedback and insights

collected were applied to develop the solution or ideas of the games much more efficiently.

The first testing phase of Ready, Set, Circuit! was on 24 November 2022 in School B. Both groups assembled their series and parallel circuits in about 30 minutes. Initially, participants were expected to combine the puzzle pieces to form electric circuit images. However, the Science teacher pointed out that the participants were too focused on correctly completing the pictures rather than understanding the concept of electric circuits. As a result, the puzzle pieces were upgraded to an electronic kit. In addition to aiding participants' comprehension of electric circuits, the modified activity was designed to promote skill acquisition and boost motivation (Kasser & Liebermen, 2003, p. 19). Due to the lack of available electronic kits at School B, the participants utilised the electronic kits donated by other schools. To protect the safety of the participants and prevent damage to the limited electronic kit, it was proposed that they would run with the laminated picture cards of the kit chosen and swap them with their Science teacher for the basic kit for them to assemble the series and parallel circuits. It was where the final design of the game materialised. The participants could play the game securely and still be able to experience assembling the electrical components to watch the bulb light up.

On 30 November 2022, School A and School B participated in Play Day, the second testing phase for Circuit Smart games. Even though Ready, Set, Circuit! was intended to be the first game, it was completed after the Circuit Smart Quiz, which could be played in less time and relied on the school's internet connection. A stable Internet connection was required for participants to connect via Google Meet and for competing teams to access their online quiz game. Participants had to briefly reintroduce themselves to one another prior to the quiz, as it was the first time they had met since posting their introductions on Padlet. The participants from both schools were divided into four teams of three, and each team was provided with a mobile device with internet access. Once participants accessed the Padlet containing the quiz questions via the provided link, they were instructed to answer all seven questions correctly within the allotted time to receive perfect scores. After the winners were announced, a summary was conducted prior to the conclusion of the Google Meet. The participants then went to the prepared court for Ready, Set, Circuit! The court measured 3 metres in width and 7 metres in length. Three defensive lines were delineated using cones spaced every 2.5 metres. Since the participants were briefed on what to do, each group successfully carried out their roles, as the attackers were able to run past the defenders with laminated picture cards of the electronic kits, exchange their picture cards into a basic electronic kit with their Science teachers, and finally assembled all electronic kits in order to create series and parallel circuits. Each group was asked to build one series and one parallel circuit, and the time it took to put the electronic kits together was tracked separately. The timer ended as their bulbs lit up, and their Science teachers certified that students had successfully connected the electronic kits. Verbal feedback on the games was gathered to evaluate the predetermined learning objectives. The Play Day lasted approximately 40 minutes, and the games were playable if each group of learners had a mobile device with internet connectivity and the physical game court was set up before the beginning of the one-hour science classes.

Furthermore, the participant feedback from both games was collected and analysed. Participants were asked several open-ended questions, and their responses were insightful. One of the topics posed to the participants was which of the two games, Circuit Smart Quiz or Ready, Set, Circuit!

would assist them in learning more about series and parallel circuits. Several responses were gathered as follows:

> *I choose Ready, Set, Circuit! The game was very interesting and helped me to understand more about electric circuits.*
>
> *I choose Ready, Set, Circuit! because I can learn while playing.*
>
> *I choose Ready, Set, Circuit! because I can play.*

The responses obtained gave insights into the type of games that interest learners while learning. It could be seen that most primary school learners would prefer an active and challenging physical activity compared to online quizzes. They also showed enthusiasm and excitement when they transitioned from playing the Circuit Smart Quiz to Ready, Set, Circuit! game.

Next, another participant's feedback was regarding the Circuit Smart game activities that helped them understand series and parallel circuits. The following was the feedback given by the participants:

> *The activities made me understand more about electric circuits.*
>
> *Yes. I understood how to assemble series and parallel circuits.*
>
> *Yes. I could learn about electric circuits.*
>
> *The activities gave positive impacts to me. I understood about the electric circuits.*

Incorporating games into the participants' learning activities enhanced their understanding of series and parallel circuits. The participants' responses indicated that the games enhanced their grasp of series and parallel circuits within the Electricity topic. In addition, they could practise and gain the skills necessary to assemble actual electronic kits to create series and parallel electronic circuits as a group. Through proper direction and systematic organisation, learners could transform their learning difficulties into valuable educational aid.

3 FINDINGS AND DISCUSSION

The game design thinking process was a systematic approach used to help organise the flow of ideas. Gameplay allows the specific interaction between players and a game. In this study, game playing allowed the study implementers to examine the participants' thought processes when playing strategic games as players (Halevy, 2016, p. 8). Besides, utilising scores from the games or the amount of time required to complete the activities represented the participants' cognitive ability. It also enabled study implementers to watch participants collaborate to achieve assigned

tasks. The teacher's experience in teaching shows that they are diligent in their duty as educators. Collaboration of the lesson by integrating technology and physical activity gives an exciting way of teaching and learning in the class. The games' or activities' goals and objectives gave an overview of how the collaboration would benefit everyone participating. Participants established trust and effective communication with each other to ensure they solved the learning problem. The collaborative learning environment encourages learners to work together, involving physical movement and critical thinking and exposing them to basic computer skills. The lesson helps learners to understand and solve a problem scientifically using the Science Process Skill (observing, classifying, communicating, and interpreting data). This experience helps in the Professional Learning Community that shares expertise and works collaboratively to improve students' teaching skills and academic performance. The Science teacher does include the Scientific Skills (Science Process Skills) as in the Standard Curriculum and Assessment Document (DSKP) in this lesson.

The online quiz game was created to increase the learners' understanding of what they learned in this lesson. Integrating it with technology gives a new aura for learners to learn interestingly. Still, collaboration is the central fact to learn in this lesson. The game helps learners to be more confident with themselves or increase their self-esteem. Indirectly, motivate them to learn more diligently and focus on getting the correct answers. To complete the learning activities by resolving issues, collaborating, and cooperating, participants will put their thoughts, mental efforts, and learning strategies to use here (Minoi et al., 2019, p. 179). Learners are very energetic when it comes to games, especially physical ones. Gamified learning activities can be utilised in the learning environment to encourage student involvement and participation, while their social, asynchronous nature can encourage students to engage with previously provided content (Buckley & Doyle, 2016, p. 1172). As learners nowadays mostly live in the housing area, their activities and movement are limited in a small compound. With the *Galah Panjang* game, the opportunity to move vigorously with a companion of friends gives a feeling of being appreciated if able to pass through the obstacles. Learners' instinct is to play and have fun, but when it is topped up to achieve, it will become a more meaningful learning experience for them.

One of the study highlights includes having a collaborative learning experience in learning the Science electricity topic through the online quiz and physical games with a twist of challenges. It was interesting to witness how the learners communicated and collaborated to solve the problems during the games. The learners are creative with solutions and manage to overcome the game's obstacles by observing or sharing knowledge. Peers will observe and appreciate others more positively if they notice their peers' accomplishments and think their involvement in an activity or game contributed meaningfully to its success (Kasser & Liebermen, 2003, p. 19). Such games might promote greater enthusiasm and satisfaction, encouraging learners to participate continuously. To stimulate students' thinking by focusing their attention on essential elements, the interactive verbal dialogue was therefore crucial (Preston et al., 2022, p. 968). Another focus point was enabling the learners to use digital devices such as mobile phones and laptops to communicate and play against each other. Conversely, there was one main problem: the Internet connection could be unstable in rural areas. This problem was mitigated through the prior planning of Play Day and relying on virtual platforms to communicate or play, such as Google Meet, WhatsApp, and Padlet, which required low Internet data.

4 CONCLUSION

The study has provided valuable insights by creating game prototypes that could support the learners in overcoming the learning problems of the Science electricity subject in primary Year 5. Collaboration amongst teachers and learners from two different schools from various places (rural areas) to improve the learning performance of learners can be successfully achieved with decent quality Internet coverage. Similarly, the physical distance was not an obstacle as the learners progressively acquired a sense of teamwork as they interacted and collaborated through social and virtual platforms. The abilities of each pupil involved in the game are unique. Hence, the combination of learners from different family backgrounds and levels of performance proficiency in science subjects in this lesson shows that they work as a team and can overcome problems well. The lesson's objective can be achieved as the team can fully complete the given task.

In addition, the study incorporated frugal education as part of creating the game prototypes. Existing technological tools on the web for designing the online game and making full use of available materials for the physical game allowed us to be economical, sustainable, and practical throughout. The frugal approach and creative thinking as innovators help teachers to design teaching and learning tools to make a significant positive change in their learners. Adding physical games and integrating technology into the lesson makes learning more relevant and engaging. The feeling of having fun and incorporating teamwork among learners helped them work together to achieve the lesson's goal. Eventually, the learners demonstrated excitement as they were engrossed in the collaborative learning experience, with some hints of competitiveness between the two schools. Integrating physical and online gamified learning environments through real-time communication enhanced learners' overall experience.

The Circuit Smart games offer strengths through their game-play mechanics and learning principles. Through a wide range of instructional techniques, the game dynamics foster qualities of cooperation and collaboration. The nature of the games encourages frequent play as improvements can be made or altered to adjust the difficulty levels through the game-play logistics whenever necessary. Given that electricity is a science subject that is strongly tied to learners' daily lives, it is advised that future studies focus on improving students' conceptual comprehension with proper teaching and learning tools. Primary school learners may have opportunities to learn about electric circuits and other science ideas through an integrated and varied teaching sequence. Future attempts may suggest enhancing the game by considering additional testing due to the limited period and players available.

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REFERENCES

Adnan, M., Shaharudin,, S., Abd Rahim, B. H., & Ismail, S. M. (2020). Quantification of physical activity of Malaysian traditional games for school-based intervention among primary school children. *Journal of Taibah University Medical Sciences*, *15*(6), 486-494. https://doi.org/10.1016/j.jtumed.2020.09.006

Arnab, S., Mahon, D., Masters, A., Morini, L., Minoi, J.-L., & Mohamad, F. S. (2021). Towards the mapping of learning, playful, and frugal aspects for developing 21st century competencies and resilience. *In Proceedings of 15th European Conference on Game-Based Learning*, 14-24. Retrieved from https://search.proquest.com/openview/9ec13e5206d1e27ad6c0daba861533ff/1?pq-origsite=gscholar&cbl=396495

Brull, S., & Finlayson, S. (2016). Importance of gamification in increasing learning. *The Journal of Continuing Education in Nursing*, *47*(8), 372-375. https://doi.org/10.3928/00220124-20160715-09

Buckley, P., & Doyle, E. (2016). Gamification and student motivation. *Interactive Learning Environments*, *24*(6), 1162-1175. https://doi.org/10.1080/10494820.2014.964263

Chuah, K.-M., Mohamad, F. S., Minoi, J.-L., & Kabilan, M. K. (2021). Of marbles and Minecraft: Designing STEM educational games for culturally diverse young learners in Malaysia. *2021 World Engineering Education Forum/Global Engineering Deans Council*, 44-49. https://doi.org/10.1109/WEEF/GEDC53299.2021.9657214

Coleman, M. C. (2016). Design thinking and the school library. *Knowledge Quest*, *44*(5), 62-68.

Dudovskiy, J. (2022). *The ultimate guide to writing a dissertation in business studies: A step-by-step assistance* (6th ed.). Business Research Methodology. Retrieved from https://research-methodology.net/research-methods/data-collection/

Estriegana, R., Medina-Merodio, J.-A., Robina-Ramírez, R., & Barchino, R. (2021). Analysis of cooperative skills development through relational coordination in a gamified online learning environment. *Electronics*, *10*(16), 2032-2052. https://doi.org/10.3390/electronics10162032

Ghipit, M. A., Abdullah, M. R., Musa, R. M., Kosni, N. A., Maliki, A. B. H. M., & Faculty of Applied Social Sciences, Universiti Sultan Zainal Abidin, Terengganu, Malaysia. (2017). The effect of traditional games intervention programme in the enhancement school-age children's

motor skills: A preliminary study. *Movement, Health & Exercise, 6*(2), 157-169. http://dx.doi.org/10.15282/mohe.v6i2.142

Halevy, N. (2016). Strategic Thinking. In J. M. Olson & M. P. Zanna (Eds.), *Advances in Experimental Social Psychology* (pp. 1-66). Elsevier Academic Press. https://doi.org/10.1016/bs.aesp.2016.03.001

Kabir, S. M. S. (2016). *Basic guidelines for research: An introductory approach for all disciplines* (1st ed.). Book Zone Publication. Retrieved from https://www.researchgate.net/publication/325846997_METHODS_OF_DATA_COLLECTION

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in science education. A systematic review of the literature. *Education Sciences*, *11*(1), 1-36. https://doi.org/10.3390/educsci11010022

Kasser, S. L., & Liebermen, L. J. (2003). Maximising learning opportunities through activity modification. *Teaching Elementary Physical Education*, *14*(3), 19-22. Retrieved from http://hdl.handle.net/20.500.12648/2465

Kernbach, S., & Nabergoj, A. S. (2018). Visual design thinking: Understanding the role of knowledge visualisation in the design thinking process. *22nd International Conference Information Visualisation*, 362-367. https://doi.org/10.1109/iV.2018.00068

Masyhuri, S. F., & Suherman, W. S. (2020). The traditional game learning model for the elementary school student character building. *In 4th International Conference on Sport Science, Health, and Physical Education, 21*, 9-13. https://doi.org/10.2991/ahsr.k.200214.003

McCombes, S. (2019, September 19). *Sampling methods | Types, techniques & examples*. Scribbr. Retrieved from https://www.scribbr.com/methodology/sampling-methods/

Meske, C., Brockmann, T., Wilms, K., & Stieglitz, S. (2017). Social collaboration and gamification. In Stieglitz, S., Lattemann, C., Robra-Bissantz, S., Zarnekow, R., Brockmann, T. (Eds.). *Gamification*, 93-109. https://doi.org/10.1007/978-3-319-45557-0_7

Minoi, J.-L., Mohamad, F., Arnab, S., Phoa, J., Morini, L., Beaufoy, J., Lim, T., & Clarke, S. (2019). A participatory co-creation model to drive community engagement in rural indigenous schools: A case study in Sarawak. *Electronic Journal of e-Learning*, *17*(3), 173-183. https://doi.org/10.34190/JEL.17.3.001

Preston, C. M., Hubber, P. J., & Xu, L. (2022). Teaching about electricity in primary school multimodality and variation theory as analytical lenses. *Research in Science Education*, *52*(3), 949-973. https://doi.org/10.1007/s11165-022-10047-9

Surendeleg, G., Murwa1, V., Yun, H.-K., & Kim, Y. S. (2014). The role of gamification in education - A literature review. *Contemporary Engineering Sciences*, *7*(29), 1609-1616. http://dx.doi.org/10.12988/ces.2014.411217

Thoring, K., & Müller, R. M. (2011). Understanding the creative mechanisms of design thinking: An evolutionary approach. *Proceedings of the Second Conference on Creativity and Innovation in Design*, 137–147. https://doi.org/10.1145/2079216.2079236

White, J. (2021). The frugal life and why we should educate for it. *London Review of Education*, *19*(1), 1-12. https://doi.org/10.14324/LRE.19.1.13

Zwarthoed, D. (2015). Creating frugal citizens: The liberal egalitarian case for teaching frugality. *Theory and Research in Education*, *13*(3), 286-307. https://doi.org/10.1177/1477878515606620