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# DIGITAL PLAY FOR A SUSTAINABLE FUTURE: ENGAGING PRESCHOOLERS WITH BEACH LITTERING AWARENESS THROUGH MOBILE GAME INTERVENTION

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SUMMARY

Beach ecosystems are important to biodiversity, tourism and coastal livelihoods yet are also facing the growing threat of plastic pollution and marine litter. Although the world has been working towards ensuring sustainability, young children especially the preschoolers are a group that is not fully addressed in terms of environmental education. The research focuses on examining how gamified mobile learning can be effective in teaching preschoolers about the sustainability of the beach at Langkawi, Malaysia, a UNESCO Global Geopark that is going through serious beach littering challenges. The goal of the study is (i) to determine the level of knowledge that preschoolers had about beach littering, (ii) improve it using a mobile game intervention, and (iii) measure the effect of the interventions. A total of 115 six-year-old were randomly divided into control and experimental groups, and pre- and post-intervention data were measured by the means of guided questions. The experimental condition involved interaction with an application called Clean My Beach, which is a mobile game that simulates responsible clean-up behaviour on the beach. The post intervention results indicated that there was much greater awareness of the experimental group ($M = 4.67$) than the control group ($M = 1.58$) with a significant difference ($p < 0.001$). The paper also shows how digital resource, such as mobile game, can encourage early digital literacy, which forms the basis of future technological skills. The results confirm that age-based gamified technologies can be used to effectively teach early sustainability education that can provide a scalable and economically viable ways to inculcate pro-environmental ideals at a young age. The paper is connected with SDGs 4 (Quality Education), 6 (Clean Water and Sanitation), 8 (Decent Work and Economic Growth) and 14 (Life Below Water) and shows the importance of digital innovations, parental involvement, and early intervention in creating environmentally responsible future generations.

Key words: *preschool environmental education, gamified learning, mobile game intervention, beach littering awareness, marine sustainability, early childhood sustainability, SDG 14*

## INTRODUCTION

Plastic pollution remains one of the most important environmental threats to the global environment, and its effects on marine biodiversity, coastal ecosystems, and lives of people relying on ocean resources are evident [24]. Although mitigation programs usually concentrate on clean-up programs and enforcement of regulations, education especially at an early age is a long term and proactive measure to promote environmental responsibility. Nevertheless, there is still a major void in linking the organized educational activities to marine litter reduction, particularly those aimed at early childhood students [5].

The pre-schoolers are between four to six years of age and are in a cognitive and behavioural developmental stage. Studies indicate that children can be involved in littering in the beach at this age because of their unintentional actions like littering food wrappers or toys when it is out recreationally [23]. It may not be their major pollutants, but their behaviours also have the potential to affect the environment, and most importantly, it has the potential to become effective agents of change once it is put in the developmentally appropriate sustainability education. Nonetheless, the majority of the environmental awareness initiatives are still poorly designed to involve young children in meaningful and prolonged learning.

The research paper is narrowed down to six-year-old preschoolers in Langkawi, Malaysia, a UNESCO Global Geopark that is home to high levels of marine biodiversity and a tourist destination. Two of its beaches; Pantai Cenang and Pantai Pasir Hitam that are ranked as the top five most littered beaches in Malaysia during the 2022 International Coastal Clean-up Day have turned into a hot spot of coast pollution in Langkawi. Nationwide, more than 24,301 kg of waste was picked on 394 km of coastline, which highlights the necessity of specific solutions in the high-visibility tourist locations.


Figure 1. Breakdown of trash collected by location – highlighting langkawi beaches

The figure 1 displays five beaches in Malaysia that had the highest number of wastes retrieved in 2022. On Pantai Cenang, Langkawi (2,534 kg), followed by Pantai Teluk Cempedak (2,214 kg), the highest amount of trash was found. The Langkawi beaches contribute to the amount of waste, and Pantai Pasir Hitam, Pantai Klebang and Pantai Cherating also show a lot of waste that can be used to define high levels of coastal pollution.

There is growing need to understand how early learning interventions can be used to underpin sustainable behaviours as children living in the locality start to interact more with these contaminated beach environments. In the modern digital era where children are habitually introduced to mobile technology, the use of digital platforms to teach environmental education has a high potential. Mobile

games are now more about digital literacy and scientific knowledge, and making sustainability issues accessible and engaging in early education can be the remedy to the accessibility and engagement gap.

The paper will discuss how preschoolers can be made more aware of sustainability through mobile game-based learning. The intervention is based on a mobile game, which is named Clean My Beach, and has been selected because it is age-appropriate and environmental-oriented. The research exposes the constructivist theory of Piaget who views children as active learners who construct the knowledge through the use of practical experience and the theory of social learning of Bandura who emphasizes on the learning through observation and imitation. All these structures support the idea that young children learn best in an interactive and experiential context, and thus gamified mobile learning is a developmentally suitable and pedagogically feasible solution. Mobile games, created on the basis of these tenets, have been identified to increase the degree of engagement and increase the knowledge retention and adoption of pro-environmental behaviours [8].

Although there has been increased attention in game-based learning, little empirical research has investigated the effects of game-based learning in early childhood environmental learning especially in terms of beach conservation. Past research has been mainly done on the older students and a major research gap remains on the interaction of the preschoolers, particularly those in coastal areas such as Langkawi with sustainability content. This paper will fill this gap by discussing the effectiveness of gamified mobile learning in developing awareness of young children about the problem of littering beaches and encouraging responsible stewardship of the environment with direct implications to SDG 4 (Quality Education) and SDG 14 (Life Below Water).

Although marine pollution is gaining more and more interest in the global community, no specific educational interventions targeting the children of preschool age are created, and especially in the areas adjacent to the ocean like Langkawi. The current environmental education programs are majorly targeting the older pupils and neglecting the cognitive and behavioural aspects of the young learners. Consequently, a valuable chance of inculcating the pro-environmental values at a tender age is not fully utilised. This is an important gap that should be resolved, since early childhood is a critical period to mould long-term attitudes and behaviours on environmental sustainability.

**Research Questions**

This study is guided by the following research questions:

1. What is the baseline level of awareness of beach littering among preschoolers?
2. Does a mobile game-based intervention significantly improve preschoolers' knowledge and awareness of beach sustainability?
3. How does gamified learning influence children's engagement and understanding of environmental concepts?

**Research Objective**

This research will attempt to answer the following objectives:

- To determine the early concept of the preschoolers on the subject of beach littering and sustainability.
- To adopt a mobile game-based learning intervention based on Clean My Beach.
- To assess the success of the intervention in increasing environmental awareness of preschoolers.

The paper is divided into a number of sections. Section 2 will be a literature review on the applicability of beach littering and game-based learning in early childhood education. Section 3 offers a research methodology including research design, sampling and data analysis. The results and findings are discussed in section 4. Section 5 discusses implications and Section 6 provides the conclusion of the study with future research directions.

## LITERATURE REVIEW

Littering in beaches is a widespread environmental challenge that has extensive changes on the marine ecosystems, biodiversity, and beach economies. Plastic pollution has become the most apparent category of marine waste, as it has impacted beaches worldwide [17]. Langkawi Island is a tourist attraction site in Malaysia and is experiencing a major problem that concerns marine litter, which endangers the ecological stability and economic viability of the area [9]. Meanwhile, beach management activities in Langkawi, especially in tourist-intensive sites such as Cenang Beach, have been largely geared towards improving the international tourist experiences with local environmental values being pushed to the periphery. This is an indication that there is need to have more inclusive beach managements in order to balance between the satisfaction of the tourists and the ecological sustainability in the long run. According to research conducted by [16], recreational areas, restaurants, and residential areas around beaches in Langkawi were the locations with the highest levels of plastic debris. Littering by tourism (48%), poor waste disposal (35%), and fishing (17%) are the major contributors to this litter. These findings underline the importance of particular environmental education, in particular the coastal area.

Though children are not the main source of marine litter, the studies indicate that it can also unwillingly get involved in littering, then leaving behind toys or packaging waste in the activities of recreation [23]. Worryingly, the use of plastic toys that constitute about 90% of all toys in the world also contributes to the complexity since it is poorly recycled and may be toxic to the environment. These reasons emphasize the need to initiate early intervention to inculcate responsible attitudes towards waste and environmental responsibility.

Many studies highlight how the concepts of environmental sustainability and waste management can be presented at the preschool level through an interesting and developmentally relevant format [11] [15]. Preschoolers are not only able to comprehend environmental issues, but are also at a very critical period of development where it develops habits and values. Sustainability education in early childhood has been demonstrated to cause long-term pro-environmental behaviours and impacts intergenerational learning in families [22]. Children are also strongly influenced by their parents and nature to develop an environmental orientation [14]. Families are often involved in beach tourism in Langkawi and all the family members take an active part in the activities related to the beach. This confirms the possibility of environmental interventions on children also having a broader impact on behaviour, which is in line with the principle of intergenerational learning.

Sustainability education in the early childhood context, however, experiences a number of challenges with its implementation. The major challenges are the unstructured character of the preschool curriculum, insufficient environmental education of early childhood teachers, and inappropriate resource access [10] [20]. Moreover, although environmental programs in Malaysia have been directed at primary, secondary, and university students, little attention has been paid to preschool children [2].

Storytelling, walks in nature, recycling art projects, role-play have been used as traditional interventions in the area of early childhood sustainability education [15] [11]. As much as these methods are positive in developing fundamental environmental values, it is oftentimes dependent on teacher mediation, physical environment, and time-intensive preparation. Also, outdoor activities such as beach cleanups can hardly be offered to preschoolers because of the safety factors, including the possibility of sharp objects, powerful currents, or dangerous sea life [13] [6]. Table 1 gives a comparative profile of these traditional ways and the mobile game interventions in terms of their respective advantages and disadvantages in providing sustainability education to preschoolers.

Considering these shortcomings, digital education, especially mobile learning in form of games has become a viable option in delivering sustainability content to young children and in teaching sustainability of beaches. Indian and European studies show that mobile games are highly effective in enhancing the knowledge of preschoolers on the topic of beach littering and waste management [21] [18]. These platforms provide interactive and fun learning processes which are consistent with the cognitive growth and learning orientations of children. Actually, research about mobile game-based learning platforms, like Classcraft, has already proven their effectiveness in increasing motivation and

academic achievement among Generation Alpha learners who are extremely sensitive to gamifying digital experiences.

Table 1. Comparison of traditional and digital interventions for preschool sustainability education according to age

| Paper (Year) | Intervention Type | Strengths | Limitations | Age Suitability | Best for Beach Sustainability |
|---|---|---|---|---|---|
| [12] | Storytelling and Role Play | Enhances empathy, imagination, and holistic learning through multimodal storytelling | Requires skilled facilitation; may lack practical application | 3–6 years | Partially |
| [3] | Children's Theatre (Storytelling) | Engages children cognitively and emotionally with sustainability concepts via creative arts | Limited to specific contexts; scalability may be challenging | 4–6 years | Partially |
| [1] | Interactive Storytelling with Big Books | Promotes socio-emotional learning, empathy, and problem-solving skills | May not directly address sustainability topics | 4–6 years | No |
| [3] | Nature Walks and Cleanups | Provides real-world connection to nature, fostering environmental awareness | Safety concerns; logistical constraints; requires supervision | 5–6 years (with supervision) | Partially |
| [19] | Mobile Games | Interactive, scalable, enhances agency and digital education; aligns with modern learning trends | Screen time concerns; requires device access | 4–6 years | Yes (best fit) |

Games like Clean My Beach use reward system, real world situation and simplified navigation enabling children to make meaningful environmental decisions. In addition, mobile games develop a feeling of agency among young children. The assumption that it can change the world by acting is reinforced by putting them in simulated environments whereby it is in charge of resolving issues. Digital interventions can also be scaled to a high level, are low-cost, and can be modified to different educational environments and thus are applicable to a wide range of sustainability education [7].

Nevertheless, even with the obvious benefits of mobile game-based learning (MGBL), the integration of mobile games into early childhood education is still not entirely welcomed by many educators-in particular, in Malaysia-as the perception of games as purely recreational activities still persists. Also, even though early childhood educators have shown a high score in technological readiness and positive attitude to digital teaching [25], the lack of exposure, training, or institutional support may continue to prevent the practical implementation of MDBL in the preschool curriculum. These biases need to be overcome to make MGBL be as good as it can be in education.

However, as educational technology is increasingly becoming popular in early learning settings, a significant proportion of research on game-based interventions to sustainability in learning is directed towards older learners. The understanding of how children in preschool age- especially those in an environmentally sensitive environment like Langkawi- use digital tools in marine conservation is lacking critically.

The proposed study seeks to fill that gap by examining the effect of a mobile game on the knowledge and awareness of six-year-old children about beach littering, and ends up as part of the wider project of introducing computer-mediated sustainability learning to preschool education.

## METHODOLOGY

The section provides the research methodology that will be used to explore the effectiveness of a mobile-based game-based intervention to improve the knowledge and awareness of preschoolers when it comes to the topic of beach sustainability. The methodology is a clear description of the design of the study, sampling, research setting, data collection tools, and data analysis. Through a systematic quantitative design, the research assesses the change in environmental awareness in preschool children pre-exposure and post-exposure to a chosen mobile educational game in a systematic manner. The research design provides a framework that guarantees validity, ethical integrity, and the suitability of the study to the goals of the research, and provides a holistic basis on which the pedagogical potential of digital tools in early childhood sustainability education can be evaluated.

### Research Design

The research design is quantitative because the study aims at assessing the efficacy of a mobile game-based intervention in improving the knowledge and awareness of the sustainability of the beach among preschoolers. The study happened in several stages, which started with the review of the available literature and the presence of the existing digital tools, then the selection of the appropriate educational mobile game, and the creation of the required tools to measure the effects of the intervention. The research was aimed at three main purposes: to determine the initial knowledge and awareness of the preschoolers about the problem of beach littering, to advance their environmental awareness with the help of a mobile game, and to determine whether the intervention can be effective to improve the sustainability awareness.

### Research Framework

The research framework gave the research process structure to follow and make sure that it is aligned with the objectives of the study. It involved five primary stages such as preparation, pre-intervention, intervention, post-intervention, and evaluation.

The framework commenced with the preparatory stage that included carrying out a literature review, selecting suitable game-based learning tools, and site visits to the beaches in Langkawi to get an understanding of actual trash profiles. This was preceded by the pre-intervention phase, which involved evaluating the level of awareness of children by administration of guided questionnaires and a colouring sheet. The intervention period entailed playing games with a chosen mobile game. The same assessment tools were applied in the post-intervention phase to define whether there were changes in the awareness. Lastly, the evaluation component involved comparison of the pre-intervention and post-intervention data to establish the success of the mobile game-based intervention in increasing sustainability awareness. The order of these steps is represented graphically in figure 3.

The conceptual framework of the study is presented in figure 2 which displays the interconnection between the mobile game intervention (Clean My Beach) and environmental awareness of preschoolers. It outlines some of the key procedures, including baseline assessment (pre-test), gameplay intervention or post-test analysis. The framework will demonstrate the impacts of gamified learning in regard to knowledge, engagement and behavior which eventually leads to the heightening of awareness of the young children regarding the problem of beach littering and sustainability.

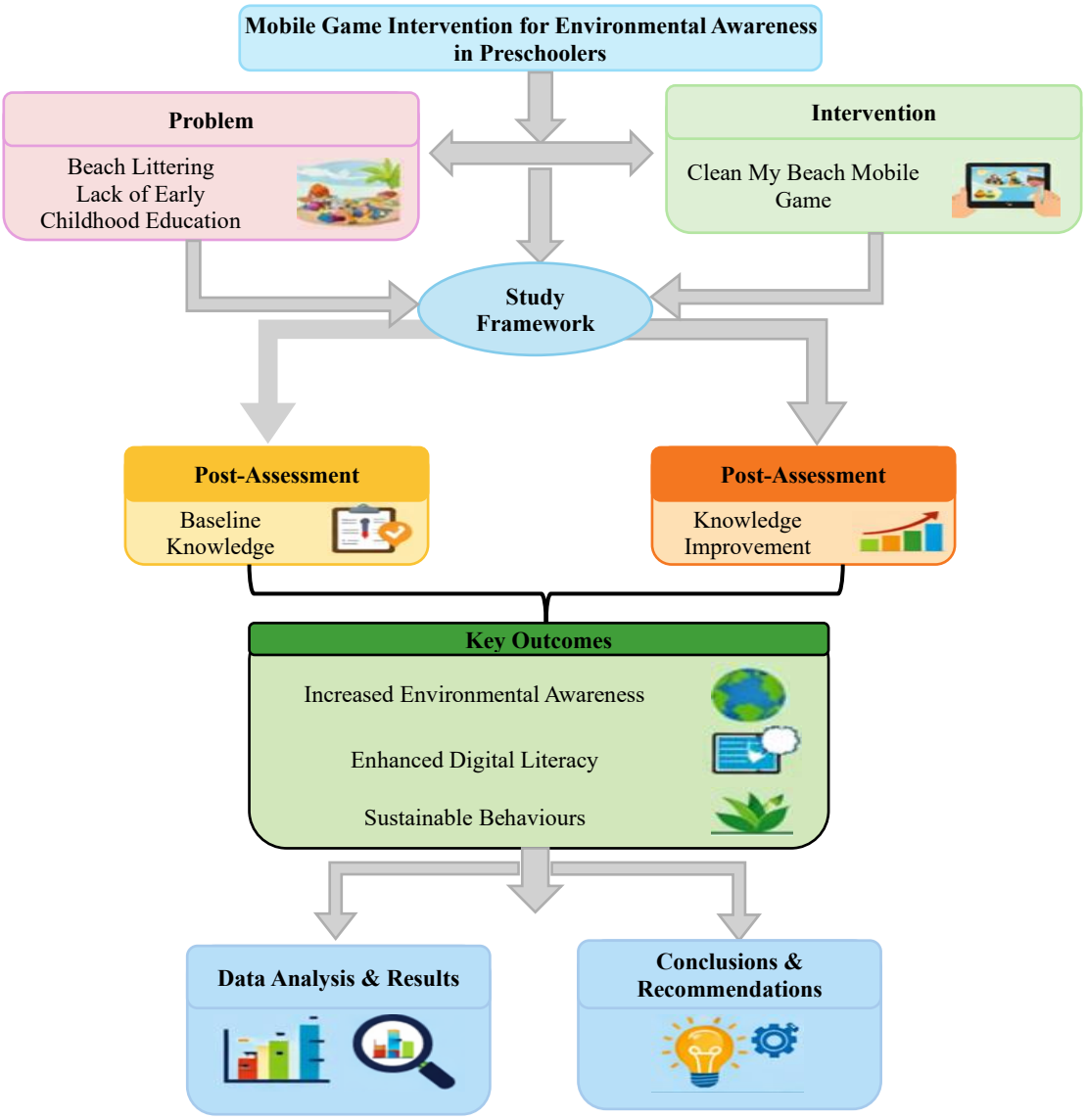


Figure 2. Conceptual framework of mobile game-based intervention for preschool environmental awareness

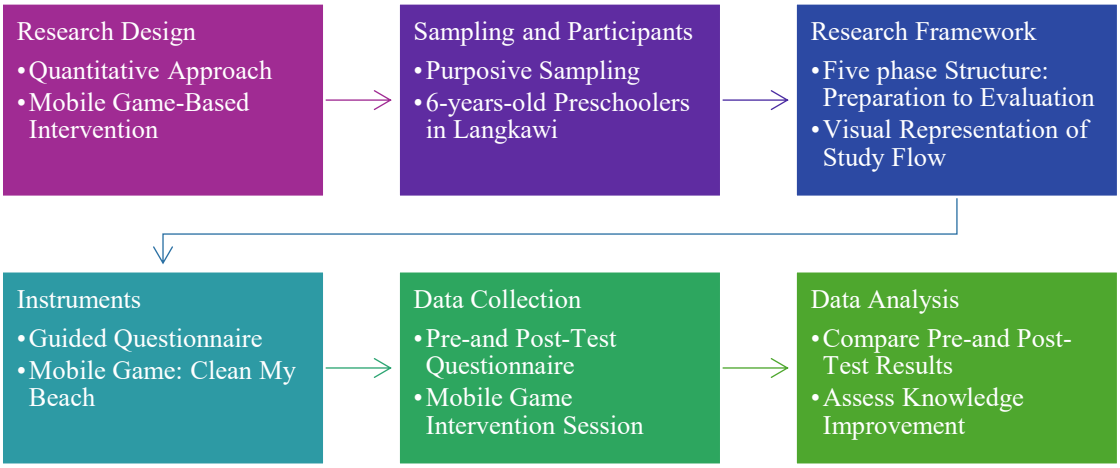


Figure 3. Research framework outlining the phased process of the study, including preparation, pre-intervention assessment, mobile game implementation, post-intervention assessment, and data evaluation to determine the effectiveness of game-based sustainability education for preschoolers

**Sampling and Participants**

The study focused on six-year-old preschoolers in Langkawi, Malaysia. The official data collected at the Langkawi District Education Office indicates that 1,542 preschool children were enrolled in the island at the moment the study was conducted. The final sample size was 115 preschoolers chosen with the help of stratified sampling in order to balance the number of males and females and the type of school. The low number of samples was due to several reasons, such as non-responses by schools, parental consent, absenteeism, and the elimination of children with learning disabilities like autism or Attention-Deficit/Hyperactivity Disorder (ADHD) to maintain consistent methodology.

The research followed the ethical guidelines of a study. Parents were informed through the informed consent forms or Google Forms after it had been briefed on the nature, objectives, and procedures of the research. The anonymity of the participants was kept confidential by making sure that no personally identifiable information was obtained. The research was intended to be non-invasive, and only the activities that were child friendly like playing an educational game and filling in basic awareness tests were involved. During the sessions, close attention was paid to the health and emotional state of the children, and it were not punished by leaving the study at any time. Researchers and teachers worked together to create a safe, inclusive, and non-coercive overall environment. These were ethical precautions that were taken to make sure that the research was carried out in the most ethical and keeping the best interest of the participants.

**Instruments**

There were 3 primary tools used in the research. The former was the mobile game Clean My Beach that was created by Kayfo Game (https://kayfo.games/gamecleanmybeachanchor) that was chosen due to its topicality, easiness, and appropriateness to the preschool age range. The game was selected after comparing it with another game, Clean the Beach. Clean My Beach was chosen due to its age-specific and focused learning environment and the lack of distracting factors. Its mechanics were to gather trash and receive a reward, such as cowrie shells and restoration of marine life, which promotes pro-environmental behaviour in an entertaining and interesting manner. It also had to be user-friendly to early learners based on visual elements and simple interactions as opposed to intricate stories and reading ability.

The second tool was a guided questionnaire which aimed at evaluating the awareness of the preschoolers on the issue of beach littering and sustainability. Using structured prompts this questionnaire enabled children to share their thoughts and allowed researchers to develop developmentally relevant conversations. This approach was also successful, as it allowed children to express their environmental knowledge through the words and sentences that could be comprehensible based on their cognitive and linguistic levels [4].

The third tool was a colouring sheet activity, which was employed to facilitate the questionnaire in eliciting the views of the children. That visual tool was very useful especially to children who could have understood it better through visuals as compared to language. Pre-and post-assessment were conducted with the help of both the questionnaire and colouring sheet to record the change in awareness.

**Data Collection Procedures**

The process of data collection was initiated by the preliminary analysis of the previous studies and literature connected with the topic of game-based learning and sustainability education among young children. This step included the process of determining applicable sources, analysing results, and deriving major concepts that assisted in the development of the research objectives, questions, and scope.

During the pre-intervention, the experimental and the control group were asked to answer a guided questionnaire and a colouring sheet. This test was used to determine the baseline of the participants in terms of knowledge and awareness of beach littering. This was followed by the intervention stage where only the experimental group played the mobile game Clean My Beach in a classroom environment. The

playing session took about 10 minutes in which the children were given the chance to navigate through the game on their own without any form of direct guidance allowing the researchers to monitor how it interacts with the material naturally.

After the session of the gameplay, the post-intervention phase was to give the same questionnaire and colouring paper to both groups. That was why responses could be compared directly and any advancements in knowledge or changes in awareness caused by the game experience could be determined. The researchers made sure that the environment was supportive and consistent throughout the phases to reduce the possible outside effects.

**Data Analysis**

The data obtained were analysed with the help of the IBM SPSS statistics software. Independent Samples T-test was used to compare the pre-intervention and post-intervention outcome in the control and experimental groups. Such statistical technique helped the researchers to establish whether there was a significant difference in the level of knowledge and awareness of children who were introduced to the mobile game and those who were not introduced to the game. The outcome of the analysis was the determination of quantifiable changes in knowledge of the children about littering of the beach and its sustainability, thus, assessing the efficiency of the game-based intervention in meeting the study educational aims.

RESULTS

This segment will provide the results of the mobile game-based intervention carried out with preschoolers in Langkawi to determine what it know and are aware about beach littering. The findings have been obtained based on quantitative data that was gathered using pre- and post-questionnaires and analysed using IBM SPSS Statistics. The insights of observations that were made during the intervention are also included in the section.

The mobile game Clean My Beach that was created by Kayfo Games served as the main software in this research. It is interactive and child friendly and designed to be used by early learners and can be used in normal Android mobile devices. The game is simple to use with its simple touch controls, colorful graphics and easy navigation without the need to read or write. Game simulations of beach-cleaning also take place, where it locates and collect different litter and receive instant visual and reward-based feedback (e.g. points, restoring marine life). The fundamental gamification elements that are incorporated into the game to increase engagement and learning are levels, rewards, and reinforcing mechanisms. Its design suits the early childhood cognitive ability which enables experiential learning, decision-making, and awareness of the environment within a secure and virtual environment.

The last dataset was comprised of 115 preschool children, who were separated into two groups: experimental (n = 58) and control (n = 57). The sample was chosen through stratified sampling technique in order to have equal representation of both genders and schools (public and private preschools). First, a list of all six-year-old children that were eligible was acquired at the participating schools. Out of this pool, simple random allocation was used to proportionately select across strata and finally allocate children to either control or experimental group to reduce selection bias. The experimental group was playing the mobile game intervention (Clean My Beach) and the control group playing the regular classroom activities and did not play the game. This stratification gave comparability of the two groups at baseline and one could make a sound determination of the effect of the intervention.

**Results Analysis Framework**

In figure 4 shows the results analysis scheme, which includes the data entry process, statistical tests, results interpretation, and the results evaluation. Pre- and post-test responses were entered into IBM SPSS and checked for completeness and accuracy. The differences between the experimental and control groups were evaluated with an Independent Samples T-test in order to establish the significance of the differences. A comparison was done in the mean scores with a p value of less than 0.05. The research

established the significance of the mobile game intervention on the knowledge and awareness of the children on the sustainability of the beach.

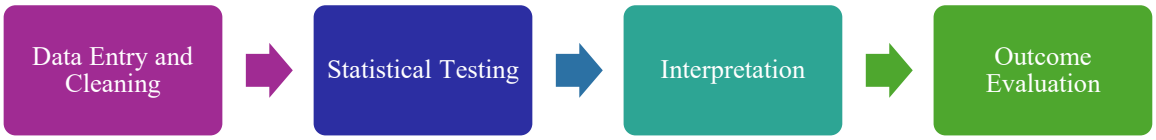


Figure 4. Results analysis framework outlining the mobile game-based intervention on preschoolers' sustainability awareness

Pre- and post-test responses of the control and experimental groups were inputted into the IBM SPSS Statistics software in the initial phase of data entry and cleaning. The dataset was filtered to ensure that it was complete and that it did not have any missing values or inconsistency. This is then succeeded by the statistical testing phase; an Independent Samples T-test was carried out to compare the means of the scores of the control and experimental groups. This test identified the existence of a statistically significant difference in the pre-intervention and post-intervention awareness. The results in the third stage of interpretation involved the interpretation of results through the comparison of the mean differences in the pre- and post-test scores. A p-value of less than 0.05 was used to assess the statistical significance. Lastly in the outcome evaluation phase, the results were employed to establish whether the mobile game intervention helped in a quantifiable achievement in sustainability awareness. The success of the intervention was validated by the fact that there were significant gains in the experimental group as compared to the control group.

**Pre- and Post-Test Comparison**

Table 2. Comparison of pre- and post-test scores between control and experimental groups

| Group | Test Phase | Mean (M) | Standard Deviation (SD) | p-value |
|---|---|---|---|---|
| Control Group | Pre-Test | 1.55 | 0.69 | 0.676 |
| Experimental Group | Pre-Test | 1.58 | 0.72 | 0.676 |
| Control Group | Post-Test | 1.58 | 0.73 | < 0.001 |
| Experimental Group | Post-Test | 4.67 | 0.83 | < 0.001 |

According to table 2 and figure 5, the pre-test results indicated that the levels of baseline awareness regarding the issue of beach littering were similar in both the control and experimental group. The experimental group scored M =1.58 (SD=0.72) with a p-value of 0.676, which is not significantly different than the control group with M= 1.55(SD=0.69). On the contrary, post-test results showed that the knowledge of the experimental group improved significantly. The experimental condition recorded a mean of M = 4.67 (SD =0.83) which was significantly higher than the control condition which was at M =1.58 (SD=0.73). Independent Samples T-test verified that this difference was statistically significant with the $p < 0.001$. These findings support the claim that the mobile game intervention is effective in enhancing the sustainability awareness of preschoolers.

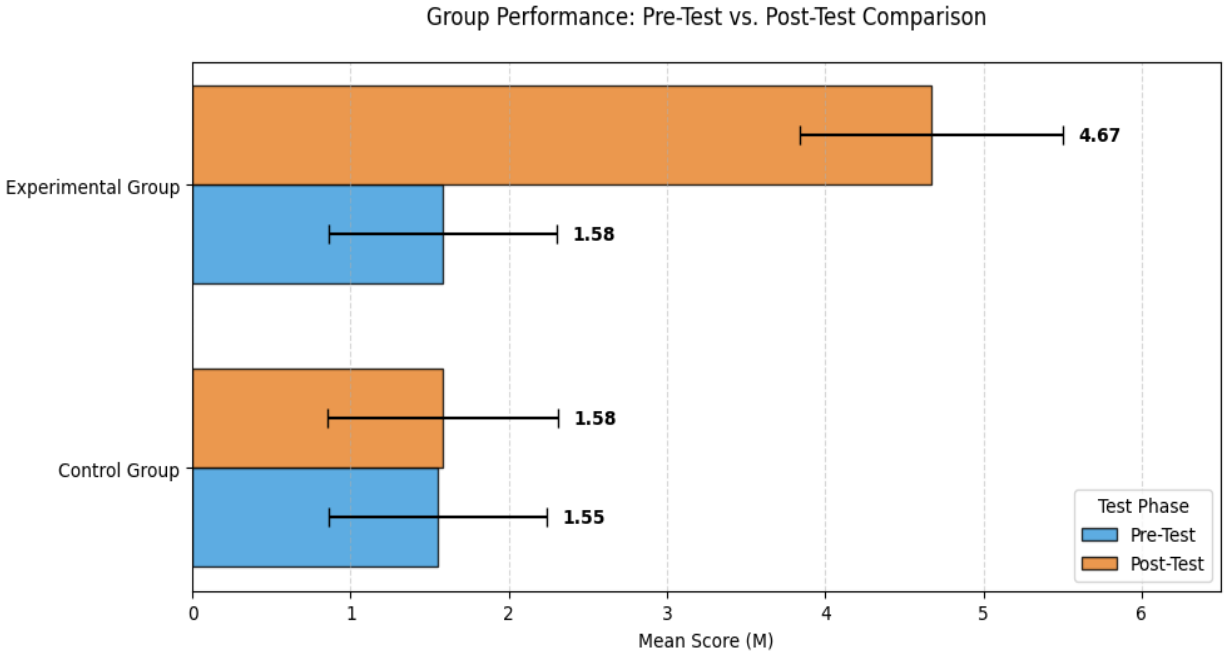


Figure 5. Comparison of pre- and post-test mean scores between groups

**Observational Insights**

Children in the experimental group were found to be highly engaged and enthusiastic during the gameplay session. It is observed that many of them were commenting on the kind of trash in the game and correlating it to what it had seen at the beach or in their homes. Others even imitated the behaviours like sorting garbage or recognizing marine animals. These behaviours are indicative of the major areas of the social learning theory proposed by Bandura in which children imitate behaviours that it observes in interactive settings. Figure 6 demonstrates a screen shot of the mobile game Clean My Beach that offered a bright, user-friendly interface comprising of realistic trash components and feedback in the form of rewards. This design assisted in active learning in terms of visual stimulus and repetition of environmentally responsible behaviours.

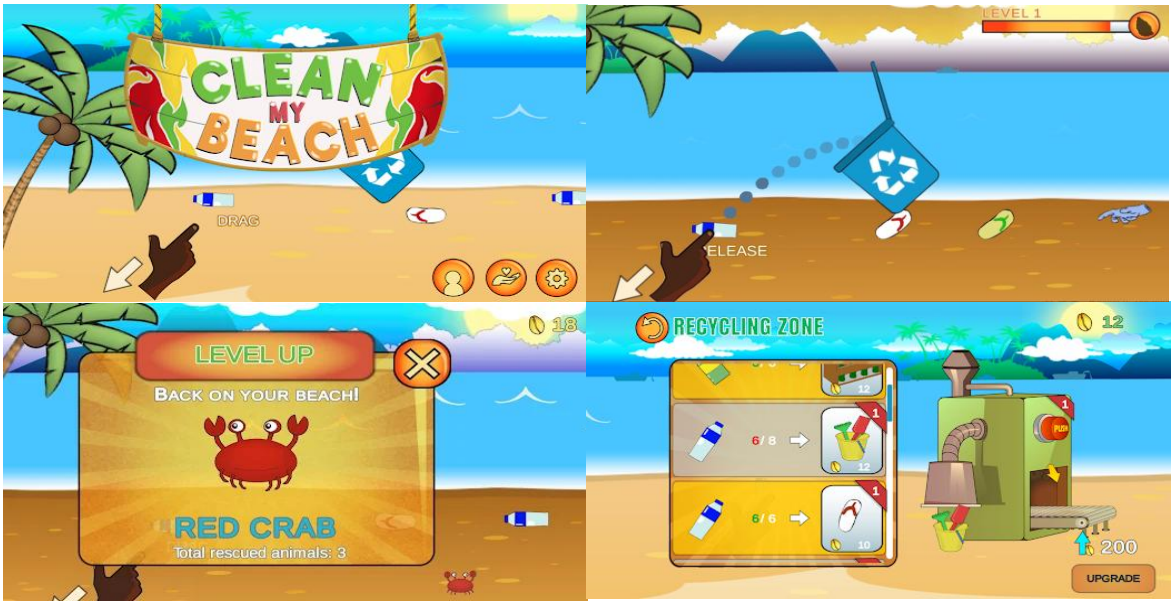


Figure 6: Screenshot of clean my beach showing interactive gameplay for trash sorting and marine conservation. source:(https://play.google.com/store/apps/details?id=games.kayfo.cleanmybeach&hl=en)

It also created spontaneous peer discussion that occurred as the game some preschoolers assisted others in naming the types of trash or showing them how to navigate the game. This form of group work can be related to the constructivist perspective of learning as proposed by Piaget, when children gain knowledge by participating in social bargaining and practical experience. As summarized in figure 7, some of the common behaviours were verbalizations of environmental actions (Put the bottle in the bin), imitation of game animation, and spontaneous peer directives. These qualitative measurements support the calculated rise in the environmental knowledge in the post-test outcomes.

Figure 7: Behavioural observation matrix summarizing verbal, visual, and peer-interactive behaviours during gameplay in the experimental group

## DISCUSSION

The results of the current research are quite convincing that the use of digital game-based learning can contribute to the development of sustainability awareness in preschoolers in a significant way. The statistically significant difference between post-test scores of the experimental and control groups confirms the hypothesis that mobile games may be a good educational intervention when developed with age-related content and based on cognitive development theories.

Based on the constructivist theory developed by Piaget, the improvements that are observed in the experimental group are a result of the capacity of children to actively build knowledge by interacting and exploring. In the same way, the social learning theory developed by Bandura is also confirmed by the behaviours observed in the gameplay, as children reproduced the environmental behaviours of the game like sorting and discarding the trash in the right way. These learning outcomes were not just reflected in better test scores, but also reflected in verbalizations and behavioural cues that were recorded in the gameplay sessions.

The present research indicates that gamified learning can help to fill the gaps in the early childhood environmental education, particularly in underserved communities. The Clean My Beach mobile game provided a simulated real environment that allowed children to relate in-game activities with real-life problems. Contextual relevance was achieved by the use of common litter objects based on visits to the beaches in Langkawi. This is in line with the earlier studies that indicated that experiential and relevant content enhances engagement and retention among the young learners.

Notably, the study fills a literature gap since no research has concentrated on preschoolers, who are usually left out in structured environmental education. Though the previous research has focused on the use of digital learning in older learners, this paper demonstrates that well-designed mobile interventions can have an equal effect on younger learners. The adoption of a non-invasive, entertaining, and interactive format led to the high rates of engagement and enabled children to internalize the sustainability ideas in a significant manner.

The implications of the findings on an educator and policymaker are also practical. As more and more people in the city and the countryside get access to mobile devices, introducing digital games into

preschool education might prove an efficient and affordable way of increasing environmental awareness. Because this study was conducted in Langkawi, where pollution caused by tourism is acute, its results demonstrate the significance of localized, digitally mediated educational interventions in the resolution of ecological issues in the real world.

However, limitations exist. It was based on short-term tests and the retention of knowledge and behaviour changes in the long-term is a subject of future research. Moreover, although this paper investigated only one game, a comparison between different types of games and mechanics can have additional information on what characteristics are most efficient to encourage sustainability learning in young children.

The efficiency of Clean My Beach game might also be justified by the analysis of the correlation of its key mechanics with sustainability learning outcomes. The game also involves the interactive elements of finding trash, sorting, and earning rewards, which directly simulate the pro-environmental behaviours in the actual world. These mechanics reinforce cause and effect dynamics which enable children to make comparisons between these activities like proper disposal of waste and good environmental outcomes, like cleaner beaches and recovered marine life. This correspondence is useful in practical training and strong theoretical understanding of sustainability during the initial years. As well, the informal feedback taken with the parents and teachers revealed that there were children who were more conscious outside the classroom, such as observing litter around them and being concerned about the environment cleanliness. These observations suggest that the impacts of the game can be applied to the real-life behaviour that suggests its capability to exert the influence not only on cognitive learning but also on the attitudes towards the real-life environment via the means of early intervention and reinforcement at the family level.

## CONCLUSION AND FUTURE WORK

The presented research depicts that the interventions that are grounded in applying mobile games could significantly influence the formation of environmental awareness among preschoolers. The findings revealed that the difference between the control group and experimental group in the pre-test condition (Control: $M = 1.55$, $SD = 0.69$; Experimental: $M = 1.58$, $SD = 0.72$; $p = 0.676$) were not significant that was a baseline equivalence. Nevertheless, awareness changed significantly in the experimental group ($M = 4.67$, $SD = 0.83$) as opposed to the control group ($M = 1.58$, $SD = 0.73$), and the difference was statistically significant ($p < 0.001$). These results are highly empirical and it indicates that the Clean My Beach mobile game was successful in increasing the knowledge of the preschoolers on the concept of beach littering and sustainability. The study also confirms the assertion that the application of gamified learning along with the preexisting theories of education such as Piaget constructivism and the social learning theory by Bandura causes improved cognitive and behavioural learning results. With children playing the game, there was an improved knowledge regarding litter type, environmental responsibility, and peer-assisted learning behaviours. Such findings can be interpreted as an indication that the abstract sustainability concepts can be successfully converted into the meaningful and age-related learning experiences and with the assistance of the interactive digital tools. Applied-wise, the study presents the possibility of introducing mobile game-based learning in early childhood education to promote environmental literacy and the acquisition of digital skills. The correspondence to the Sustainable Development Goals and SDG 4 and SDG 14 in particular justifies the overall applicability of such interventions in ensuring the encouragement of sustainable behaviours at an early age. The main areas of future research ought to be long-term studies on how knowledge and behavioural change is retained in children. In addition, the comparative analyses of the different game designs, the new technologies such as an augmented or virtual reality, and the integration of parental and teacher feedback would provide a more global view of the real-world impact of such interventions.

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