Empowering the Next Generation: Using Minecraft Education to Teach Solar Photovoltaic Concepts in Secondary School

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***Abstract*—In the realm of science education, particularly in renewable energy, innovative and engaging teaching methods are crucial. Acknowledging the growing significance of renewable energy sources, this study investigates the effectiveness of Minecraft Education as a platform for teaching solar photovoltaic (PV) concepts to forty secondary school students in Penang, Malaysia. A mixed-methods research design was employed by combining quantitative data from pre-tests, post-tests, and delayed post-tests with qualitative data from focus group discussions. The findings revealed that Minecraft Education significantly enhances and retains students' knowledge of solar PV technology. Notably, it emerged as an effective pedagogical tool that renders complex scientific principles more accessible and engaging. This underscores the potential of digital game-based learning environments to improve students' conceptual understanding, promote active participation, and foster critical thinking. Furthermore, the findings suggest that such innovative educational approaches can effectively prepare students for future challenges in renewable energy and environmental sustainability by equipping them with essential knowledge and skills for a rapidly evolving technological landscape. This study contributes to the broader educational strategy discourse by advocating for the integration of digital tools in science education to improve learning outcomes and student engagement.**

***Keywords*—Solar Photovoltaic (PV) technology, secondary school education, Minecraft Education, digital game-based learning**

I. Introduction

Digital game-based learning is a pedagogical approach that integrates game elements into the learning process to enhance students' knowledge and interest [1]. Utilizing Minecraft Education as a platform for digital game-based learning presents a unique and effective method for teaching solar photovoltaic (PV) concepts in secondary schools, thus enhancing student engagement, understanding, and retention of complex scientific principles. The allure of Minecraft stems from its ability to emulate real-life scenarios within a safe and controlled environment, allowing students to grasp concepts, make observations, conduct experiments, and gain a unique and interactive learning experience.

Studies by Cohen *et al*. [2] and Spangenberger *et al*. [3] indicate that learning approaches incorporating elements of digital games can stimulate students' knowledge about the use of renewable energy technologies. Engaging in these games allows students to experience positive interactions and actively participate in tasks related to renewable energy technology. Through digital games, students can interact and 'play' with solar PV technology virtually, eliminating the need for expensive and complex equipment. This approach helps students understand the principles of solar PV technology through simulation and interaction, as seen in games that might include elements like adjusting the angle of solar panels to maximize sunlight absorption. Such engagement not only enhances technical knowledge but also hones practical skills in problem-solving and critical thinking.

Furthermore, research by Kaczmarczyk and Urych [4], supported by findings from Keramitsoglou [5], Edsand and Broich [6], Revák *et al*. [7], and Muslim *et al*. [8], revealed that high school students are aware of the importance of environmental conservation but lack knowledge about the use of renewable energy technologies. This knowledge gap is characterized by limited awareness and misconceptions about technology utilization, particularly solar PV technology, which can impede its acceptance and future usage. The urgent need to bridge such knowledge gap underscores the potential of integrating this vital topic into mainstream science learning through engaging platforms like Minecraft, which merges the interactive experience of digital gaming with the complex and abstract principles of solar PV technology. Introducing students to the intricacies of solar PV through a familiar digital platform makes the learning process not only more accessible but also more engaging.

This investigation focuses on assessing the effectiveness of the Minecraft Education platform in enhancing and retaining students' knowledge about solar PV technology. Motivated by the pressing need to find innovative instructional tools that facilitate a deeper understanding of sustainable technologies among students, the study is driven by two principal inquiries. The first seeks to determine the extent to which the Minecraft Education platform serves as an effective instructional medium for enhancing and retaining students' knowledge related to the application of solar PV technology. The second inquiry delves into students' perceptions regarding the integration of the Minecraft Education platform into their learning process, specifically focusing on its influence on their comprehension of solar PV technology. The research aims to provide a comprehensive understanding of the potential role of digital game-based learning environments in environmental education.

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II. Literature Review

A. Digital Game-Based Learning

Digital game-based learning stands at the forefront of e-learning innovation, deeply rooted in the theories and perspectives of Marc Prensky. While Prensky [9] did not explicitly define digital game-based learning, he characterized it as employing computer games within educational settings to achieve desired learning outcomes. He suggests that digital game-based learning relies on two key principles: first, today's learners have evolved cognitive patterns due to their inherent proficiency with digital media; and second, their extensive exposure to sophisticated computer and video games from a young age not only shapes their skills but also opens up vast learning opportunities throughout childhood and adulthood.

There is a broad consensus among researchers on the use of digital games in bolstering student learning. A primary benefit highlighted is the significant boost in learning motivation [1, 10], with digital games sometimes drawing interest to subjects that students previously overlooked [11]. Additionally, digital games can lead to students spending more time on subjects compared to traditional educational methods [12], encouraging them to invest greater effort into learning.

Moreover, digital game-based learning has the potential to improve academic achievements by providing an engaging, enjoyable learning experience. It challenges students, fosters participation, and enhances motivation toward the curriculum presented by teachers [11]. However, for digital game-based learning to fully realize its potential, its implementation must be meticulously designed and aligned with educational objectives to ensure that it complements and enhances the learning process effectively.

B. Digital Gaming: Minecraft

Minecraft is a widely celebrated digital sandbox game that boasts over 100 million downloads globally. This game introduces players to a 3D block universe, offering unparalleled freedom to explore and construct their own worlds [13]. Within this 'open world,' individuals can venture without constraints, making Minecraft an expansive, limitless digital game. Players engage with various cubic stones or blocks—each featuring six square faces—to collect, break, reconstruct, remove, and place 3D block-shaped objects at will in this virtual landscape. Such interactions foster creativity and enable players to design structures limited only by their imagination, which serves as a potent catalyst for a multitude of learning projects.

The versatile nature of Minecraft has been leveraged as an educational tool across various subjects worldwide, including English language [14], Mathematics [13, 15], and Science [16, 17]. This underscores its capability to captivate and educate students in a diverse array of academic disciplines, thus demonstrating its significant impact on contemporary education.

C. Learning Theories Associated with Minecraft Education

The theoretical foundation of this research is anchored on Vygotsky's [18] concept of learning through play, which posits learning as a social activity and identifies play as a vital source of developmental growth. Constructivism, though defined differently by scholars, fundamentally describes the process through which students build their own knowledge both independently and through collaborative efforts [19]. Contrary to the notion that constructivism primarily concerns teaching methods, Brooks *et al.* [20] argue that it is more accurately a theory about knowledge and learning. Jenkins [21] further emphasizes constructivism as an educational approach that prioritizes students' active engagement in their learning process. These perspectives collectively underscore that constructivism advocates for an active, collaborative learning process whereby students construct meaning together.

This discourse naturally extends to social constructivism, which emphasizes a student-centered learning environment that is conducive for collaboration and shared knowledge construction. Such an environment, as advocated by social constructivism, promotes a collaborative atmosphere where students inspire and learn from each other through interaction. Engaging with peers or mentors allows students to refine their understanding, aligning with the view that knowledge construction is a communal process. Hetherington *et al.* [22] suggest that constructivism revolutionizes traditional teaching and learning paradigms, encouraging students to build upon their prior knowledge and experiences to forge new understandings. This process of adjusting and manipulating existing knowledge enables the creation of new insights within the learner's mind and embodies the essence of constructivist learning.

Furthermore, profound learning often stems from active engagement with both the physical and social environments [23], allowing students to generate their own knowledge rather than merely absorbing information. The constructivist theory thus champions a student-centered approach where learning occurs through hands-on activities and meaningful engagement. This approach not only keeps students actively involved but also fosters the discovery of new knowledge, hence demonstrating the transformative power of constructivism in educational contexts.

D. Learning Solar PV Concepts through Minecraft Education

The integration of Minecraft Education into teaching solar PV concepts exemplifies the principles of constructivist learning theories, which advocate experiential, hands-on learning environments for active knowledge construction [17]. This pedagogical approach is especially relevant for intricate scientific topics like solar PV where interactive and contextual learning experiences can substantially enhance conceptual understanding [24].

Minecraft's virtual environment offers students a distinctive chance to visualize and engage with solar PV systems directly [25]. By constructing and manipulating these systems within the game, learners will acquire a practical understanding of how solar PV technology operates, the factors influencing its efficiency, and its applications in the real world. The hands-on, exploratory method promotes a deeper comprehension of solar PV concepts, encouraging learners to move beyond mere theoretical knowledge toward a holistic understanding of the subject [26].

Minecraft's potential to enrich understanding and conceptual knowledge of solar PV lies in its facilitation of hands-on activities using 3D blocks within the game's virtual world, especially during simulations that demonstrate photovoltaic effects. In Minecraft, students can arrange 3D blocks to simulate structures or objects that mimic PV cells, making the photovoltaic effects more accessible and understandable. For example, the simulation in Fig. 1 shows that a PV cell does not power a *redstone* lamp at night due to the lack of sunlight, illustrating that without sunlight, electrons remain static and no electric current is generated. Fig. 2 demonstrates that the PV cell produces minimal electric current under low sunlight conditions. Conversely, in Fig. 3, the PV cell 'excites' electrons when exposed to full sunlight, resulting in their movement and the generation of an electric current sufficient to light a *redstone* lamp during the day. These interactive simulations provide a clear, tangible understanding of the photovoltaic effect, thereby enhancing students' grasp of solar PV concepts.

Fig. 1. The PV cell does not conduct electric current due to the absence of sunlight.

Fig. 2. The PV cell conducts minimal electric current due to insufficient sunlight.

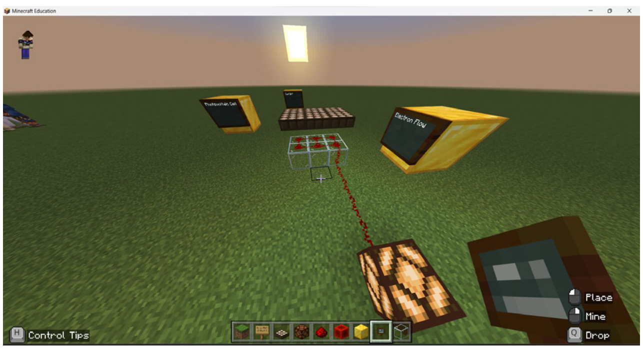

Fig. 3. The PV cell successfully powers the *redstone* lamp in the presence of sunlight.

E. Challenges and Opportunities of using Minecraft Education in the Educational Context.

The appeal of the Minecraft teaching platform transcends traditional gaming stereotypes, which attract a broad spectrum of students with varying academic abilities and interests. As noted by Wilson and Rennie [14], Minecraft's appeal is not confined to a specific type of student, thus highlighting its universal allure. This observation is further supported by Sarıçam and Yıldırım [16] who emphasize the game's ability to engage learners across different academic spectrums. Minecraft serves as a unifying platform that offers a welcoming environment for even the most reserved students and effectively combines social interaction with technological engagement through its online multiplayer capabilities. Contrary to skepticism about video games in education, empirical evidence consistently praises Minecraft for fostering collaboration, and enhancing essential digital skills [17] while teaching students to navigate online spaces responsibly.

However, integrating Minecraft into educational settings presents its own set of challenges. Technological limitations, especially in schools located in economically disadvantaged areas, pose significant barriers for adopting this digital tool. This can potentially sideline these institutions from the digital education movement. Even though Minecraft's technical requirements are relatively low, the necessary infrastructural investment may be out of reach for some schools [27]. Additionally, the time commitment required for educators to familiarize themselves with the game and its educational applications is non-trivial. For those new to gaming, mastering Minecraft's intricate world can seem overwhelming [28, 29]. Resistance to new teaching methods is a common hurdle in education and reluctance to embrace a game-based pedagogy can hinder the effective use of Minecraft, leading to inefficient use of both time and resources.

III. Methodology

A. Research Design

The research design of this study employed a mixed-methods approach, integrating both quantitative and qualitative methodologies to comprehensively assess the effectiveness of the Minecraft Education platform in teaching solar PV technology. Quantitative data were collected using a pre-experimental design, specifically a one-group pre-test-post-test model [30], to measure changes in students' knowledge of solar PV technology before and after the intervention. Although the inclusion of a control group is deemed optimal for educational research [31], logistical constraints such as limited time, available teachers, and the challenge of forming a comparable control group necessitated a focus solely on an intervention group.

This study was conducted outside regular school hours during co-curricular activities, with the participants being students already enrolled in the study group. The absence of a control group is not expected to detract from the validity of the findings as the study's aim was not to compare the intervention to traditional teaching methods but to assess its standalone impact [32]. The structure of the research design is detailed in Table 1, which outlines the sequence of pre-test, intervention, post-test, and delayed post-test to evaluate both immediate and retained knowledge impacts.

Table 1. Pre-experimental design: One-group pre-test and post-test evaluation

Group	Pre-test	Intervention	Post-test	Delayed Post-test
Group R_1	O_1	X	O_2	O_3

The dependent variable (O_1), which was students' knowledge on the utilization of solar PV technology, was measured in the pre-test. Subsequently, Group R_1 underwent an intervention (X) using the Minecraft Education platform for eight weeks. After the intervention, the same dependent variable (O_2) was measured in the post-test followed by a calculation of the difference between the pre-test and post-test scores (O_1–O_2) to determine the effect of the intervention (X). Delayed post-test (O_3) was conducted seven weeks later to measure the retention of the intervention's effects on the dependent variable when compared to the mean score of the post-test (O_2).

Qualitatively, in-depth insights into students' perceptions were garnered through focus group discussions (FGDs). Thematic analysis was employed to identify recurring themes and patterns within the qualitative data that could offer a nuanced understanding of the students' conceptual grasp and the overall impact of the Minecraft Education platform. This qualitative exploration serves to complement and validate the quantitative findings, presenting a holistic view of the intervention's effectiveness.

B. Research Sample

The school sample was selected through simple random sampling to ensure that each school in Penang, one of Malaysia's 14 states, had an equal chance of being chosen. This method aimed to minimize selection bias and improve the representativeness of the sample. The study comprised 40 Form Two students (aged 14) from a secondary school in the Central Seberang Perai district of Penang with diverse backgrounds and academic performances. These students voluntarily participated in the study for the 2023 school year. The diversity within the sample was instrumental in mitigating the impact of voluntary participation bias as it reduced the likeliness for all participants to have a prior interest or familiarity with the Minecraft Education platform or solar PV technology.

The choice of Form Two students was grounded in Piaget's theory of cognitive development, specifically the stage of formal operations. At this stage, students' cognitive structures are considered to be at their peak development, making it an ideal time for them to engage in logical problem-solving and grasp scientific concepts [33]. A pre-test was administered before the intervention to assess the students' initial understanding of solar PV concepts. This was crucial for measuring the actual learning progress attributable to the intervention, thereby reducing the likelihood that the observed results were merely a reflection of the participants' pre-existing knowledge or interest in the subject. Moreover, this stage of development is when students are likely capable of appreciating others' perspectives and applying collaborative learning strategies.

C. Research Instrument

The solar PV technology knowledge test was utilized to examine the effectiveness of the Minecraft Education platform in enhancing students' understanding of solar PV technology utilization. A well-structured set of 15 multiple-choice and 5 matching items was developed by the researcher based on the Revised Bloom's Taxonomy to assess the basic knowledge level related to solar PV technology. These items were not only tailored for knowledge assessment but also employed to test abstract concepts and potential misconceptions that may arise during the learning process. The items covered five topics involved in the treatment: basic principles of solar PV, solar PV system components, solar PV applications, benefits and challenges of solar PV, and innovation in solar PV technology.

The items were verified by four experts in the field, namely two university lecturers and two experienced physics teachers with over fifteen years of expertise in teaching science and physics. This ensured that the proposed objective questions aligned with the desired constructs. The instrument's face validity and content validity were confirmed prior to conducting the pilot study. The Scale-Content Validity Index/Average (S-CVI/Ave) for the solar PV technology knowledge test was 0.84, exceeding the acceptable threshold of 0.80 as detailed in Table A1 (Appendix A). A pilot study with 40 participants revealed a Kuder-Richardson (KR-20) reliability value of 0.815 as shown in Table B1 (Appendix B), indicating suitable use due to its acceptable reliability. This value, along with additional reliability analyses [34] described in Tables B2-B6 (Appendix B), affirm that values exceeding 0.700 are considered adequate.

Three assessments were administered in total: a pre-test before the intervention, a post-test following the intervention, and a delayed post-test conducted seven weeks after the immediate post-test. The arrangement of items in the post-test and delayed post-test was modified from their placement in the pre-test to mitigate the threat of students potentially recalling the positions of the questions.

Meanwhile, the Focus Group Discussions (FGDs) involved face-to-face group interviews with 20 informants who were selected using a purposive sampling strategy based on 1) exposure to the Minecraft Education platform, and 2) a range of academic performances to encompass a wide spectrum of student experiences.

The FGDs were conducted in five steps, beginning with the formation of groups and followed by four interview sessions, each lasting between 35 to 45 minutes in a private and harmonious room. The informants were organized into four focus groups with each group consisting of five members. This group size was chosen to foster a comfortable environment for discussion that allowed every informant ample opportunity to share their thoughts while benefiting from the dynamics of group conversation. The composition of each focus group included a mixture of participants with different characteristics, thus enriching the discussions with varied viewpoints and insights.

The second step involved appointing a moderator, a role fulfilled by the researcher in this study. According to

Nyumba *et al*. [35], an ideal moderator should foster a friendly, supportive, and comfortable environment to cultivate open and honest dialogue among participants. The moderator's primary responsibility was to chair the discussions, take notes, record, and ensure the smooth progression of the discussion sessions.

The third step featured a brief introductory session before the discussion began where informants introduced themselves and shared their class and other details. This aimed to reduce feelings of shyness or embarrassment. The fourth step involved a discussion session about the study, which was crucial for data collection. The moderator posed several questions (Appendix C) to elicit responses while ensuring no individual dominated the conversation. Probing techniques were also employed to gain deeper insights from the informants. All discussions were recorded with consent using an MP4 recorder and a smartphone. The informants' participation was entirely voluntary and they were informed about the research objectives and their rights to withdraw at any time. The recordings were transcribed for analysis. Finally, the researcher thanked the informants for their participation in the study.

D. Research Procedure

The primary objective of this study is to examine the implications of utilizing Minecraft Education as a digital game-based learning platform for understanding the concepts of solar PV technology. This was achieved by initially obtaining a formal authorization letter addressed to the school principal to ensure a mutual understanding between the researcher and the school administration regarding the study's execution. Table 2 visualizes the entire phase of the study to provide a clear and concise timeline from the pre-test to the delayed post-test. It includes the 8-week intervention period where the Minecraft Education platform was utilized, followed by a 7-week interval leading up to the delayed post-test.

Table 2. Research procedure

Phase	Activity	Timeline	Explanation
1	Preliminary Assessment	Week 1	Before the Minecraft Education intervention, the participants underwent a solar PV technology knowledge test to gauge their initial comprehension of solar PV concepts.
2	Minecraft Education Intervention	Week 2—Week 9	Following the pre-test, the intervention phase commenced for 8 weeks during which the students engaged with Minecraft Education to learn about solar PV concepts.
3	Post-Assessment	Week 10	The post-test was administered immediately after the 8-week intervention concluded. This assessment was designed to evaluate the immediate educational impact of the intervention on the students' understanding of the subject matter.
4	Focus Group Discussions	Week 10	An interview in the form of focus group discussion was conducted with a purposive sampling strategy to complement the quantitative data. Through a pre-established interview protocol, students were queried about their experiences of utilizing the Minecraft Education platform to learn about solar PV concepts.
5	Delayed Post-test	Week 18	A delayed post-test was conducted 7 weeks after the post-test to assess the retention of knowledge and the long-term impact of the intervention. It aimed to evaluate the durability of the educational outcomes over a period without continuous reinforcement.

E. Implementation of Minecraft Education Platform on Students

Implementing Minecraft Education to teach solar PV concepts involves a strategic, step-by-step approach. In this study, the 5E instructional model was selected for integration with the Minecraft Education platform. Initially, the 'Engage' phase captured students' attention through an intriguing Minecraft scenario that introduced the basics of solar PV technology. A custom Minecraft world was developed, containing scenarios that required the application of solar PV concepts to solve in-game challenges. Next, the 'Explore' phase gave students the freedom to experiment within Minecraft by manipulating solar PV systems and observing the outcomes of their actions. This hands-on experience is vital for anchoring their learning in practical, real-world applications. Students were tasked with collaborative projects that required them to design and build structures using solar PV within Minecraft. It activity encouraged peer learning and allowed students to explore the principles of solar PV collaboratively.

Furthermore, the 'Explain' phase guided students through the complexities of solar PV systems within the Minecraft environment. It ensured that theoretical concepts met practical application, allowing students to understand and apply their knowledge effectively. The 'Elaborate' phase further challenged students by requiring them to design and implement their own solar PV systems in Minecraft, simulating real-world scenarios and problems. Students participated in interactive lessons within the game, which included virtual experiments with solar PV panels, building circuits, and managing power generation. These lessons were designed to reflect real-world solar PV applications. Finally, the 'Evaluate' phase assessed students' understanding and application of solar PV concepts using Minecraft projects and reflective discussions to gauge their learning outcomes. After each session, time was allocated for students to reflect on their learning experiences and engage in discussions, allowing them to articulate their understanding and reinforce their learning.

F. Data Analysis

The quantitative and qualitative data were analyzed using IBM SPSS version 23.0 for descriptive and inferential statistics and NVivo 12 for thematic analysis. The quantitative data analysis involved employing descriptive statistics to ascertain the mean scores from the pre-test, post-test, and delayed post-test by focusing on students' knowledge on the application of solar PV technology. The research hypothesis was tested using inferential statistics, specifically ANOVA with repeated measurements, at a significance level of $p = 0.05$.

Qualitative data gathered from the FGDs were transcribed and subjected to thematic analysis as per the method outlined by Braun *et al*. [36]. The analysis followed four cycles of coding by adopting a structured and iterative approach. Each cycle involved a comprehensive examination of the data to refine and distill the information into coherent themes. Throughout this process, codes were meticulously reviewed, revised, and, merged (where necessary) to ensure they accurately represented the underlying data. This iterative process culminated in the identification of four main themes: visualizing abstract concepts, engaging with solar PV concepts during gameplay, real-world applications, and overcoming technical challenges. These themes represent the core insights derived from the data, reflecting the nuanced understanding of the subject matter facilitated by the rigorous analytical process employed in the study.

IV. Result

A. Knowledge of Solar PV Technologies

The analysis of quantitative data, which included pre-test, post-test, and delayed post-test scores, aimed to measure the impact of the Minecraft Education platform on students' knowledge of solar PV technology. The following hypotheses were developed in accordance to Research Question 1 and tested using inferential statistics:

H_{01}: There is no significant difference between the mean scores of the pre-test and post-test regarding students' knowledge pertaining to the utilization of solar PV technology.

H_{02}: There is no significant difference between the mean scores of the post-test and the delayed post-test regarding students' knowledge pertaining to the utilization of solar PV technology.

Results from preliminary descriptive statistics analysis revealed an increase in mean scores from the pre-test (M = 8.68, SD = 1.817) to the post-test (M = 14.80, SD = 2.078), suggesting a significant improvement in knowledge following the intervention. However, a slight decrease in mean score was observed in the delayed post-test (M = 14.13, SD = 1.924), indicating a potential decline in knowledge retention without ongoing reinforcement.

As shown in Table 3, the skewness and kurtosis values obtained are close to zero. It suggests a normal distribution of the data, as Lay and Khoo [37] noted that skewness and kurtosis values within the range of −1 to +1 indicate normal distribution. This is further supported by normal Q-Q plots of the mean score distributions for the pre-test, post-test, and delayed post-test as shown in Figs. D1-D3 (Appendix D) where the data points are closely aligned with the straight line, hence indicating normality.

Table 3. Descriptive statistics for knowledge of solar PV technology

	N	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
Pre-test	40	8.68	1.817	5	12	0.000	−0.835
Post-test	40	14.80	2.078	10	18	−0.459	−0.519
Delayed Post-test	40	14.13	1.924	10	18	−0.300	−0.279

Additionally, normality was tested using Shapiro-Wilk statistics by focusing on the p-value. A non-significant p-value ($p > 0.05$) suggests that the data distribution is normal. Table 4 presents the Shapiro-Wilk statistics for the solar PV technology knowledge across all tests. It can be seen that non-significant results ($p > 0.05$) were obtained across all datasets, thus indicating normal distribution.

Table 4. Normality test based on Shapiro-Wilk statistics for knowledge of solar PV technology

Knowledge of Solar PV Technology	Shapiro-Wilk		
	Statistic	df	Sig.
Pre-test	0.957	40	0.129
Post-test	0.950	40	0.075
Delayed Post-test	0.965	40	0.242

The analysis proceeded with repeated measures ANOVA, which revealed significant effects of time on knowledge scores (Wilks' Lambda = 0.126; F(2,38) = 131.214, $p < 0.001$; $\eta^2 = 0.874$) as shown in Table 5. This indicates a large effect size and substantial improvement in students' knowledge over time.

Furthermore, Mauchly's Test of Sphericity (Table 6) confirmed that a value of p=0.174 which is greater than 0.05. These results are not significant and indicate that the assumption of sphericity was met [38]. This allowed for further analysis through tests of within-subjects effects (Table 7), which also indicated significant effects (F = 166.766, $p < 0.001$, $\eta^2 = 0.810$).

Table 5. Multivariate test results for knowledge of solar PV technology

Effect	Wilks' Lambda	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Time	0.126	131.214	2	38	0.000	0.874

Table 6. Mauchly's test of sphericity results

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	0.912	3.501	2	0.174	0.919	0.962	0.500

Table 7. Tests of within-subjects effects

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Sphericity Assumed	902.317	2	451.158	166.766	0.000	0.810
Greenhouse-Geissser	902.317	1.838	490.872	166.766	0.000	0.810

Next, the Bonferroni Post Hoc test (Table 8) identified significant differences in mean scores between the pre-test and post-test and between the pre-test and delayed post-test, but not between the post-test and delayed post-test.

Table 8. Bonferroni post hoc test results for knowledge of solar PV technology

(I)Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.
Pre-test	Post-test	−6.125*	0.381	0.000
	Delayed Post-test	−5.450*	0.405	0.000
Post-test	Pre-test	6.125*	0.381	0.000
	Delayed Post-test	0.675	0.311	0.108
Delayed Post-test	Pre-test	5.450*	0.405	0.000
	Post-test	−0.675	0.311	0.108

Based on *estimated marginal means*
*The mean difference is significance at the 0.05 level

These findings suggest that while the intervention significantly improved knowledge, the retention of this knowledge was not significantly reduced over time. Hence, H_{01} was rejected, indicating a significant increase in knowledge following the intervention. Meanwhile, H_{02} was not rejected, suggesting sustained knowledge retention. The results are further supported by Table 9, which presents the estimated marginal means for knowledge of solar PV technology, reinforcing the conclusion that the intervention via the Minecraft Education platform significantly enhances and retains students' knowledge regarding solar PV technology.

Table 9. Estimated marginal means for knowledge of solar PV technology

Time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Pre-test	8.675	0.287	8.094	9.256
Post-test	14.800	0.329	14.135	15.465
Delayed Post-test	14.125	0.304	13.510	14.740

B. Role of Minecraft Education Platform on Conceptual Understanding

The students shared valuable insights on how Minecraft Education enhanced their understanding of solar PV technology by highlighting several key areas:

1) Visualizing abstract concepts

"Minecraft aided us in grasping the topic discussed by the teacher more thoroughly. Given that not all of us were familiar with solar panels, Minecraft was highly beneficial in helping us comprehend the function of solar PV." (G1I3: "G" stands for group number, indicating the specific group being referenced, and "I" represents the number of informants within that group.)

"I found it fascinating how using Minecraft helped me visualize the photovoltaic effect. It's one thing to read about it, but seeing the sunlight convert into electricity in the game made it so much clearer." (G1I5)

"I remember the moment when I set up the solar panels and watched them generate electricity as the sun rose in the game. It was like an "aha" moment where everything clicked." (G2I2)

"It's interesting how those challenges made us learn the complexity of solar PV systems. It's not just about placing panels; it's about optimizing every aspect for efficiency and effectiveness." (G4I4)

The feedback indicates that Minecraft significantly aided in visualizing and understanding abstract concepts, thus emphasizing the platform's effectiveness in teaching complex scientific principles.

2) Engaging with the solar PV concepts while playing

"Minecraft made learning about solar cells feel like an adventure. The challenges and goals in the game made me want to explore and learn more." (G1I1)

"I've never been so engaged in a science class before. The Minecraft activities made learning about energy conversion feel exciting and relevant." (G2I3)

"It's like we were learning by doing. I didn't just memorize facts; I understood the concepts by applying them in the game." (G3I5)

The students reported that Minecraft made the learning process more engaging and hands-on, leading to a deeper understanding and retention of scientific concepts.

3) Real-world applications

"What impressed me the most was how we could simulate real-world scenarios in the game. I felt more confident about applying solar PV concepts to practical situations." (G2I1)

"It was eye-opening to design and optimize our solar setups for different locations and weather conditions. I started considering factors like latitude and shading which are crucial in actual solar panel installations." (G3I1)

"Definitely. The Minecraft module made me think about how solar energy could be used in my community, and I could see the direct impact of what I was learning." (G4I5)

The students appreciated the opportunity to simulate and apply solar PV concepts in real-world scenarios, which enhanced their practical understanding and application skills.

4) Overcoming technical challenges

"I won't deny it; there were times when I faced challenges in the game. I had trouble with my internet connection during some sessions, which made it frustrating to fully engage in the activities." (G4I2)

"It's true. At times, my device would freeze or lag, disrupting the flow of the learning experience." (G4I3)

While being innovative, the integration of Minecraft presented technical difficulties for some, underscoring the need for reliable technology to ensure effective learning experiences.

In summary, feedback on the use of Minecraft Education was predominantly positive, with students noting improved engagement and understanding of solar PV technology. The game-based learning approach clarified complex concepts and enhanced motivation. However, technical challenges highlighted the importance of reliable digital infrastructure to maximize the educational benefits of such platforms.

C. Evidence of Knowledge Enhancement

This section presents a visual representation (screenshots and images) of the virtual cities developed by the students. The visuals provide a tangible view of the students' creative and innovative ways of integrating solar PV systems into their designs. As demonstrated in Fig. 4, student projects feature complex solar panel arrays, the utilization of *redstone* circuits to simulate electrical energy flow, and the implementation of advanced automation systems for energy management in residential areas. Fig. 5 shows the installation of solar PV panels on poles to harvest sunlight throughout the day for street lighting. The energy is converted and stored in batteries, which then powers streetlamps overnight, thus eliminating the reliance on grid electricity.

Fig. 4. Solar PV system installed in residential area.

Fig. 5. Solar PV system installed on poles and roof of vehicles.

Furthermore, solar PV panels can be mounted on the roofs or other sun-exposed surfaces of vehicles, such as trucks and cars, allowing them to generate electricity while moving or when parked in sunny areas. This generated power can recharge electric vehicle batteries or power its electrical systems. Fig. 6 illustrates the application of solar PV in agriculture, specifically to power irrigation systems in paddy fields, thus reducing dependency on fossil fuels and enhancing farmers' ability to water their crops sustainably. For instance, solar-powered water pumps can autonomously manage water distribution to the fields, bypassing the need for grid electricity or fossil fuel-based generators.

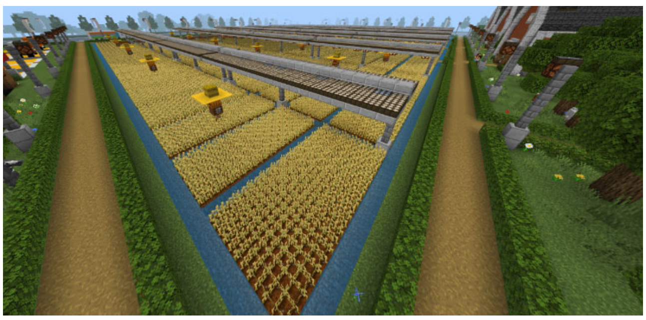

Fig. 6. Solar PV system used in paddy fields.

The depicted projects underscore the strategies devised by the student groups to enhance energy production, storage, and distribution within their virtual city. This section also examines how skills and knowledge gained from Minecraft-based learning are transferable to real-world applications of solar PV technology. Furthermore, it considers the scalability of these approaches to larger solar PV projects, encouraging students to see themselves as future innovators and contributors to sustainable energy solutions.

V. Discussion

The findings of this study align with the digital game-based learning theory proposed by Prensky [9], which emphasizes the role of interactive digital environments in engaging learners and enhancing their motivation. As propounded by Chen and Tu [1] and Kärki *et al*. [10], the utilization of gaming platforms in educational settings has been effective to significantly boost student involvement and interest. This study contributes to the existing discourse by demonstrating that Minecraft Education not only captures students' attention but also facilitates their understanding of complex scientific concepts. This merging of theoretical insights with practical educational outcomes highlights Minecraft's versatility as an educational tool, as underscored by Wilson and Rennie [14], Tangkui and Keong [15], and Saricam and Yıldırım [16]. This also advocates the capability of Minecraft Education to transcend traditional learning paradigms by offering an innovative platform for engaging with subjects such as solar PV technology. It bridges the gap between abstract concepts and tangible understanding, ultimately reinforcing the game's transformative potential in education.

This study showcases the power of interactive play and social collaboration in learning in line with Vygotsky's constructivist learning theory [18]. Minecraft Education embodies these principles by promoting a learner-centered approach that encourages exploration, creativity, and problem-solving. The immersive learning experience not only enhances knowledge acquisition but also fosters critical thinking and collaboration skills, effectively addressing the challenge of teaching abstract scientific concepts. The integration of Minecraft Education into the curriculum as an innovative, experiential learning method resonates with the emphasis on active, hands-on education advocated by educational theorists.

Researchers like Kaczmarczyk and Urych [4] and Keramitsoglou [5] have identified prominent gaps in students' understanding of renewable energy technologies. This study addresses such concern by positing Minecraft Education as an effective platform to bridge these gaps. The interactive nature and capability to simulate real-life scenarios make Minecraft Education an ideal tool for enhancing students' comprehension of renewable energy concepts, subsequently contributing to a more informed and environmentally conscious generation. This aligns with previous literature that emphasizes the importance of engagement and retention in STEM fields, illustrating Minecraft Education's significant contributions to these areas through an immersive, interactive gaming experience that maintains student interest and potentially leads to better retention of complex concepts and sustained interest in STEM subjects.

The present study utilized Minecraft Education to create a dynamic and interactive learning environment that conveyed solar PV concepts both theoretically and practically. Despite the effectiveness of this hands-on approach to deepen the students' understanding and ensure knowledge retention, technical challenges encountered during the study highlight the necessity for robust digital infrastructure to support effective digital game-based learning. These challenges resonate with the concerns raised in the literature regarding digital divide and the need for equitable access to technological resources. This study also emphasizes the importance of addressing these issues to ensure that the benefits of innovative educational tools like Minecraft Education are accessible to all students. Apart from contributing to the evolving landscape of educational technology, the findings of this study align with the literature's perspective on preparing students for a future dominated by digital proficiency and technological innovation. Minecraft Education, as demonstrated in this research, offers a glimpse into the potential of digital tools in shaping future educational paradigms by equipping students with the skills and knowledge required to navigate and succeed in a technologically advanced society.

Reflecting on the study's findings and limitations, further research is encouraged to explore the long-term impact of Minecraft Education on knowledge retention, the customization of the platform for diverse learning needs, and the application of digital tools in various educational contexts. Such research will broaden the current understanding of digital game-based learning and contribute to the development of more inclusive, effective, and engaging educational practices.

VI. Conclusion

This study underscores the efficacy of Minecraft Education as a pedagogical tool for imparting the knowledge of solar PV technology among secondary school students. The quantitative analyses revealed an enhancement and retention of students' knowledge, which is further corroborated by qualitative feedback emphasizing the platform's role in facilitating a tangible and interactive learning experience. Minecraft Education's collaborative and experiential learning environment not only deepens understanding but also cultivates problem-solving skills and creativity, enabling students to incorporate solar PV systems within a virtual setting effectively. Nonetheless, the success of digital game-based learning hinges on a robust digital infrastructure. Stable internet connectivity and access to adequate hardware emerge as critical factors influencing the outcome of such educational interventions.

The absence of a control group, owing to practical limitations within the school environment, limits the capacity to directly benchmark the intervention's efficacy against conventional teaching methodologies. Despite this, the study contributes valuable insights into Minecraft Education's potential to enhance students' learning. Future research should incorporate a control group that can facilitate a comparative analysis of Minecraft-based learning's impact on knowledge acquisition and retention. Additionally, while the study engaged a relatively small cohort, the findings lay the groundwork for more extensive, diversified investigations that could further elucidate the effectiveness of game-based learning tools across various educational landscapes and cultural contexts.

This study advocates for the integration of digital game-based learning within formal education settings to promote an engaging, meaningful approach for teaching complex scientific concepts. It also calls for a systematic approach to build the capacity of science educators in adopting digital game-based teaching methodologies. Expanding upon this research can significantly contribute to a more comprehensive understanding about the role of game-based learning in modern education, ultimately facilitating the development of innovative, effective teaching strategies that resonate with students in the digital age.

Appendix

A. Content Validity Index (CVI) & Scale-Content Validity Index (S-CVI) for the Solar PV Technology Knowledge Test

Table A1. CVI and S-CVI for the Solar PV technology knowledge test. Items selected as 4 or 5 on the 5-point relevance scale for the Subject Matter Expert Suitability Test (SSTS)

Item	Expert 1	Expert 2	Expert 3	Expert 4	Number of agreements.	Item CVI
1	X	X	X	X	4	1.00
2	X	X	X	X	4	1.00
3	X	X	X	X	4	1.00
4	-	X	X	X	3	0.75
5	-	X	X	X	3	0.75
6	X	X	X	X	4	1.00
7	-	X	X	X	3	0.75
8	-	-	X	X	2	0.50
9	-	-	X	X	2	0.50
10	-	X	-	X	2	0.50
11	X	X	X	-	3	0.75
12	X	X	X	-	3	0.75
13	-	X	X	X	3	0.75
14	-	X	X	X	3	0.75
15	X	X	X	X	4	1.00
16	X	X	X	X	4	1.00
17	X	X	X	X	4	1.00
18	X	X	X	X	4	1.00
19	X	X	X	X	4	1.00
20	X	X	X	X	4	1.00
Value S-CVI/Average = 0.84						

B. KR-20 Internal Consistency Reliability, Item Discrimination and Item Difficulty for the Solar PV Technology Knowledge Test Content

Table B1. Kuder-Richardson 20 (KR-20) internal consistency reliability for the solar PV technology knowledge test content

TotalScore		
N	Valid	40
	Missing	0
Variance		19.272
PQ		
N	Valid	20
	Missing	0
Sum		4.36

$$\text{KR-20} = [20/(20-1)] \times [(1 - (4.36/19.272)] = 0.815$$

Table B2. Description of Kuder-Richardson 20 (KR-20)

KR-20 Value	Reliability
0.90–1.00	Excellent
0.80–0.89	Good

0.70–0.79	Acceptable
0.60–0.69	Questionable
0.50–0.59	Poor
Less than 0.5	Unacceptable

Table B3. Item difficulty index for the solar PV technology knowledge test

Item	Difficulty Index	Description
Q1	0.80	Very Easy
Q2	0.83	Very Easy
Q3	0.80	Very Easy
Q4	0.40	Fair
Q5	0.35	Difficult
Q6	0.35	Difficult
Q7	0.75	Easy
Q8	0.80	Easy
Q9	0.45	Fair
Q10	0.53	Fair
Q11	0.45	Fair
Q12	0.42	Fair
Q13	0.45	Fair
Q14	0.43	Fair
Q15	0.35	Difficult
Q16	0.70	Easy
Q17	0.40	Fair
Q18	0.63	Easy
Q19	0.40	Fair
Q20	0.32	Difficult

Table B4. Description of difficulty index

Difficulty Index	Description
0.00–0.19	Very Difficult
0.20–0.39	Difficult
0.40–0.59	Fair
0.60–0.79	Easy
0.80–1.00	Very Easy

Table B5. Item discrimination value for the solar PV technology knowledge test

Item	Discrimination value	Description
Q1	0.69	Very good
Q2	0.64	Very good
Q3	0.55	Good
Q4	0.73	Very good
Q5	0.55	Good
Q6	0.73	Very good
Q7	0.55	Good
Q8	0.27	Fair
Q9	0.64	Very good
Q10	0.27	Fair
Q11	0.64	Very good
Q12	0.18	Low (need to improve)
Q13	0.45	Good
Q14	0.64	Very good
Q15	0.45	Good
Q16	0.91	Very good
Q17	0.55	Good
Q18	0.64	Very good
Q19	0.55	Good
Q20	0.64	Very good

Table B6. Description of discrimination value

ID Value	Description
0.60–1.00	Very good
0.40–0.59	Good
0.20–0.39	Fair
0.10–0.19	Low (need to improve)
0.00–0.09	Very low (need to discard)
Less than 0.00	NOT classify (need to discard)

C. Focus Group Discussion.

This section assesses the interview protocol for exploring students' perspectives on the impact of using the Minecraft Education platform in enhancing their knowledge regarding the use of solar PV technology.

1) What do you know about solar energy?
2) Where does solar energy come from?
3) Can you tell me some good things about the sun?
4) Have you heard about solar panels that make electricity, called solar photovoltaic (PV)?
5) Have you seen these solar PV before? (while showing a set of solar panels)
6) Where did you see these solar PV?
7) What do you think about these solar PV?
8) Do you think these solar PV would be good to use at your home? Why or why not?
9) Do you think using solar PV can help lower your family's electricity bill? Why do you think that?
10) Do you believe that solar PV technology could be the main way we get electricity in Malaysia in the future? Tell me more about your thoughts.
11) What's your opinion on learning with digital games?
12) Would you like to use digital games to learn about how solar PV work?
13) Do you enjoy playing digital games like Minecraft?
14) Can you tell me about any problems you've faced while playing Minecraft?
15) Has playing Minecraft helped you understand more about solar PV technology?
16) What are some good and bad things you've noticed about learning with Minecraft?
17) Do you think learning with Minecraft will help you use solar PV technology in real life later on?
18) In what ways has Minecraft made you understand solar PV technology better?
19) How do you think Minecraft can help you in using solar PV in future?

D. The Normal Q-Q Plots of the Mean Score Distributions for the Pre-test, Post-test, and Delayed Post-test

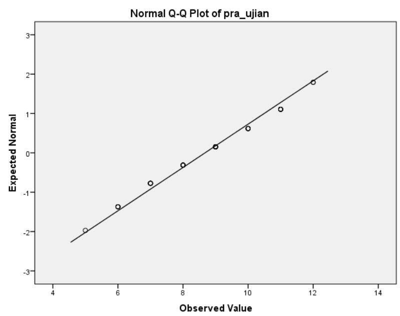

Fig. D1. The normal Q-Q plots of the mean score distributions for the pre-test.

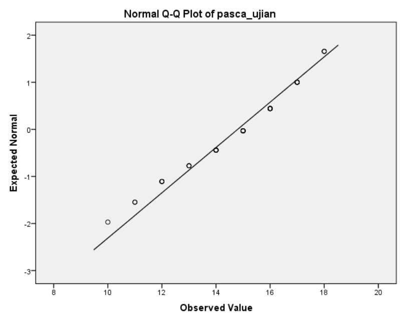

Fig. D2. The normal Q-Q plots of the mean score distributions for the post-test.

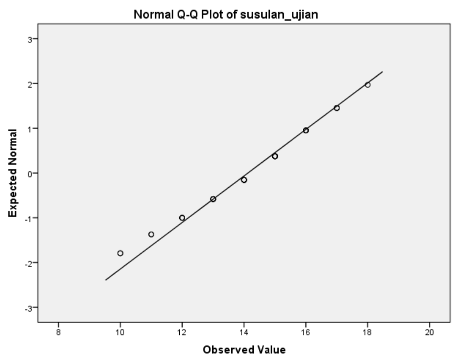

Fig. D3. The normal Q-Q plots of the mean score distributions for the delayed post-test.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

MKAS and MAS conducted the research, collected the data, and wrote the manuscript; LH and NMA analyzed the manuscript, discussed, and supervised our study; RMY supervised the preparation of this manuscript. All authors had approved the final version.

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REFERENCES

[1] C. C. Chen and H. Y. Tu, "The effect of digital game-based learning on learning motivation and performance under social cognitive theory and entrepreneurial thinking," *Frontiers in Psychology*, vol. 12, Dec. 2021.

[2] M. A. Cohen, G. O. Niemeyer, and D. S. Callaway, "Griddle: Video gaming for power system education," *IEEE Transactions on Power Systems*, vol. 32, no. 4, pp. 3069–3077, July 2017.

[3] P. Spangenberger, N. Matthes, L. Kruse, I. Draeger, S. Narciss, and F. Kapp, "Experiences with a serious game introducing basic knowledge about renewable energy technologies: A practical implementation in a german secondary school," *Journal of Education for Sustainable Development*, vol. 14, no. 2, pp. 253–270, Sept. 2020.

[4] B. Kaczmarczyk and I. Urych, "Perception of the transition to a zero-emission economy in the opinion of polish students," *Energies*, vol. 15, no. 3, p. 1102, Feb. 2022.

[5] K. M. Keramitsoglou, "Exploring adolescents' knowledge, perceptions and attitudes towards renewable energy sources: A colour choice approach," *Renewable & Sustainable Energy Reviews*, vol. 59, pp. 1159–1169, June 2016.

[6] H. E. Edsand and T. Broich, "The impact of environmental education on environmental and renewable energy technology awareness: Empirical evidence from Colombia," *International Journal of Science and Mathematics Education*, vol. 18, no. 4, pp. 611–634, June 2019.

[7] I. M. Revák, E. Jász, E. Kovacs, K. Teperics, J. U. Visi, and J. Máth, "Primary and secondary school students' knowledge related to renewable energy and some of its influencing factors," *Journal of Baltic Science Education*, vol. 18, no. 6, pp. 924–942, Dec. 2019.

[8] R. Muslim, H. Saputro, and A. G. Thamrin, "Case study: Vocational student's knowledge and awareness level toward renewable energy in Indonesia," *Open Engineering*, vol. 11, no. 1, pp. 690–708, Jan. 2021.

[9] M. Prensky, "Digital natives, digital immigrants part 2: Do they really think differently?" *On The Horizon*, vol. 9, no. 6, pp. 1–6, Nov. 2001.

[10] T. Kärki, J. McMullen, and E. Lehtinen, "Improving rational number knowledge using the NanoRoboMath digital game," *Educational Studies in Mathematics*, vol. 110, no. 1, pp. 101–123, Nov. 2021.

[11] T. Bouzid, F. Kaddari, H. Darhmaoui, and E. G. Bouzid, "Enhancing math-class experience throughout digital game-based learning, the case of Moroccan elementary public schools," *International Journal of Modern Education and Computer Science*, vol. 13, no. 5, pp. 1–13, Oct. 2021.

[12] K. Supramaniam and W. Shahirah, "Second language acquisition opportunities during digital game interactions," *Asian Journal of University Education,* vol. 18, no. 4, pp. 1142–1155, Oct. 2022.

[13] R. B. Tangkui and T. C. Keong, "Enhancement of achievement in fractions: A conceptual framework for digital game-based learning using Minecraft," *Journal of ICT in Education,* vol.7, no. 2, pp. 39–53, July 2020.

[14] S. Wilson and J. Rennie, "The very ugly duckling' meets Minecraft: Identity work and interpretive competence," *Literacy*, vol. 53, no. 4, pp. 206–215, Feb. 2019.

[15] R. B. Tangkui and T. C. Keong, "Kesan Pembelajaran Berasaskan Permainan Digital Minecraft Terhadap Pencapaian Murid Tahun Lima Dalam Pecahan," *Malaysian Journal of Social Sciences and Humanities*, Aug. 2020.

[16] U. Saricam and M. Yıldırım, "The effects of digital game-based STEM activities on students' interests in STEM fields and scientific creativity: Minecraft case," *International Journal of Technology in Education and Science*, vol. 5, no. 2, pp. 166–192, Mar. 2021.

[17] M. Nkadimeng and P. Ankiewicz, "The affordances of Minecraft education as a game-based learning tool for atomic structure in junior high school science education," *Journal of Science Education and Technology*, vol. 31, no. 5, pp. 605–620, Oct. 2022.

[18] L. S. Vygotsky, "Mind in society. The development of higher psychological processes," *American Journal of Psychology*, vol. 92, no. 1, p. 166, Mar. 1979.

[19] R. B. Davis, *Constructivist Views on the Teaching and Learning of Mathematics. Journal for Research in Mathematics Education: Monograph No. 4*, National Council of Teachers of Mathematics, 1906 Association Drive, Reston, VA 22091, 1990.

[20] J. G. Brooks and M. Brooks. (1993). *In Search of Understanding: The Case for Constructivist Classrooms.* [Online]. Available: https://goo.by/wBltRu

[21] E. W. Jenkins, "Constructivism in school science education: Powerful model or the most dangerous intellectual tendency?" *Science & Education*, vol. 9, pp. 599–610, Nov. 2000.

[22] L. Hetherington, M. Hardman, J. Noakes, and R. Wegerif, "Making the case for a material-dialogic approach to science education," *Studies in Science Education*, vol. 54, no. 2, pp. 141–76, July 2018.

[23] K. S. Krahenbuhl, "Student-centered education and constructivism: Challenges, concerns, and clarity for teachers," *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, vol. 89, no. 3, pp. 97–105, May 2016.

[24] L. Landay, "Minecraft: Transitional objects and transformational experiences in an imaginary world," *Revisiting Imaginary Worlds*, Routledge, 2016, pp. 157–178.

[25] T. Kersánszki, I. Holik, and Z. Márton, "Minecraft game as a new opportunity for teaching renewable energy topics," *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 5, pp. 16–29, July 2023.

[26] K. J. E. Hewett, G. Zeng, and B. C. Pletcher, "The acquisition of 21st-century skills through video games: Minecraft design process models and their web of class roles," *Simulation & Gaming*, vol. 51, no. 3, pp. 336–364, June 2020.

[27] B. Andrade, A. Poplin, and I. S. Sena, "Minecraft as a tool for engaging children in urban planning: A case study in Tirol town, Brazil," *ISPRS International Journal of Geo-Information*, vol. 9, no. 3, p. 170, Mar. 2020.

[28] P. Y. Jiea, T. Y. Chuan, S.S.S. Ahmad, N. K. Thoe, and L. S. Hoe, "Minecraft education edition: The perspectives of educators on game-based learning related to STREAM education," *Learning Science and Mathematics*, vol. 15, Dec. 2021.

[29] A. H. Elmerghany and G. Paulus, "Using Minecraft as a geodesign tool for encouraging public participation in urban planning," *GI_Forum2017*, vol. 1, pp. 300–314, Jan. 2017.

[30] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education,* 8th ed, Routledge, 2018.

[31] E. Marsden and C. Torgerson, "Single group, pre- and post-test research designs: Some methodological concerns," *Oxford Review of Education*, vol. 38, no. 5, pp. 583–616, Oct. 2012.
[32] M. Tincani and J. C. Travers, "Publishing single-case research design studies that do not demonstrate experimental control," *Remedial and Special Education*, vol. 39, no. 2, pp. 118–28, Apr. 2017.
[33] R. Ramadhani, U. M. A. M. Rofiqul, A. Abdurrahman, and M. Syazali, "The effect of flipped-problem based learning model integrated with LMS-Google classroom for senior high school students," *Journal for the Education of Gifted Young Scientists*, vol. 7, no. 2, pp. 137–158, June 2019.
[34] N. Ketui, K. Homjun, K. Poonyasiri, J. Deepinjai, and P. Luekhong, "Item-based approach for online exam performance and its application," in *Proc. 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, IEEE, Jun 2016, pp. 1–5.
[35] T. O. Nyumba, K. Wilson, C. J. Derrick, and N. Mukherjee, "The use of focus group discussion methodology: Insights from two decades of application in conservation," *Methods in Ecology and Evolution*, vol. 9, no. 1, pp. 20–32, Jan. 2018.
[36] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, Jan. 2006.
[37] Y. F. Lay and C. K. Khoo, *Introduction to Statistical Analysis in Social Sciences Research (Series 1),* Venton Publishing, 2009.
[38] D. C. Howell, "Statistical methods for psychology," *The Statistician*, vol. 43, no. 1, p. 211, Jan. 1994. doi:10.2307/2348956.