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Quantifying Learning Outcomes: A Quasi-Experimental Study of Minecraft-Driven Engineering Design Process on Energy Concept Mastery and Creativity in Primary Classrooms

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Abstract: Minecraft and other forms of digital gaming-based learning systems are becoming a very integrative part of STEM learning and teaching, as they promote engagement with learning and conceptual mastery. This investigation was set out to analyse how a Minecraft-enabled Engineering Design Process (EDP) would alter the achievement of energy concepts in primary students, and how the knowledge of ICT, as well as attendance, influences students. A quasi-experimental design was pretest-post-test with 100 students and was analysed using ANCOVA, correlation, and paired t-test in SPSS 25. Outcomes indicated that after corrections on pretest scores, the effect of the business-as-usual group mean of 5.48 was higher than the 3.93 mean of the Minecraft-EDP group ($F(1,97) = 28.54$, $p < .001$, 227), ICT familiarity exhibited a negative connection with the post-test scores ($r = -.200$, $p = .046$), and attendance was insignificant. The researchers conclude that to effectively use game-based learning, one must exercise caution in scaffolding. Proposed solutions are the implementation of long-term interventions and the training of teachers. Implication sets are used to show how the curriculum is in line with the tasks in progress. Limitations are non-random sampling and shortness.

Keywords: Minecraft-EDP, Game-based Learning, Energy Concepts, ANCOVA, Primary Education.

1. Introduction

Digital game-based learning in elementary schools has recently received a lot of traction, with such games as Minecraft: Education Edition gaining traction to promote problem-solving, collaborative work, and conceptualisation. As the education systems in various parts of the world are trying to ensure that the students are equipped with 21st-century skills, the engineering design process (EDP), formulated into a game-based environment, provides a potential pedagogical approach to developing the subject-specific expertise in addition to creative thinking. Amid the changing STEM education climate, digital integration has emerged as one of the key learning strategies to increase conceptual understanding with a view toward empowering learners to take part in real-life problem-solving situations. Well-planned game-based learning has been demonstrated to increase students' motivation and concept retention and application

(Yu, Denham & Searight, 2022). As an open-ended sandbox game, Minecraft has demonstrated the potential for inquiry and project-based learning, also giving the students a chance to model and investigate the various dimensions of complex scientific phenomena dynamically (Tablatin, Casano & Rodrigo, 2023). During such a context within the scope of energy education, the EDP can provide a structured but dynamic platform where students test, design, experiment, and re-design solutions and concepts that will foster content knowledge and transferable skills (Ali & Tse, 2023).

In addition, Behnamnia, Kamsin and Hayati (2024) have stated that gaming environments can improve spatial thinking, systems thinking, and imagination because learners are allowed to experiment with designs in sustainable environments through immersive gaming experiences. The iterative thinking in STEM classrooms is encouraged and is circular in the tradition of the EDP (Subramanian, Bairaktarova & Huxtable, 2022). Besides, the potential to edit and include elements of curricular content into Minecraft creates the possibilities of equipping a teacher with the capability to diversify the learning experience to establish a more equal balance between theoretical and applied knowledge (Hewett, Zeng & Pletcher, 2020). This incorporation would not only boost engagement but would also contribute to diverse instructions based on the different levels of the students' knowledge of ICT (Wang et al., 2022). The proposed research is quasi-experimental in design as it would measure the learning results of primary school students who participate in an EDP unit on energy concepts based on Minecraft and compare them with students who had a conventional education.

1.1. Problem Statement

Although the use of Minecraft in education is increasingly present in learning, empirical data that demonstrates the benefits of Minecraft on domain-specific content grasping of concepts and its creative application are lacking, especially at the primary level in the case of energy education. Several studies have shown increased engagement in students when using game-based learning, but the manifestation of increased engagement in quantifiable learning is not so consistent in terms of science concepts (Chen & Tu, 2021). In addition, past studies have mostly used weak experimental or quasi-experimental designs that fail to involve control of confounding factors like prior knowledge, ICT familiarity, and attendance (Wang et al., 2022). Moreover, some of the existing literature concentrates on secondary or tertiary education, which leads to a gap in current knowledge on the reactions of younger learners to complex ideas related to STEM, when mediated by a game-based EDP method (Nadeem, Oroszlanyova & Farag, 2023). Furthermore, although creativity is an essential 21st-century skill, those studies that involve the assessment of creativity with respect to conceptual mastery during Minecraft-based STEM learning are limited (Saricam & Yildirim, 2021). Lack of effective comparative studies also prevents the possibility of educators explaining the need to allocate resources and redesign curriculum based on the digital game-based practice (All, Castellar & Van Looy, 2021). In the absence of empirical data gathered under the circumstances of a controlled study, the educational value of such interventions may become determined by anecdotal or inspirational terms as opposed to the measured results of a learning process (Tsai & Tsai, 2020).

1.2. Aims and Objectives

This study is set out to examine the effects of the Minecraft-based Engineering Design

Process unit on the mastery of energy concepts and creativity by primary students. It aims at measuring the learning advantage by comparing the pretest and post-test performance of two groups (experimental and comparison groups) and taking into consideration important variables of the learners. The study pursues the following objectives:

- To examine the effect of instructional condition (Minecraft-EDP vs. business-as-usual) on post-test energy concept mastery, controlling for pretest scores.
- To investigate the influence of ICT familiarity on post-test energy concept mastery in primary classrooms.
- To assess the relationship between attendance during the unit and post-test energy concept mastery.

1.3. Significance of the Study

This study holds significance for both educational practitioners and policymakers by providing robust, quantitative evidence on the learning outcomes associated with integrating Minecraft-EDP into primary science instruction. By employing a quasi-experimental design with pretest–post-test measures, the research offers insights into causality that extend beyond descriptive accounts of engagement. The findings have the potential to inform curriculum development, particularly in integrating game-based environments into STEM education in ways that measurably improve conceptual understanding and creativity. Moreover, by examining moderating factors such as ICT familiarity and attendance, the study addresses practical considerations in classroom implementation, thereby enhancing the relevance and applicability of its results. In the broader context, the research contributes to the ongoing dialogue on leveraging digital tools for equitable, high-impact learning experiences in primary education, aligning with global priorities for digital literacy, creativity, and STEM competence in young learners.

2. Literature Review

Game-based learning has appeared in front of us as a paradigm-shifting kind of tool or mechanism in education that provides a multidimensional learning experience that can be used by people to vastly improve their learning process. Using Minecraft, as well as other similar platforms, to support STEM learning in primary-level classrooms opens the potential to facilitate deeper learning about core concepts within a rich, creative environment, which encourages problem-solving skills. In this chapter, the author aims to conduct a review of the existing literature on which the three objectives of the research are based, so that the theoretical framework and hypotheses that lead the current study are developed.

2.1. Impact of Instructional Condition on Energy Concept Mastery

The first research question is an examination of the influence of the instructional condition, Minecraft-driven Engineering Design Process (EDP) and business-as-usual, on post-test energy concept mastery.

2.1.1. Digital Game-Based Learning in Science Education

Digital game-based learning (DGBL) could have been increasingly valuable to

construct conceptual knowledge in science due to its capability in immersing students in action experiences (Gil-Doménech & Berbegal-Mirabent, 2019). Minecraft can be used as a form of sandbox in primary school education to digitally allow students to have concrete visualisations of scientific phenomena to enable student manipulation to understand how phenomena work, such as the transfer and conservation of energy (Wang & Zheng, 2021). Research indicates that through this interactive learning approach, the mind processes greater levels of information and retains it in the long term than in the more conventional approach to teaching (Lee et al., 2021). According to empirical evidence, DGBL promotes higher-order thinking skills by means of problem-solving activities in authentic contexts (Wang et al., 2022). Combined with the EDP, Minecraft enables students to generate, experiment, and revise solutions to energy-related problems and, in this manner, reinforce the mastery of concepts by iterative learning processes (Gebbing, Lattemann & Büdenbender, 2023).

2.1.2. Comparative Effectiveness of Game-Based and Traditional Methods

The experimental group involving game-based science learning has reported increased achievement scores after intervention, regardless of the comparison to other science learning modes, especially lecture-based ones (Chen, Lu & Lien, 2021). The combination of simulations with digital design tools, when applied to energy learning environments, allows students to test energy solutions and limits the emergence of misconceptions, at least on the theoretical level, before applying the result to concrete models (Fongsamut, Tanasittikosol & Phaksunchai, 2023). In addition, quasi-experimental designs in primary science contexts have shown that intervention groups that utilised Minecraft-EDP reported a statistically significant improvement in content mastery with moderate-to-high effect sizes (Pranata, 2024). The latter is explained by a twofold effect of more active participation and the use of conceptual knowledge in problem-based activities (Lei et al., 2022).

2.2. Influence of ICT Familiarity on Energy Concept Mastery

The second research hypothesis is interested in the issue of how ICT familiarity serves as a determinant of the post-test performance.

2.2.1. ICT Skills and Learning Performance

Previously sub-medicated and comfortable with digital tools, known as ICT familiarity, can result in better navigation and task performance in technology-mediated teaching and learning experiences. Highly skilled students in terms of ICTs prove to be fast learners on virtual platforms, so that they learn the content instead of facing the operational challenges (Abubakar, Ogunlade & Ibrahim, 2024). In the game-based setting, ICT literacy increases the capacity of a learner to manipulate game mechanics and take part in embedded learning aims (Ilić, Ivanović & Klašnja-Milićević, 2024). The pre-exposure of the science students to weaker gaming mechanics can limit the load placed on the mind's cognitive resources, contributing to the increased availability of resources towards conceptual problem solving (Pellas & Mystakidis, 2020).

2.2.2. Moderating Effects of ICT Familiarity in Game-Based Learning

The studies have shown that familiarity with ICT could mitigate the correlation between teaching styles and learning achievements (Khampirat, 2021). As an illustration, students with better ICT capacity have better chances of using the in-game tools to model and experiment with EDP tasks in Minecraft (Daniels & Lee, 2022). Nonetheless, performance gaps in the same instructional condition may increase with the differences in ICT skills (Burušić, Šimunović & Šakić, 2021). This increases the role of a scaffold that can help to assist the learners with less familiarity with ICT to justify an equal amount of access to the rewards of learning through game-based EDP interventions (Haas & Tussey, 2022).

2.3. Relationship Between Attendance and Energy Concept Mastery

The third research question is based on the correlation between attendance in the unit and learning outcomes.

2.3.1. Attendance as a Predictor of Academic Performance

The attendance of students has been widely known as a significant factor that defines their achievement at every learning institution (Goos et al., 2020). When using intervention-based instruction, regular attendance gives more consistency in experiencing content, maintaining continuity in projects, and having regular feedback from the instructors. In STEM learning through games, the ability of the students to engage in collaborative problem-solving processes, as well as iterative designing processes, is directly correlated with attendance (Powell, 2024). Such absence of sessions can break the learning sequence, and conceptual knowledge integration can be weaker (Wibowo, 2024).

2.3.2. Attendance and Engagement in Game-Based Environments

Research in primary science settings demonstrates that regular attendance increases comfort with the technological and pedagogical processes of learning with the help of games (Wu, 2023). In Minecraft-EDP, sessions have a chain of implications, and the failure to attend them can disrupt the opportunity to complete intricate design tasks, thus decreasing the chances of certain content mastery (Yi, 2021). There is also empirical evidence that attendance is coupled with engagement; engagement is also linked to content gains because the more the school sessions a student attends, the better the content gains and the more creative the student will be in attempting to solve problems (Khalid, Abdullah & Fadzil, 2024). This denotes that presence, participation and performance come together in technology-enhanced learning environments.

2.4. Theoretical Framework

The research can be grounded on the theory of Constructivist Learning because it assumes that learners can build knowledge by interacting with the environment and cooperating with their peers. Constructivism is popular in Minecraft-EDP in how the students can explore, Morris, hypothesise and refine their structures, solving problems

related to energy issues. Situated learning in the virtual environment primes the condition to associate new knowledge with previous one and be able to construct a solution collectively (Gao, Li & Sun, 2020). Additionally, sing the constructivist beliefs, the best means of learning is when the learners are in real and realistic activities, like building energy patterns in Minecraft, to match practical applications (Meylani, 2024). This theory supports the fact that the inclusion of the EDP in a game-based platform is one methodology that resonates with natural learning and application of STEM concepts by students.

2.5. Hypotheses Development

Based on the reviewed literature and theoretical framework, the following hypotheses are proposed:

- H1: Students receiving Minecraft-EDP instruction achieve significantly higher post-test energy concept mastery scores compared to students receiving business-as-usual instruction, controlling for pretest scores.
- H2: ICT familiarity is positively associated with post-test energy concept mastery in primary classrooms.
- H3: Attendance during the unit is positively associated with post-test energy concept mastery in primary classrooms.

2.6. Literature Gap

Although significant research highlights the potential of game-based learning to improve outcomes in STEM education, important gaps remain in understanding its effectiveness and implementation. To begin with, the quantitative evidence of studies conducted on the primary level (at present with the use of a robust quasi-experimental design) isolating the effects of Minecraft-EDP on conceptual mastering is also limited. Second, ICT familiarity is not fully examined as a moderating variable in the process of such interventions, whereas its value is discovered in the aspect of the adaptation of learners to gaming-based environments. Third, attendance has rarely been considered as an independent predictor of technology-enhanced STEM learning, even though consistent attendance is essential to enjoying interactions with iterative design processes. By filling these gaps, not only would it build on the empirical evidence base but also guide effective as well as practical implementation plans, should efficient measures be put in place to help bring digital game-based EDP into the primary science curriculum.

3. Research Methodology

The methodology includes the descriptions of the systematic steps that were undertaken to explore the role of a Minecraft-driven Engineering Design Process (EDP) in developing the understanding of primary students in terms of mastering energy concepts. The quasi-experimental pretest-post-test method allows making a strong comparison between the experimental group (receiving the Minecraft-EDP intervention) and the group that is taking business-as-usual instruction, compared to the control group. In this section indicate the research method and design, the approach of data collection, the data sampling and the data analysis strategy, and the ethical considerations.

3.1. Research Method and Design

This research study used a non-equivalent groups pretest-post-test quantitative quasi-experimental research design. Quantitative designs are particularly suitable for quantifying the transformations brought about in the numeric outcomes and the provision of an objective means of assessing the impact of an intervention (Takona, 2024; Wright, 2020). The reason why the Non-equivalent group was selected is that the experiment involved whole intact classrooms, and it would not be suitable to randomly assign a school facility. The experimental group was to use a Minecraft-based EDP unit focused on the ideas of energy in its structure relative to the design pattern of the problem identification, ideation, prototyping, testing, and iterating. The control group received conventional teaching on the same ideas, through lectures and worksheets. The reason behind this was that the design possessed a statistical control over initial differences through pretest scores, which further constituted internal validity (Gopalan, Rosinger & Ahn, 2020).

3.2. Data Collection Method

The two stages of collection of data collection took the form of an intervention and a post-intervention activity in one week. The pretest and post-test performances of the two groups were determined by the Energy Concept Mastery Test (ECMT). The ECMT included short answer and multiple-choice tasks with mapping to the national primary science program, specifically on the concepts of energy forms, transfer and conservation. It enables it to reduce test-retest bias since (A and B) parallel forms (after pretesting and post-test) were applied (Maric et al., 2023). The observation checklist was applied to follow the delivery of the Minecraft-EDP lessons better in terms of sequence and learning targets that would provide the necessary measures to ensure intervention fidelity (Parker et al., 2019). The attendance records and the familiarity with ICT scores were also obtained, and the dataset contained them, being obtained through a short survey formed in the Likert-scale format as a part of the secondary objectives of the study.

3.2.1. Samples and Sample Size

The sample was based on a population of 100 primary school students, 2 intact classroom teachers in 2 schools, 2 classes in the experimental group (n = 50) and 2 classes in the comparison group (n = 50). The students were between 9-11 years old and equally represented in gender aspects. It employed a convenience sampling method, which is standard in school studies due to logistical reasons that do not allow full randomisation (Adeoye, 2023).

3.3. Data Analysis Method

SPSS 25 was used to analyse data. Descriptive statistics were calculated to sum up the demographic variables, pretest scores, post-test scores, ICT familiarity and levels of attendance. The main comparison was Analysis of Covariance (ANCOVA) among the groups that enabled the comparison of post-test ECMT scores after controlling for pretest scores, as it is recommended in quasi-experimental designs (Field, 2024).

The analysis of the interrelationships between ICT familiarity, attendance and post-test scores was done using Pearson correlation analysis. Statistical significance was set at $p < .05$, and effect sizes were reported using partial eta squared (η^2) for ANCOVA and Cohen's r for correlations (Lakens, 2022). Normality, homogeneity of the regression slopes and homoscedasticity were also assumed and tested to make results valid.

3.4. Ethical Consideration

The respect for ethics was therefore observed according to the institutional and national research ethics regulations. Before data collection, permission was given by the school administration and the pertinent ethics committee. Parental informed consent was obtained from guardians, and consent of the students was taken in words suited to their age. Volunteer participation was ensured, and there were no penalties in case a participant wished to withdraw at any point (Head, 2020). The confidentiality was preserved by anonymising all personal characteristics information and giving participants numerical codes. All information was kept in an encrypted database, and only the research team could access it. The functioning of the intervention being organised in a manner, that, in turn, aligns with the previously presented curriculum, does not disadvantage any cohort because the Minecraft-EDP unit was provided to the comparative group after the study, as it was precisely an innovation to the learning experience that provided the equal opportunity to all individuals (Clark et al., 2021).

4. Data Analysis

The section included the statistical point analysis and the interpretation of the data that were supposed to examine the impact of the Minecraft-enabled Engineering Design Process (EDP) on the mastery of the energy concepts by the primary students, as well as the impact of familiarity with the ICT and attendance. SPSS version 25 was used to analyse the data, and it was collected using both descriptive and inferential statistical methods that entailed ANCOVA, correlation and paired t-tests. In its analysis, the goals of the research and the hypotheses provided in the previous chapters have been discussed.

4.1. Descriptive Statistics Analysis

The descriptive analysis gave the demographic picture of the participants and summarised the central variables in the study. This aids in contextualising the ensuing inferential statistics and provides an initial clue as to the trends in the data.

4.1.1. Demographic Analysis

Table 1: Gender of Respondents.

Gender					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Male	50	25.0	50.0	50.0
	Female	50	25.0	50.0	100.0
Total		100	100.0		

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Table 2: Instructional Condition of Respondents.

Instructional condition					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Business-as-usual	78	39.0	78.0	78.0
	Minecraft-EDP	22	11.0	22.0	100.0
Total		100	100.0		

Table 3: ICT Familiarity (gaming/EDU).

ICT familiarity (gaming/EDU)					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Average Familiar	41	20.5	41.0	41.0
	Familiar	20	10.0	20.0	61.0
	Very Familiar	39	19.5	39.0	100.0
Total		100	100.0		

The gender distribution of participants was evenly split, with 50 males (50%) and 50 females (50%), as shown in Table 1. This balanced representation ensures that gender-related effects on learning outcomes are minimised in the overall results. Regarding instructional conditions (Table 2), the majority of participants (78%) were in the business-as-usual group, while 22% received the Minecraft-EDP intervention. This uneven distribution reflects the allocation of intact classroom groups rather than random assignment. In terms of ICT familiarity (Table 3), 41% of students rated themselves as “average familiar” with gaming or educational digital tools, 20% as “familiar,” and 39% as “very familiar.” This distribution suggests that while most students have some degree of ICT familiarity, there is notable variation in prior digital competence, which may influence performance in technology-mediated learning environments.

4.1.2. Descriptives

Table 4: Descriptive Statistics.

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
ECMT pretest	100	60	71	65.03	3.619
ECMT post-test	100	68	82	75.26	4.483
Attendance during the unit	100	95	100	97.41	1.747
Teacher experience	100	3	6	4.40	1.119
Valid N (listwise)	100				

Table 4 shows that the ECMT pretest scores ranged from 60 to 71, with a mean of 65.03 (SD = 3.62), while the ECMT post-test scores ranged from 68 to 82, with a higher mean of 75.26 (SD = 4.48), indicating an overall improvement in energy concept mastery after the intervention period. Attendance during the unit was very high, with a mean of 97.41% (SD = 1.75), suggesting strong participation across groups. Teacher experience ranged between 3 and 6 years (M = 4.40, SD = 1.12), indicating that both novice and moderately experienced teachers were involved in the study.

4.2. Criteria of Analysis of Covariance (ANCOVA)

Before conducting ANCOVA, assumptions of normality, homogeneity of variances, and linearity were checked to ensure the validity of the results.

4.2.1. Normality Analysis

Table 5: Normality Analysis of Post Test.

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ECMT post-test	.209	100	.200	.995	100	.200
a. Lilliefors Significance Correction						

The Shapiro–Wilk test in Table 5 shows that ECMT post-test scores were normally distributed ($p = .200 > .05$). This satisfies the normality assumption required for ANCOVA.

4.2.2. One-way Anova

Table 6:Test of Homogeneity of Variances.

Test of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
ECMT post-test	Based on Mean	5.565	1	98	.020
	Based on Median	5.198	1	98	.025
	Based on Median and with adjusted df	5.198	1	96.364	.025
	Based on the trimmed mean	5.842	1	98	.017

Table 7: ANOVA.

ANOVA					
ECMT post-test					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	379.704	1	379.704	23.119	.000
Within Groups	1609.536	98	16.424		
Total	1989.240	99			

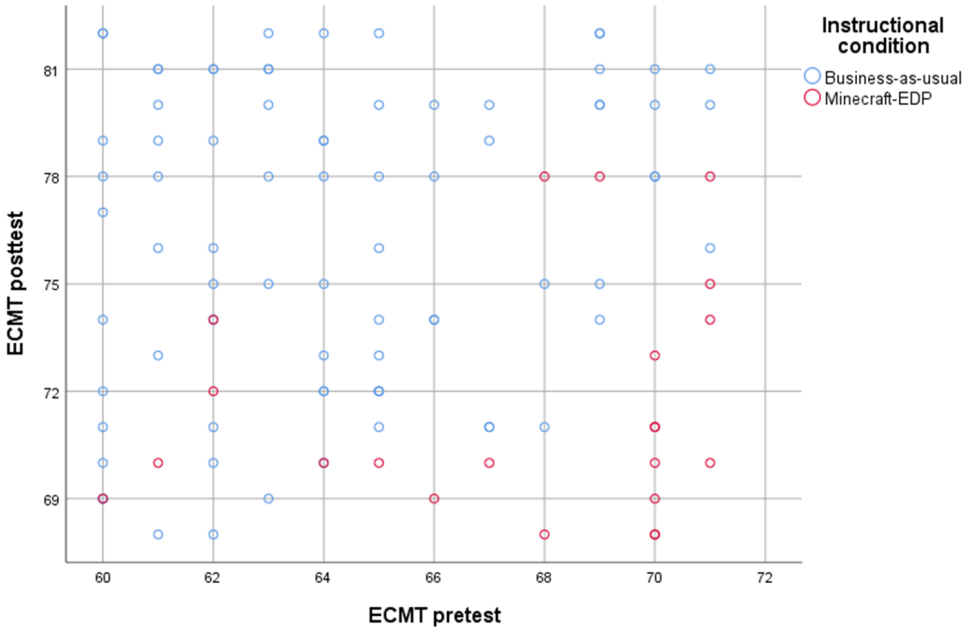
Levene's test (Table 6) indicated a statistically significant result ($p = .020$), suggesting some variance inequality between groups. However, ANCOVA is relatively robust to minor violations when sample sizes are adequate. The one-way ANOVA results in Table 7 reveal a significant difference between the instructional groups on ECMT post-test scores ($F(1, 98) = 23.12$, $p < .001$), indicating that, without controlling for pretest scores, there is already a notable difference between the groups.

4.2.3. Post Test by Instructional Condition

The scatterplot (Figure 1) illustrates the distribution of ECMT post-test scores relative to ECMT pretest scores for both instructional groups. The visual pattern suggests that students in the business-as-usual group generally scored higher on

the post-test than those in the Minecraft-EDP group, even after similar pretest scores, which is further explored in the ANCOVA results.

Figure 1: Scatter Plot of Post Test by Instructional Condition.



4.3. Correlations Coefficient

Table 8: Correlation Coefficient.

Correlations					
			ICT familiarity (gaming/EDU)	**Attendance During the Unit**	**ECMT Post-test**
Spearman's rho	ICT familiarity (gaming/EDU)	Correlation Coefficient	1.000	.035	-.200*
		Sig. (2-tailed)	.	.727	.046
		N	100	100	100
	Attendance during the unit	Correlation Coefficient	.035	1.000	-.142
		Sig. (2-tailed)	.727	.	.159
		N	100	100	100
	ECMT post-test	Correlation Coefficient	-.200*	-.142	1.000
		Sig. (2-tailed)	.046	.159	.
		N	100	100	100
*. Correlation is significant at the 0.05 level (2-tailed).					

The Spearman's rho correlation results in Table 8 show a significant negative correlation between ICT familiarity and ECMT post-test scores ($r = -.200$, $p = .046$), indicating that higher self-reported ICT familiarity was associated with slightly lower post-test performance. While this result is counterintuitive, it may reflect overconfidence or differences in learning engagement among more ICT-adept students. Attendance

did not show a significant correlation with ECMT post-test scores (r = –.142, p = .159), suggesting that high attendance across the board may have reduced variability, limiting its predictive value in this dataset. ICT familiarity and attendance were not significantly correlated with each other (r = .035, p = .727), indicating independence between these two predictors.

4.4. Univariate Analysis of Variance

Table 9: Between-Subjects Factors.

Between-Subjects Factors			
		Value Label	**N**
Instructional condition	0	Business-as-usual	78
	1	Minecraft-EDP	22

Table 10: Descriptive Statistics of Model.

Descriptive Statistics			
Dependent Variable: ECMT post-test			
Instructional condition	**Mean**	**Std. Deviation**	**N**
Business-as-usual	76.29	4.243	78
Minecraft-EDP	71.59	3.261	22
Total	75.26	4.483	100

Table 11:Levene's Test of Equality of Error Variances.

Levene's Test of Equality of Error Variances[a]			
Dependent Variable: ECMT post-test			
F	df1	df2	Sig.
5.609	1	98	.020
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.			
a. Design: Intercept + ECMTpretest + Instructionalcondition			

Table 12: Breusch-Pagan Test for Heteroskedasticity.

Breusch-Pagan Test for Heteroskedasticity[a,b,c]		
Chi-Square	**df**	**Sig.**
.534	1	.465
a. Dependent variable: ECMT post-test		
b. Tests the null hypothesis that the variance of the errors does not depend on the values of the independent variables.		
c. Predicted values from design: Intercept + ECMTpretest + Instructionalcondition		

The between-subjects factors in Table 9 confirm the group sizes of 78 for business-as-usual and 22 for Minecraft-EDP. Table 10 shows that the mean ECMT post-test score for the business-as-usual group (M = 76.29, SD = 4.24) was higher than that for the Minecraft-EDP group (M = 71.59, SD = 3.26). Levene's test in Table 11 again shows a significant result (p = .020), indicating slight inequality in variances, though the subsequent Breusch–Pagan test for heteroskedasticity (Table 12) was non-significant (p = .465), supporting the homoscedasticity assumption for the ANCOVA model.

4.4.1. Tests of Between-Subjects Effects

Table 13: Tests of Between-Subjects Effects.

Tests of Between-Subjects Effects						
Dependent Variable: ECMT post-test						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	452.601[a]	2	226.301	14.285	.000	.228
Intercept	836.010	1	836.010	52.773	.000	.352
ECMTpretest	72.897	1	72.897	4.602	.034	.045
Instructionalcondition	452.111	1	452.111	28.539	.000	.227
Error	1536.639	97	15.842			
Total	568396.000	100				
Corrected Total	1989.240	99				
a. R Squared = .228 (Adjusted R Squared = .212)						

The ANCOVA results in Table 13 reveal that the model explained approximately 22.8% of the variance in ECMT post-test scores ($R^2 = .228$, adjusted $R^2 = .212$). After controlling for ECMT pretest scores, there was a statistically significant effect of instructional condition on ECMT post-test scores ($F(1, 97) = 28.54$, $p < .001$, partial $\eta^2 = .227$), indicating a large effect size. This result supports the hypothesis that instructional condition significantly impacts post-test performance, even after adjusting for baseline differences. The covariate, ECMT pretest score, was also significant ($F(1, 97) = 4.60$, $p = .034$, partial $\eta^2 = .045$), suggesting that higher pretest scores were modestly associated with higher post-test scores. The adjusted means also revealed that the business-as-usual group had a higher score in the ECMT post-test than the Minecraft EDP group, and the direction in which the effect was supposed to go was the opposite. This result can be indicative of problems with the implementation fidelity, the variation in the instruction pace, or the assimilation period that the Minecraft-EDP approach needs to become effective in primary science settings.

4.5. Paired T-Test

Table 14: Paired Samples Descriptive Statistics.

Paired Samples Statistics					
		Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Pair 1	ECMT pretest	65.03	100	3.619	.362
	ECMT post-test	75.26	100	4.483	.448

Table 15: Paired Samples Correlation.

Paired Samples Correlations				
		N	**Correlation**	**Sig.**
Pair 1	ECMT pretest & ECMT post-test	100	.016	.877

The paired samples descriptive statistics in Table 14 show that the mean ECMT pretest score was 65.03 (SD = 3.62) and the mean ECMT post-test score was 75.26

(SD = 4.48), indicating an overall improvement of about 10.23 points. The paired samples correlation in Table 15 was non-significant (r = .016, p = .877), suggesting that pretest and post-test scores were not strongly linearly related at the individual level. The paired samples t-test in Table 16 confirmed a statistically significant increase from pretest to post-test (t(99) = –17.89, p < .001), with a mean difference of –10.23 (95% CI: –11.36 to –9.10). This indicates that, regardless of instructional condition, students demonstrated substantial learning gains in energy concept mastery over the course of the study.

Table 16: Paired Samples Test Statistics.

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ECMT pretest - ECMT post-test	-10.230	5.717	.572	-11.364	-9.096	-17.894	99	.000

Overall, the descriptive and inferential analyses show that although the intervention period has brought considerable improvements in the ECMT scores in the entire sample, the business-as-usual group had better adjusted scores in the post-test compared to the Minecraft-EDP group. Also, ICT experience was negatively related to the post-test performance, and attendance did not have any impact on the results. The ANCOVA outcomes demonstrate the considerable influence of baseline knowledge and learning method on the outcome of post-intervention results.

5. Discussion

The chapter discusses the outcomes of the study, taking into consideration the objectives of the research and the literature base. The analysis is based on the results given in Chapter 4, integrating the results with previous research to bring out both the anticipated and the outcomes. Each of such subsections deals with a single research objective and frames the findings within the focus of game-based learning theory and empirical evidence, together with methodological considerations.

5.1. Impact of Instructional Condition on Energy Concept Mastery

The first research hypothesis was to consider how the factor instructional condition influenced the post-test performance measured as mastery of energy concepts, controlling for pretest scores. The ANCOVA statistical tests demonstrated the statistically significant impact of instructional condition, where the business-as-usual condition performed better in comparison to the Minecraft-EDP condition. This observation contrasts with a number of previous studies that found more significant benefits associated with game-based learning interventions than more traditional instructions on achievement gains (Chen et al., 2021; Gil-Doménech & Berbegal-Mirabent, 2019). Nevertheless, it agrees with the literature stating that the success of learning using digital games requires substantial implementation fidelity, scaffolding, and matching to the pace of the curriculum (Gebbing et al., 2023;

Lei et al., 2022). Alternatively, this discrepancy in the results in the Minecraft-EDP group can be explained by the newness of the platform to a part of the student population, possible cognitive overload in the process of the prescribed EDP, or a learning curve compromising short-term knowledge acquisition (Wang et al., 2022). The constructivist theory substantiates the assumption that learning by exploring needs sufficient time and guided assistance, implying that prolonged exposure could have other outcomes (Gao et al., 2020).

5.2. Influence of ICT Familiarity on Energy Concept Mastery

The second research hypothesis investigated the kind of relationship that existed between ICT familiarity and the ECMT post-test scores. However, ICT familiarity, contrary to expectations, was observed to be significantly negative in the correlation between the same and the post-test. This finding is contrary to pre-existing evidence that better ICT skills facilitate learning in technology-enhanced settings by minimising the barriers in operation (Ilić et al., 2024; Khampirat, 2021). It could be one of the possible reasons since highly familiar students might have had an overconfidence issue as they might have been more concentrated on mechanisms within the game than on applying the concept, which is what Haas and Tussey (2022) raised regarding equity and engagement in game-based learning. This observation solidifies the idea that a structured framework pedagogy is needed to make sure the competence in ICT is directed to producing the desired learning outcomes and not merely technical proficiency (Burušić et al., 2021).

5.3. Relationship Between Attendance and Energy Concept Mastery

The third research hypothesis explored a prediction of attendance of post-test ECMT Scores. The findings pointed towards indicating that there was no significant statistical relationship between the attendance rates and the post-test performance, though attendance was high within both groups. This is contrasted with previous research, which has reported attendance to be a positive variable in predicting achievement in both conventional and technology-mediated learning settings (Goos et al., 2020; Powell, 2024). The absence of meaningfulness of this study can be attributed to the limited scope of the range of attendance figures since most students were present in virtually all sessions, hence low variability and poor statistical power. Moreover, the quality of interactions on attendance may be even more important than attendance, according to Wu (2023), as, in collaborative learning with an element of gamification, conceptual growth depends on participating in the process of iterative design.

6. Conclusion

The aim of this research was not only to assess the effectiveness of a Minecraft-improved Engineering Design Process (EDP) on primary students' learning energy consumption, but also to analyse the effects of ICT familiarity on not just attendance. Within the context of a quasi-experimental pretest-post-test design and ANCOVA, the results indicated that, when the pretest scores were controlled, the business-as-usual group had significantly better post-test scores in comparison with the Minecraft-EDP one. Familiarity with ICT was negatively related to performance on

the post-test, unexpectedly, but attendance was not significantly related to learning later. These results indicate that game-based EDP solutions have the potential to stimulate engagement and creativity, but these solutions may show less potential to develop conceptual mastery depending on how long the exposure is, how much scaffolding is offered and whether the platform used is sufficiently interconnected with the other objectives of the unit of study. These findings indicate that learners who are experienced with ICT tend to perform worse, which explains how complicated the learner traits are concerning ICT-mediated learning through technology, which encourages pedagogical approaches that channel digital skills towards specific learning objectives. The insignificant correlation between attendance and performance supports the notion that being there is not enough, but the richness of the mentation and cooperation is the essential factor. The research adds to a developing body of knowledge on the subtler impact of game-based digital learning in STEM education and proposes practical implications of introducing such to primary science classrooms.

6.1. Recommendation

Future iterations of Minecraft-EDP as a teaching tool in primary science are required to include longer intervention durations so that students can acclimatise to the platform and the repetitive process of problem-solving. Both game facilitation training and content integration of the teachers are necessary to keep the curriculum at the same level of performance and prevent cognitive overloading. Moreover, it can be suggested that the introduction of a clear connection between in-game actions and learning tasks may also be used to ensure student attention is focused on the understanding of concepts instead of paying attention to the game mechanics.

6.2. Practical Implication

The results imply that they are practical to the curriculum designers, teaching staff, and policymakers. The results indicate the need for a combination of game-based learning conditions and well-organised teaching methods to make the best use of the former. In the case of educators, it implies a combo of teacher-led conceptual scaffolding and the exploration offered using digital solutions. To the curriculum developers, in-game tasks need to be related as much as possible to assessment goals so that technological innovation can be transformed into practical learning improvements.

6.3. Limitations

A limitation of the study is that it involved convenience sampling and intact groups of participants in classes, and thus, it is not very easy to generalise. The results might also have been affected by the fact that the size of the uneven groups differed between instructional conditions. Also, the brief intervention period could have limited the many targets of the Minecraft-EDP cohort to make full use of the strategy. To overcome such limitations, future studies ought to use randomised controlled research designs, balanced groups, and a longer intervention term to observe the long-term effects of learning.

References

Abubakar, U., Ogunlade, O. O. & Ibrahim, H. A. (2024). The Influence of Technology-Integrated Curriculum Resources on Student Engagement and Academic Achievement in Higher Education. *Advances in Mobile Learning Educational Research, 4*(2), pp. 1208-1223. doi: https://doi.org/10.25082/AMLER.2024.02.014

Adeoye, M. A. (2023). Review of Sampling Techniques for Education. *ASEAN Journal for Science Education, 2*(2), pp. 87-94. Retrieved from https://ejournal.bumipublikasinusantara.id/index.php/ajsed/article/view/230

Ali, M. & Tse, A. W. C. (2023). Research Trends and Issues of Engineering Design Process for STEM Education in K-12: A Bibliometric Analysis. *International Journal of Education in Mathematics, Science and Technology, 11*(3), pp. 695-727. doi: https://doi.org/10.46328/ijemst.2794

All, A., Castellar, E. N. P. & Van Looy, J. (2021). Digital Game-Based Learning effectiveness assessment: Reflections on study design. *Computers & Education, 167*, pp. 104160. doi: https://doi.org/10.1016/j.compedu.2021.104160

Behnamnia, N., Kamsin, A. & Hayati, S. (2024). Impact of Digital Game-Based Learning on STEM education in Primary Schools: A Meta-Analysis of Learning Approaches. *Innoeduca: International Journal of Technology and Educational Innovation, 10*(2), pp. 113-140. doi: https://doi.org/10.24310/ijtei.102.2024.18122

Burušić, J., Šimunović, M. & Šakić, M. (2021). Technology-based activities at home and STEM school achievement: the moderating effects of student gender and parental education. *Research in Science & Technological Education, 39*(1), pp. 1-22. doi: https://doi.org/10.1080/02635143.2019.1646717

Chen, C.-C. & Tu, H.-Y. (2021). The Effect of Digital Game-Based Learning on Learning Motivation and Performance Under Social Cognitive Theory and Entrepreneurial Thinking. *Frontiers in Psychology, 12*, pp. 750711. doi: https://doi.org/10.3389/fpsyg.2021.750711

Chen, Y.-C., Lu, Y.-L. & Lien, C.-J. (2021). Learning environments with different levels of technological engagement: a comparison of game-based, video-based, and traditional instruction on students' learning. *Interactive Learning Environments, 29*(8), pp. 1363-1379. doi: https://doi.org/10.1080/10494820.2019.1628781

Clark, T., Foster, L., Bryman, A. & Sloan, L. (2021). *Bryman's Social Research Methods*. Oxford University Press. Retrieved from https://global.oup.com/ukhe/product/brymans-social-research-methods-9780198796053

Daniels, D. & Lee, J. S. (2022). The Impact of Avatar Teachers on Student Learning and Engagement in a Virtual Learning Environment for Online STEM Courses. In P. Zaphiris & A. Ioannou (Eds.), *Learning and Collaboration Technologies. Novel Technological Environments* (pp. 158-175). Springer International Publishing. doi: https://doi.org/10.1007/978-3-031-05675-8_13

Field, A. (2024). *Discovering Statistics using IBM SPSS Statistics*. Sage Publications Limited. Retrieved from https://us.sagepub.com/en-us/nam/discovering-statistics-using-ibm-spss-statistics/book285130

Fongsamut, K., Tanasittikosol, M. & Phaksunchai, M. (2023). Effectiveness of the simulation-based learning (SBL) assisted with scaffolding approach to address students' misconceptions about projectile motion. *Physics Education, 58*(2), pp. 025002. doi: https://dx.doi.org/10.1088/1361-6552/aca57d

Gao, F., Li, L. & Sun, Y. (2020). A systematic review of mobile game-based learning in STEM education. *Educational Technology Research and Development, 68*(4), pp. 1791-1827. doi: https://doi.org/10.1007/s11423-020-09787-0

Gebbing, P., Lattemann, C. & Büdenbender, E. N. (2023). Towards a Creative Virtual Environment for Design Thinking. *Pacific Asia Journal of the Association for Information Systems, 15*(4), pp. 1. doi: https://doi.org/10.17705/1pais.15401

Gil-Doménech, D. & Berbegal-Mirabent, J. (2019). Stimulating students' engagement in mathematics courses in non-STEM academic programmes: A game-based learning. *Innovations in Education and Teaching International, 56*(1), pp. 57-65. doi: https://doi.org/10.1080/14703297.2017.1330159

Goos, M., Stillman, G., Herbert, S. & Geiger, V. (2020). *Teaching Secondary School Mathematics: Research and Practice for the 21st Century*. Routledge. doi: https://doi.org/10.4324/9781003117810

Gopalan, M., Rosinger, K. & Ahn, J. B. (2020). Use of Quasi-Experimental Research Designs in Education Research: Growth, Promise, and Challenges. *Review of Research in Education, 44*(1), pp. 218-243. doi: https://doi.org/10.3102/0091732X20903302

Haas, L. & Tussey, J. (2022). Equity and Engagement Through Digital Storytelling and Game-Based Learning. In I. R. Management Association (Ed.), *Research Anthology on Developments in Gamification and Game-Based Learning* (pp. 1451-1472). IGI Global Scientific Publishing. doi: https://doi.org/10.4018/978-1-6684-3710-0.ch070

Head, G. (2020). Ethics in educational research: Review boards, ethical issues and researcher development. *European Educational Research Journal, 19*(1), pp. 72-83. doi: https://doi.org/10.1177/1474904118796315

Hewett, K. J. E., Zeng, G. & Pletcher, B. C. (2020). The Acquisition of 21st-Century Skills Through Video Games: Minecraft Design Process Models and Their Web of Class Roles. *Simulation & Gaming, 51*(3), pp. 336-364. doi: https://doi.org/10.1177/1046878120904976

Ilić, J., Ivanović, M. & Klašnja-Milićević, A. (2024). Effects Of Digital Game-Based Learning In Stem Education On Students' Motivation: A Systematic Literature Review. *Journal of Baltic Science Education, 23*(1), pp. 20-36. doi: https://doi.org/10.33225/jbse/24.23.20

Khalid, I. L., Abdullah, M. N. S. & Fadzil, H. M. (2024). A systematic review: Digital learning in STEM education. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 51*(1), pp. 98-115. doi: https://doi.org/10.37934/araset.51.1.98115

Khampirat, B. (2021). Relationships between ICT competencies related to work, self-esteem, and self-regulated learning with engineering competencies. *PloS One, 16*(12), pp. e0260659. doi: https://doi.org/10.1371/journal.pone.0260659

Lakens, D. (2022). Sample Size Justification. *Collabra: Psychology, 8*(1), pp. 33267. doi: https://doi.org/10.1525/collabra.33267

Lee, S. W.-Y., Shih, M., Liang, J.-C. & Tseng, Y.-C. (2021). Investigating learners' engagement and science learning outcomes in different designs of participatory simulated games. *British Journal of Educational Technology, 52*(3), pp. 1197-1214. doi: https://doi.org/10.1111/bjet.13067

Lei, H., Chiu, M. M., Wang, D., Wang, C. & Xie, T. (2022). Effects of Game-Based Learning on Students' Achievement in Science: A Meta-Analysis. *Journal of Educational Computing Research, 60*(6), pp. 1373-1398. doi: https://doi.org/10.1177/07356331211064543

Maric, D., Fore, G. A., Nyarko, S. C. & Varma-Nelson, P. (2023). Measurement in STEM education research: a systematic literature review of trends in the psychometric evidence of scales. *International Journal of STEM Education, 10*(1), pp. 39. doi: https://doi.org/10.1186/s40594-023-00430-x

Meylani, R. (2024). Blueprint for the 21st Century Online Learning Environment in Stem Education Through a Systematic Review and Qualitative Synthesis. *Edelweiss Applied Science and Technology, 8*(6), pp. 8196-8226. doi: https://doi.org/10.55214/25768484.v8i6.3763

Nadeem, M., Oroszlanyova, M. & Farag, W. (2023). Effect of Digital Game-Based Learning on Student Engagement and Motivation. *Computers, 12*(9), pp. 177. doi: https://doi.org/10.3390/computers12090177

Parker, C. E., Stylinski, C. D., Bonney, C. R., DeLisi, J., Wong, J. & Doty, C. (2019). Measuring Quality Technology Integration in Science Classrooms. *Journal of Science Education and Technology, 28*(5), pp. 567-578. doi: https://doi.org/10.1007/s10956-019-09787-7

Pellas, N. & Mystakidis, S. (2020). A Systematic Review of Research about Game-based Learning in Virtual Worlds. *Journal of Universal Computer Science, 26*(8), pp. 1017-1042. doi: https://doi.org/10.3897/jucs.2020.054

Powell, K. (2024). *Analyzing the Impact of STEM Bins on Fourth-Grade Student Attendance in a Georgia Elementary School: A Quantitative Causal Comparative Study* (Doctoral dissertation, American College of Education). Retrieved from https://www.proquest.com/openview/1a9a35cced2e2231f745354bd31bb9c5

Pranata, O. D. (2024). Physics Education Technology (PhET) as a Game-Based Learning Tool: A Quasi-Experimental Study. *Pedagogical Research, 9*(4), pp. em0221. doi: https://doi.org/10.29333/pr/15154

Saricam, U. & Yildirim, M. (2021). 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, 5*(2), pp. 166-192. doi: https://doi.org/10.46328/ijtes.136

Subramanian, S., Bairaktarova, D. & Huxtable, S. (2022). Development and evaluation of a virtual learning tool to enhance comprehension of energy concepts. In *2022 IEEE Frontiers in Education Conference (FIE)* (pp. 1-8). IEEE. doi: https://doi.org/10.1109/FIE56618.2022.9962710

Tablatin, C. L. S., Casano, J. D. & Rodrigo, M. M. T. (2023). Using Minecraft to cultivate student interest in STEM. *Frontiers in Education, 8*, pp. 1127984. doi: https://doi.org/10.3389/feduc.2023.1127984

Takona, J. P. (2024). Research design: qualitative, quantitative, and mixed methods approaches / sixth edition. *Quality & Quantity, 58*(1), pp. 1011-1013. doi: https://doi.org/10.1007/s11135-023-01798-2

Tsai, Y.-L. & Tsai, C.-C. (2020). A meta-analysis of research on digital game-based science learning. *Journal of Computer Assisted Learning, 36*(3), pp. 280-294. doi: https://doi.org/10.1111/jcal.12430

Wang, L.-H., Chen, B., Hwang, G.-J., Guan, J.-Q. & Wang, Y.-Q. (2022). Effects of digital game-based STEM education on students' learning achievement: a meta-analysis. *International Journal of STEM Education, 9*(1), pp. 26. doi: https://doi.org/10.1186/s40594-022-00344-0

Wang, M. & Zheng, X. (2021). Using Game-Based Learning to Support Learning Science: A Study with Middle School Students. *The Asia-Pacific Education Researcher, 30*(2), pp. 167-176. doi: https://doi.org/10.1007/s40299-020-00523-z

Wibowo, A. A. (2024). A Comprehensive Systematic Review on Effective Strategies for Student Engagement in Blended Learning Environments. *Journal of Blended and Technical Education, 1*(1), pp. 87-101. doi: https://doi.org/10.70764/gdpu-jbte.2024.1(1)-08

Wright, D. (2020). *Implementing effective positive psychology interventions to support the well-being of young people in schools: A meta-analysis of randomised and non-randomised interventions and a Q study of educational psychologists' perceptions regarding effective implementation* (Doctoral dissertation, Cardiff University). Retrieved from https://orca.cardiff.ac.uk/id/eprint/133195

Wu, J. Z. J. (2023). *Reviving the May Fourth Spirit: Student Activism, the Diaoyu/Senkaku Islands, and the Geopolitics of Chineseness* (Doctoral dissertation, The University of North Carolina at Chapel Hill). doi: https://doi.org/10.17615/zzvc-n522

Yi, S. (2021). *The Impacts of a Science-Based Videogame Intervention on Interest in Stem for Adolescent Learners* (Doctoral dissertation, University of Illinois at Urbana-Champaign). Retrieved from https://hdl.handle.net/2142/110501

Yu, J., Denham, A. R. & Searight, E. (2022). A systematic review of augmented reality game-based Learning in STEM education. *Educational Technology Research and Development, 70*(4), pp. 1169-1194. doi: https://doi.org/10.1007/s11423-022-10122-y