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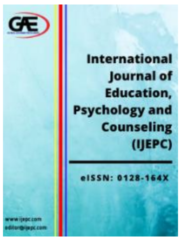


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# GAMIFYING SCIENCE EDUCATION: MINECRAFT EDUCATION BOOSTS TEACHERS' DIGITAL PROFICIENCY IN STEM EDUCATION

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**Abstract:**

In creating interactive and stimulating STEM to supplement the current educational trends, it is essential to include technology learning environments (Nungu et al., 2023). However, teachers may be reluctant to use digital tools due to the insufficient training or have little experience with new educational technologies (Munna & Kalam, 2021; Nungu et al., 2023). Therefore, this study was undertaken to determine the extent to which digital proficiency was improved among the 39 science teachers through the utilization of Minecraft Education (ME) in the workshop. The technological pedagogical content knowledge of digital games (TPACK-G) framework was used to assess the digital proficiency in pre-test and post-test. Teachers' digital proficiency was assessed from the perspective of game knowledge (GK), game content knowledge (GCK), and game pedagogical content knowledge (GPCK). The results showed that science teachers' digital skills improved significantly after the intervention with ME, with the GPCK showing the highest increase predictor. This was true for GK, GCK, and GPCK. The findings suggest that educational policymakers, curriculum designers, and professional developers should consider the potential of ME in enhancing teachers' and students' digital proficiency.

**Keywords:**

Digital Proficiency; Gamification; Minecraft Education; Science Teachers; STEM Education; TPACK-G Framework

## Introduction

The digital revolution has a profound effect on the education system in the 21st century, necessitating a paradigm shift from conventional ways of teaching to meaningful experiential

Volume 9 Issue 56 (December 2024) PP. 250-268
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learning, especially emphasizing STEM education (Ahmad et al., 2023). It is now a necessity for teachers to embrace more creative practices that broaden student engagement and learning beyond just giving knowledge. At the very heart of this transformation is the idea of digital literacy, which empowers teachers to draw upon appropriate technologies to enrich their pedagogical practices. Several studies show a significant relationship between teachers' digital proficiency and student engagement, learning achievements, and creativity, especially in the STEM disciplines (Tai et al., 2022; Harris et al., 2018).

Traditional science teaching methods often do not engage students or develop high-level skills such as critical thinking, problem solving, and collaboration when dealing with abstract science concepts. While there is growing global interest in STEM education, it remains difficult to create enriching pedagogical practices aligned with curriculum goals and accurately represent STEM fields (Tan et al., 2021). Teachers also expressed uncertainty about incorporating digital technologies into their teaching practices due to concerns about misalignment with curricular objectives and insufficient training (Li et al., 2020). In addition, the existing emphasis on STEM education promotes only computer science and programming while neglecting other disciplines, resulting in a lack of interdisciplinary problem-solving skills (Tan et al., 2021).

Researches have presented gamification as an innovative and effective pedagogical technique that leverages game fundamentals to transform educational contexts into more engaging, student-centered learning moments (Smiderle et al., 2020). Of all of these, Minecraft Education (ME) has emerged as a powerful potential tool for changing the manner in which teachers teach science content. Known for building immersive, open-world experiential learning environments that are collaborative and exploratory in nature, ME is a digital sandbox style platform. The versatile tool not only facilitates the integration of science into STEM learning environments (Panja & Berge, 2021), but also offers students interactive opportunities to explore science in a real-life context. Studies have reported that ME, in conjunction with other techniques, fosters interdisciplinary learning and boosts student motivation through active learning experiences (Van den Beemt et al., 2020)

However, even though ME has enormous potential to accelerate change for the better, many teachers experience huge barriers in using platforms like it due to low digital literacy and lack of professional development. Teachers often lack the digital competencies necessary for effectively implementing gamified teaching strategies, such as game knowledge (GK), game pedagogical knowledge (GPK), and game pedagogical content knowledge (GPCK), despite using gamification in pedagogical approaches that involve games (Hofer, 2015). The parameters of this study are ME, digital proficiency, and science teachers. Therefore, this study has analyzed the significance of ME in enhancing the digital skills of science teachers within TPACK-G. Thus, ME can play a crucial role in enhancing science education by preparing teachers to deliver better STEM learning experiences, thereby contributing to improved student outcomes.

## Literature Review

### *Technological Pedagogical Content Knowledge-Games (TPACK-G)*

The TPACK-G framework by Hsu et al. (2013) serves as the theoretical foundation for this study, emphasizing the integration of digital tools like Minecraft Education (ME) to enhance digital proficiency among science teachers. The framework comprises General Knowledge

International Journal of Education, Psychology and Counseling
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Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016
(GK), General Pedagogical Knowledge (GPK), and General Pedagogical Content Knowledge (GPCK). GK forms the base, providing teachers with fundamental knowledge on utilizing digital game tools such as ME in teaching. GPK builds upon GK by assessing teachers' understanding of ME's characteristics that support teaching methods. GPCK, the most advanced level, focuses on effectively guiding students in acquiring science knowledge through appropriate pedagogical methods using ME.

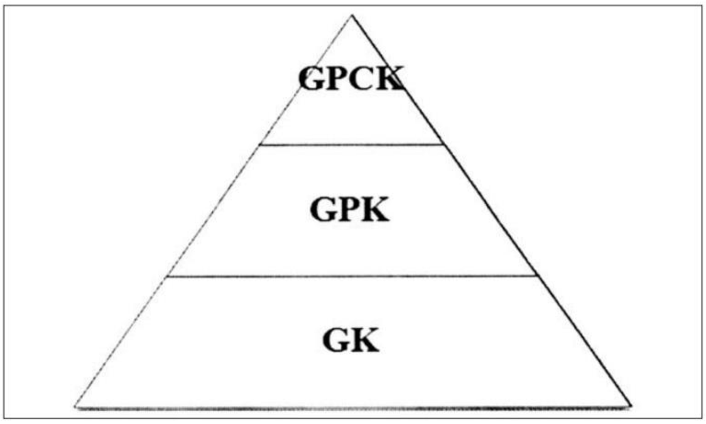


**Figure 1: The Framework of Technological Pedagogical Content Knowledge-Games (TPACK-G) by Hsu et al. (2013)**

According to Subaveerapandiyan et al. (2022), GK refers to the fundamental skills that prepare teachers to implement game-based tools such as ME in classroom environments. This requires a technical understanding of the platform and the ability to utilize its various features effectively. Basics of GK include knowing how to find the way in the Minecraft world (Yuan et al., 2023) and having a brief idea about its interface. Teachers learn about the operation and potential of ME. GPK expands on GK (König et al., 2020) and goes deeper into ME support for teaching processes. At this level, the focus is on knowing how such affordances may serve to enhance classroom engagement, collaboration, or motivation for students via ME. GPCK requires teachers to harmonize technical and pedagogical knowledge with subject-specific content knowledge. In examples such as science education, GPCK means utilizing the chemistry features of ME to show chemical reactions or using the Redstone component of ME to teach simple circuitry. There is also the need for teachers to constantly tie these activities back to curriculum standards and learning objectives so that gamification drives sustainable and meaningful content acquisition.

According to research by Ilomäki et al., professional development programs on digital literacy should be accompanied by practical use of the tools, enabling teachers to become confident in utilizing these tools outside their classrooms. In addition, Bertrand and Namukasa (2020) reported that teachers receiving targeted professional development on ME felt more confident in developing interactive STEM lessons, that was aligned with the curriculum. The increasing evidence of this need has come to indicate the critical role of adequately equipping teachers with the effective use of gamification tools in STEM education, and provides grounds for demonstrating the TPACK-G framework as a possible implemented guidance of such.

***Digital Proficiency for Science Teachers***

Digital proficiency has been viewed through multiple lenses, which can serve as a foundation for its theoretical concept. Ferrari (2012) provided a definition of digital proficiency that

Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016

encompasses three primary domains: knowledge, affective skills, and skills. These domains are crucial for effectively using technology to solve problems and create solutions in daily life. Ilomäki et al. (2016) comprehensively described digital proficiency as a broad perspective that integrates technological domains and scientific knowledge with the essential skills required for individuals to effectively engage and participate in a digital knowledge community. To conclude, digital proficiency for teachers is not merely based on the fundamental understanding of technology and computer programs but involves full comprehension of knowledge, abilities, and attitudes that relate to digital, moral, and legal aspects (Althubyani, 2024). This digital proficiency serves as a powerful tool for teachers in science teaching, particularly when integrating STEM elements, as science curricula have a strong connection to technology through their practical topics.

The effort and support for this technology integration are needed with opportunities to improve teachers' proficiency in using digital tools and contemplate the teaching methods in driving the science education higher into more digitalize (Althubyani, 2024). Digital technologies play a crucial role by offering engaging, interactive learning environments that foster flexible, adaptive, and distant learning. The presence of technology allows students to easily obtain up-to-date scientific material, thereby improving their learning experiences (Althubyani, 2024). Ferrari (2012) and Ilomäki et al. (2016) present critical theoretical underpinnings of digital profociency, emphasizing the connection to knowledge, affective aspects, and skills necessary for problem-solving and engagement in digital communities. However, the discussions of Ferrari (2012) and Ilomäki et al. (2016) lack a practical focus, particularly when it comes to implementing digital competence in STEM education to address real-life classroom challenges. However, while the European Commission (2019) and Althubyani (2024) emphasize the significant potential of technology in fostering collaborative and interactive environments for science teaching, they fail to offer practical solutions to address structural barriers such as inadequate pre-service and in-service teacher training, limited availability of digital tools, and a reluctance to adopt new pedagogical approaches.

Tai et al. (2022) outline digital proficiency gaps for teachers, illustrating the deep structural and systemic issues embedded within education systems. The Khairy Jamaluddin Report (2022) and the Ministry of Education, Malaysia (2013) also provide data that corroborate these findings, revealing that almost 8 out of 10 teachers spend less than one hour a week integrating ICT into their lessons. There is a strong correlation between the low student recurrent ITER trend in global assessments such as TIMSS and PISA (Joseph, 2017), indicating that education is still cautious in its adoption of digital technology. While these studies often find major issues with teacher preparation programs or courses, the programs don't always go beyond just listing the lack of well-trained teachers or providing evidence for why some teacher training and course designs aren't up to par. Even less often, they offer practical solutions to problems found in over 100 programs for future teachers or thousands of pre-college courses.

The current study attempts to fill these gaps by further containing digital literacy in STEM education. It investigates the opportunity gamified tools such as ME have to provide educators with the relevant skills and confidence levels needed for effortless inclusion of technology in their practice. The critical lens that guides this research not only identifies gaps in practice but also guides the creation of new frameworks and professional development. It strives to transform the theoretical implications of educational theory and practice into actionable ideals.

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***Gamification in Education***

Education has widely adopted gamification, or the application of game-based elements outside of gaming contexts, to transform the learning process. It encourages engagement, motivation, and active participation, which is useful in overcoming traditional problems of education, such as low retention of concepts, disinterest, and inactivity (Pham et al.,2021). The gamified method takes advantage of such components as competition, incentives, and energetic obstacles to raise the learning process. Despite its promising potential in education, a more complicated view of gamification and STEM education seems warranted. The difficulty is to combine fun with educational goals that lead to effective, deep learning (Panja & Berge, 2021). Recent studies, such as those by Papadakis and Kalogiannakis (2019), have recognized that incorporating gaming into the simulation and teaching of STEM concepts can enhance the effectiveness of teaching innovative complexities through interactive illustrations. Many of these simulations use scenarios that allow the student to see abstract concepts and explore those in a safe environment. Yet, despite these advantages, existing educational games targeting the STEM focus have been criticized for their narrow reach. Such programs tend to focus on drill-type or rote learning rather than nurturing higher-order thinking, problem-solving, and creative exploration (Balasubramanian & Wilson, 2022). This points to a significant gap in the literature: the lack of gamified tools that go beyond superficial gimmicks.

ME is one tool that has received some recognition for moving toward better addressing some of these gaps. Unlike many conventional STEM games, ME provides a highly configurable and open-ended platform capable of supporting different educational goals. Teachers can design activities specifically for curricula, ensuring that the items align with the learner's specific needs in many cases. For instance, the chemistry component of ME enables students to experiment and produce diverse reactions or compounds, and its Redstone capabilities facilitate the creation of circuitry, thereby integrating engineering concepts into the learning process (GoE-Craft, 2020). According to Bertrand & Namukasa (2020), ME not only promotes creativity and critical thinking but also acts as a natural linkage between theoretical STEM content and its practice. The idea of using gamification in STEM learning has potential, yet the combination is not without its challenges. One of the key obstacles is the lack of digital skills among teachers. Limited training and lack of experience with sophisticated advanced digital platforms make teachers unable to effectively utilize gamified tools such as ME (Subhash & Cudney, 2018; Nebel et al., 2015). That is especially an issue in STEM education, where technology tools typically go beyond mere content knowledge and pedagogy. Research has repeatedly demonstrated that even with the most innovative gamification tools, their impact would be limited without targeted professional development (Bertrand & Namukasa, 2020). The second issue pertains to the scarcity of gamified tools specifically designed for STEM education. Despite a rising literature on gamification, the majority of studies focus on general education rather than the specific requirements of STEM subjects (Balasubramanian & Wilson, 2022). STEM education requires not only tools that can engage students but also the means to convey complex and interrelated ideas to them. Although ME has demonstrated its creative potential, its effectiveness in teaching advanced subjects such as calculus, organic chemistry, or machine learning remains uncertain.

***STEM in Minecraft Education (ME)***

ME opens up a platform for dynamic STEM support through the provision of immersive, interactive, and gamified experiences. Minecraft's sandbox approach enables students to explore scientific principles, design virtual world simulations, and participate in project-based

Volume 9 Issue 56 (December 2024) PP. 250-268
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learning experiences that foster creativity, collaboration, and critical thinking, essential skills for the 21st century (Squire, 2011). Gamification encourages students in ways that traditional pedagogy often overlooks, increasing their interest in STEM subjects.

One of the main features of ME is the incorporation of various STEM fields into a single learning activity. For instance, the Redstone feature teaches students foundational engineering and electrical circuitry concepts along with logic gate principles, and the code builder allows them to advance their programming skills and computational thinking (Papert, 1993). Students calculate areas, measure angles, and manage resources to reinforce mathematical principles, while chemistry experiments and ecological simulations differentiate scientific exploration. ME's unique ability to blend disciplines creates a holistic approach to STEM education (Papadakis & Kalogiannakis, 2019).

ME allows students to engage with their applied and conceptual understandings of challenging STEM concepts through an avenue for tactile and experiential learning, as noted by Baek et al. (2020). However, as strong as these positive attributes are, ME can be a difficult fit within STEM education. A major drawback is dependence on teacher knowledge. In fact, educators only use ME effectively when they have not only a proficiency in digital technology but also interdisciplinary knowledge to combine different STEM components within it (Tan et al., 2021). However, as noted by Roehrig et al., (2021), not all teachers have engineering knowledge, which presents a barrier to designing tasks that utilize ME to its full potential. There are fewer, and the quality of resources isn't great, not just for industry development but for the type of teaching this should really develop into because it is absolutely interdisciplinary and even harder to create effective professional development programs to prepare teachers for truly integrated STEM.

Similar challenges include curriculum alignment and the scalability of ME. A study by Papadakis (2020) reveals that training initiatives for teachers frequently neglect to prioritize the use of STEM and gamification tools, leaving teachers with insufficient knowledge about these methods. Of course, curriculum alignment presents another challenge, making it difficult to adapt a game-based tool to meet curriculum standards. Teachers need to guarantee that gameplay is in line with learning objectives and does not pay too much interest to game mechanics (Subhash & Cudney, 2018). Although ME allows teachers to design lessons tailored specifically to their students, it can often take a lot of time and work to figure out how those activities fit into standardized curricula. In particular, the inadequacy of technology and necessary funding for professional development programs in many schools limits the effectiveness of ME as a learning tool.

These barriers are particularly severe in disadvantaged areas, where the digital gap continues to hinder growth through the use of innovative educational technology (Panja & Berge, 2021). Bertrand and Namukasa's (2020) studies demonstrate that ME enhances students' conceptual understanding of problems, but there are limited longitudinal studies on its impact on performance. Conversely, although they provided a tremendous deal of evidence for its value in student engagement, few studies have discussed how ME also mixes with the challenges posed when teaching advanced STEM topics like calculus, organic chemistry, or robotics. Another significant gap concerns the adaptability of ME in various settings. This has led to a narrow focus in current research, predominantly examining its application in high-resourced settings, with minimal evidence as to the transferability of this work into lower-resourced

Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016
schools. Such scarcity in research hinders the global scalability of ME as a solution for STEM education. Furthermore, research shows that gamification enhances motivation and engagement (Dichev & Dicheva, 2017). However, studies like Balasubramanian and Wilson (2022) show that this benefit is context-sensitive, meaning that mere integration of game elements does not lead to improvement. Instead, the effectiveness relies on the quality of teacher facilitation. This again argues that teacher training programs should be able to use effective gamification learning tools to their fullest potential.

## Aim And Research Question

While prior research explores the benefits of gamification and ME for student learning in science, a gap exists regarding the impact of these tools on science teachers' digital proficiency. This research aims to address this gap by investigating how ME can contribute to boosting digital proficiency in science teachers. Therefore, the research objective is to leverage the interactive features and educational potential of the ME to promote innovative teaching methods among science teachers and foster a vibrant STEM learning community.

Accordingly, the research questions of this study were as follows:

1. What is the level of digital proficiency with Minecraft Education after the intervention?
2. Do differences exist in science teachers' GK, GPK, and GPCK of the digital proficiency?

## Methodology

### *Research Participants*

39 science teachers participated in the research. To prevent cross-contamination between the groups, the science teachers were selected from different schools that shared the same teaching environment, specifically the daily school setting. The inclusion criteria included participants were selected from among teachers who were currently teaching science subjects in secondary schools and must have had a minimum of two years of teaching experience, while having a limited knowledge about digital tools and educational technologies. This stipulated that the teachers should also have experience on teaching STEM related subjects.

Exclusion criteria included teachers who had either never used digital games or other educational technologies in their teaching and *those* who had attended previous Minecraft-related professional development workshops. Participants had similar qualifications (at least a bachelor's degree in science education) and comparable socio-economic back grounds which prevented a diverse professional experience and educational background in the sample.

### *Research Instrument*

The study employed the Digital Proficiency Teacher Survey with 21 items, to investigate the proficiency of science teachers. The instruments were adapted from Hsu et al.'s (2013) Technological Pedagogical Content Knowledge-Games (TPACK-G) survey items, which included game knowledge (GK), game pedagogical knowledge (GPK), and game pedagogical content knowledge (GPCK). The respective reliability coefficients (Cronbach's alpha) were GK (0.93), GPK (0.93) and GPCK (0.94). The overall reliability coefficients were 0.95, recommended that the survey items is highly reliable to evaluate the sample of science teachers confidence in TPACK-G.

International Journal of Education, Psychology and Counseling
EISSN : 0128-164X
IJEPC
Volume 9 Issue 56 (December 2024) PP. 250-268
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The descriptions of the three scales are below:

1. Game Knowledge (GK): Evaluating confidence level of teacher in comprehension of how to utilise digital games, such as "I felt confident using ME."
2. Game Pedagogical Knowledge (GPK): Evaluating confidence level of teachers in comprehension of the way of digital games support teaching methods, such as "I know how to use ME to support students in developing ideas."
3. Game-Pedagogical-Content Knowledge (GPCK): Evaluating confidence level of teachers in effectively guiding students' acquisition of specific subject matter by using appropriate teaching methods in ME, such as "I can use ME to provide opportunities to the students to develop their content understanding in the ME world."

The adapted instrument items were presented on a 5-point Likert scale, with 1 denoting strongly disagree, 2 disagree, 3 neither agree nor disagree, 4 agree, and 5 strongly agree. Two professionals analyzed and validated the content's validity.

***Justification for TPACK-G and Minecraft Education (ME)***

The choice of the TPACK-G framework and the focus on ME are central to this study's objectives. The TPACK-G framework is highly suitable for addressing the research questions as it provides a structured model for evaluating the integration of technology (digital games) into teaching practices (Voithofer & Nelson, 2021). TPACK-G assists in identifying the extent to which teachers can integrate game knowledge with pedagogical and content knowledge for positive student learning outcomes in STEM (Aktaş & Özmen, 2020). Considering that using digital tools ME is taking on greater significance in education both in teaching and in STEM, TPACK-G provides a holistic framework to the extent of teachers' space users' readiness for tool use.

Additionally, ME is selected for this study because the project aims to improve teachers' digital proficiency, and the chosen educational game ME is well-known. ME is a creativity-based problem solving and collaboration interactive game-based learning environment that works very well with STEM essentials (Baek et al. 2020). Minecraft has been gaining a lot of traction in classrooms across the globe, providing students with role-play environments for hands-on labs that combine science explorations, engineering design, and mathematics problem solving (Baek et al. 2020). This study investigates how science teachers can use such digital tools to promote deeper engagement and learning in STEM through integrating ME into professional development.

TPACK-G combined with ME in the classroom provides a double approach for improving digital literacy. Although the TPACK-G framework provides a granular analysis of teachers' ability to utilize technology in their teaching practice, ME is a practical outlet as it enables teachers to translate this within actual teaching events. This combination is expected to contribute to the field by providing insights into how game-based learning can enhance teachers' pedagogical practices and improve student outcomes in STEM education.

***Procedure***

The 39 science teachers who attended the Minecraft workshop were required to design a ME learning lesson project, which took them about five weeks to complete. The teachers were required to investigate existing ME games that could enhance student learning in their future

Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016
subject areas, conduct an analysis feature and criteria of ME, develop a lesson plan that incorporates ME and finally design the Minecraft World based on the designed lesson plan. At the beginning of the project, the instructor provided an overview of the project and relevant resources (i.e., project procedures, methods of using ME in STEM education, lesson plan templates, etc.) for digital game search in ME and lesson plan development. The lesson plan had to incorporate STEM elements into the teaching and learning process. The science application was used in the lesson plan when students or teachers explained the scientific concepts. Students utilized ME to create technology applications, such as games or science projects. Students create engineering applications by designing science projects that assess their understanding and proficiency in scientific concepts. The mathematics application measures the block movement in ME. Before the intervention, a pre-test was conducted to determine the teachers' initial digital proficiency. Two months later, the post-test was administered, and the teachers were also required to present the chosen ME digital games and create lesson plans that incorporated STEM elements into their lessons in the Minecraft workshop and the creation in ME. In the workshop, teachers acted as the role of the students as the mathematicians and scientists when exploring and interacting with the virtual world in ME through engineering and technology application during the project designing in Minecraft world. The instructor and peers provided feedback to help science teachers refined their lesson plans.

***Data Collection***

The study was conducted using the Digital Proficiency Teacher Survey. The pre-test and post-test were provided to science teacher at the beginning and the end of the Minecraft Workshop. The survey questionnaire consisted of four sections: teacher background information, GK, GPK, and GPCK (Table 1).

**Table 1: Instruments**

| Scales | Number of items | Range | Cronbach’s alpha |
|---|---|---|---|
| GK | 7 | 1-5 | 0.93 |
| GPK | 7 | 1-5 | 0.93 |
| GPCK | 7 | 1-5 | 0.91 |

The Digital Proficiency Teacher Survey, originally developed by Hsu et al. (2017), was adopted to measure science teachers’ proficiency in GK, GPK, and GPCK components (Table 1).

***Data Analysis***

Two tests were used in testing the research hypotheses: (a) paired sample t-test, (b) repeated measure ANOVA. A paired sample t-test was conducted to compare the means of digital proficiency over the time test (pre-test and post-test) for one group of science teachers. The descriptive data likes number, mean percentages, and standard deviations for pre-test and post-test, were calculated for the dependent variable group. The step was substantial and tested the null hypothesis and determined that significant differences exist for the pre-test and post-test among the science teachers. Secondly, the repeated measure ANOVA was applied as only one group of participants in this research study, to investigate possible digital proficiency percentage differences and among the three GK, GPK and GPCK component. The descriptive statistics was conducted to determine the differences of digital proficiency and the GK, GPK, and GPCK of the digital proficiency. Therefore, the second step was focused on completing follow-up tests to explain the test differences in digital proficiency and the GK, GPK, and GPCK of the digital proficiency. The repeated measure ANOVA was undertaken to test differences gradually on the two tests on the digital proficiency. This enables the test of hypotheses on the effect of the ME in increasing the digital proficiency in GK, GPK, and GPCK simultaneously. Additionally, the repeated measure ANOVA distinguishes whether statistical differences exist in the interaction between test time and the GK, GPK, and GPCK.

**Results**
In answering the first research question,

**Q1**: What is the level of digital proficiency with Minecraft Education (ME) after the intervention?

The pair sample t-test was carried out in analysing the effectiveness of ME in Minecraft Workshop in increase digital proficiency among science teachers. Table 2 shows the paired sample statistics for the pre-test and post-test of the digital proficiency.

**Table 2: Paired Samples Statistics**

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Pre-Test | 64.95 | 39 | 15.96 | 2.56 |
| Post-Test | 85.62 | 39 | 6.24 | .99 |

In the pre-test of the digital proficiency, the mean score is 64.95 with the sample size is 39 science teachers. The standard deviation is 15.96, indicating a moderate amount of variability in the scores. The standard error of the mean is 2.56, suggesting that the sample mean is reasonably precise. In post-test of the digital proficiency, the mean score is 85.62. The standard deviation is 6.24, indicating a lower variability in the scores compared to the pre-test. The standard error of the mean is 0.99. Comparably, the means and standard deviation, it can observe that the post-test mean (85.62) is significantly higher than the pre-test mean (64.9487). The standard deviation post-test (6.24) is smaller than the pre-test (15.96). This indicates that there might be a positive effect of the intervention or treatment between the two tests (Refer Table 1). Based on Cohen’s guidelines (1988) and Sawilowsky (2009), the Cohen's d of -3.32 indicates a very large effect size and practical significance of the difference between the pre-test and post-test scores. The negative sign simply indicates that the mean of the second group (post-test) is larger than the mean of the first group (pre-test). This suggests a substantial improvement in scores from the pre-test to the post-test. Based on Cohen’s guidelines (1988) and Sawilowsky.

Table 3 showed the comparable result in the paired sample test between the pre-test and post-test of digital proficiency for 39 science teachers.

Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016

**Table 3: Paired Samples Test**

| Paired Differences | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 95% Confidence Interval of the Difference | | | | |
| | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| PreTest-PostTest | -20.67 | 19.11 | 3.06 | -26.86 | -14.47 | -6.75 | 38 | .00 |

Based on the provided output Table 3, the mean difference between pre-test and post-test of digital proficiency total scores is -20.67. This indicates that, on average, participants scored 20.67 points higher on the post-test compared to the pre-test. The t-value is -6.75 with 38 degrees of freedom. The p-value is .00. By given that the p-value is less than .05, the null hypothesis is rejected and conclude that there is a statistically significant difference between the pre-test and post-test total scores. This implements that Minecraft Workshop intervention with ME had a positive impact on science teachers' overall performance in digital performance. The overall performance among science teachers increases with the assistance of the ME in lesson study. In another words, the result gave strong evidence showing that participants performed significantly better on the post-test compared to the pre-test.
In answering the second research question,

**Q2**: Do differences exist in science teachers' GK, GPK, and GPCK of the digital proficiency?

The three components of the digital proficiency: GK, GPK and GPCK of the pre-test and post-test are analysed with repeated measure ANOVA in Table 4, 5 and 6.

**Table 4: Descriptive Statistics**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| PreGK_Total | 22.05 | 4.24 | 39 |
| PostGK_Total | 26.67 | 2.93 | 39 |
| PreGPK_Total | 20.23 | 5.48 | 39 |
| PostGPK_Total | 30.26 | 3.11 | 39 |
| PreGPCK_Total | 22.67 | 8.24 | 39 |
| PostGPCK_Total | 29.54 | 2.69 | 39 |

All pre-test means for GK, GPK, GPCK are lower than their corresponding post-test means, implying a great potential improvement in scores after the intervention. Pre-test for GPCK has the highest standard deviation (8.24) (refer to Table 4), indicating a wider range of scores for this variable compared to the others. All post-test means for GK, GPK, GPCK are higher than their corresponding pre-test means, reinforcing the potential positive impact of the Minecraft Workshop with ME intervention. Post-test for GK has the lowest standard deviation, suggesting less variability in scores compared to the other post-test variables. There seems to be an increase in scores from pre-test to post-test for all three areas. The variability in scores

International Journal of Education, Psychology and Counseling
IJEPC
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Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016

differs across variables, with Pre-test for GPCK showing the highest variability in both pre and post-test.

Table 5 shows the multivariate test for the repeated measure ANOVA on one group of 37 science teachers in this research study and Table 6 shows the tests of within-subject contrasts.

**Table 5: Multivariate Test**

| Effect | | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|---|
| Between Subjects | Intercept | Pillai's Trace | .995 | 2405.216[b] | 3.000 | 36.000 | .000 | .995 |
| | | Wilks' Lambda | .005 | 2405.216[b] | 3.000 | 36.000 | .000 | .995 |
| | | Hotelling's Trace | 200.435 | 2405.216[b] | 3.000 | 36.000 | .000 | .995 |
| | | Roy's Largest Root | 200.435 | 2405.216[b] | 3.000 | 36.000 | .000 | .995 |
| Within Subjects | Time | Pillai's Trace | .760 | 38.101[b] | 3.000 | 36.000 | .000 | .760 |
| | | Wilks' Lambda | .240 | 38.101[b] | 3.000 | 36.000 | .000 | .760 |
| | | Hotelling's Trace | 3.175 | 38.101[b] | 3.000 | 36.000 | .000 | .760 |
| | | Roy's Largest Root | 3.175 | 38.101[b] | 3.000 | 36.000 | .000 | .760 |

a. Design: Intercept
Within Subjects Design: Time
b. Exact statistic

**Table 6: Tests of Within-Subjects Contrasts**

| Source | Measure | Time | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|---|
| Time | GameKnowledge | Linear | 415.39 | 1 | 415.39 | 23.50 | .000 | .38 |
| | GamePedagogy Knowledge | Linear | 1960.01 | 1 | 1960.01 | 85.96 | .000 | .69 |
| | GamePedagogyContent Knowledge | Linear | 920.82 | 1 | 920.82 | 21.85 | .000 | .37 |
| Error (Time) | GameKnowledge | Linear | 671.62 | 38 | 17.67 | | | |
| | GamePedagogy Knowledge | Linear | 866.49 | 38 | 22.80 | | | |
| | GamePedagogyContent Knowledge | Linear | 1601.18 | 38 | 42.14 | | | |

A repeated measures ANOVA (refer to Table 5) was conducted to examine changes in digital proficiency among science teachers from pre-test to post-test across three components: game knowledge, game pedagogy knowledge, and game pedagogy content knowledge. The analysis revealed a significant main effect of time, $F(3, 36) = 38.101$, $p < .001$, partial eta squared = .760, indicating a significant improvement in overall digital proficiency from pre-test to post-test. Significant Main Effect of Time: The significant main effect of time (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root, all $p < .001$) indicates that there is a significant difference in digital proficiency between the pre-test and post-test. Based on the main effect of time, There was a significant main effect of time, $F(3, 36) = 38.101$, $p < .001$, partial eta squared

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
**Volume 9 Issue 56 (December 2024) PP. 250-268**
**DOI 10.35631/IJEPC.956016**
= .760, indicating a significant improvement in overall digital proficiency from pre-test to post-test. Besides that, the univariate tests also shows the significant differences between pre-test and post-test for all three components GK, GPK and GPCK as indicated by the p-values of .000 for each component. Further analysis using univariate tests indicated significant improvements in all three components: GK, $F(1, 38) = 23.502$, $p < .001$, partial eta squared = .382; GPK, $F(1, 38) = 85.957$, $p < .001$, partial eta squared = .693; and GPCK, $F(1, 38) = 21.853$, $p < .001$, partial eta squared = .365. (refer to Table 5). This finding reveals that the science teachers tended to have more confidence in GPK.

**Discussion**

This study aimed to evaluate the effectiveness of the Minecraft workshop with ME at enhancing the digital proficiency of science teachers in STEM teaching. The Digital Proficiency Teacher Survey that was given before and after the intervention gives enough proof for the research study results to show that ME can help teachers become more digitally proficient (Gutiérrez et al., 2017). Despite acknowledging the potential usefulness of TPACK-G in integrating digital games into educational practices, its application in STEM education remains relatively understudied. The study showed that ME successfully supported science teachers in STEM education, providing them with exposure to multi-interdisciplinary STEM teaching (Hsin et al., 2014; Hamari et al., 2016). Science teachers showed an increase in Science teachers demonstrated an increase in their digital proficiency across the three components of digital proficiency: GK, GPK, and GPCK, and were able to apply STEM applications during lesson activity design with ME. These results provide strong evidence that ME was effective in improving teachers' professional development in digital literacy, as supported by researchers who assert that experience with games and knowledge in game-based learning are crucial factors in directing the application of games in lessons (Hsu et al., 2013). This aligns with previous research suggesting that immersive and interactive learning environments like ME can significantly enhance digital literacy and pedagogy (Gutiérrez et al., 2017; Hsin et al., 2014).

ME is effective because it offers an experiential, collaborative learning space that encourages problem-solving. In this workshop, teachers utilized ME's virtual worlds to create STEM-focused lesson plans, learning how to simulate scientific processes through hands-on activities. One case study from the workshop, for example, illustrated teacher teams planning a physics lesson on force and motion. The teachers gained a greater appreciation of STEM applications while laying the foundation to help them feel more comfortable designing gamified experiences like this for their students by creating a virtual environment for students to build simple machines and see how their mechanics worked in action. In a similar manner, ME also fostered its collaborative approach to allow teachers to work through ideas and refine their lesson designs. One of the more significant examples was a biology teacher who used ME to depict an ecological system, allowing students to visualize and explore food chains and energy transfer in an interactive visual representation. The hands-on exercises played a crucial role in equipping teachers with the confidence to incorporate digital tools into their interdisciplinary STEM teaching, which emphasizes the need for practical and applied training.

In answering Research Question 1, the research results confirm the intervention's success in increasing digital proficiency. Table 2 illustrates a change in science teachers' digital proficiency in the pre- and post-test. Before the intervention using ME, the digital proficiency of the science teachers was still at an average level of 64.95. ME in STEM teaching was new

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016
to the teachers before the intervention. Teachers found it difficult to apply gamification techniques to teaching and struggled to apply ME to interdisciplinary STEM education (Becker & Park, 2011). The pre-test revealed that science teachers encountered challenges in comprehending and implementing ME, as evidenced by their low mean scores. The concepts of applying ME in lesson planning were unclear to most teachers, and they lacked confidence in using ME to teach science concepts. Consequently, the high value of the standard deviation (15.92) indicated significant variation in teachers' digital proficiency with ME (refer to Table 2). As teachers' knowledge levels in GK, GPK, and GPCK increased, the likelihood of meeting educational goals and acquiring knowledge across the STEM elements also increased (Mishra & Koehler, 2006). As teachers gained a deeper understanding of ME's potential to deliver interdisciplinary STEM teaching, their acceptance of ME grew (Cheng & Tsai, 2019).

Nevertheless, this group of teachers achieved high scores in the Digital Proficiency Teacher Survey post-intervention using ME. The number of teachers demonstrating digital proficiency with ME increased, with greater competence in game design for science concepts (Table 2). The science teachers independently developed lesson plans integrated with ME at the end of the intervention. Data showed a significant increment in the mean score of the post-test compared to the pre-test, with an increase of 20.67 points, from a pre-test mean score of 64.95 to a post-test mean score of 85.62. This proves that ME had a positive impact on teachers' digital proficiency, enabling them to design interactive lesson plans using ME as well as utilizing digital game search features within ME to explain science concepts (DeMarree et al., 2016). Even though some researchers have questioned the use of digital games in lessons ( Hsu et al., 2013), appropriate levels of GK, GPK, and GPCK can enable teachers to plan lessons that align well with learning goals (Angeli & Valanides, 2009). This study proposes the TPACK-G framework to address its needs.

Each of the three components of digital proficiency (GK, GPK, GPCK) showed significant (d) effects, with GPK demonstrating the largest mean score difference. This indicates that teachers felt more confident about taking advantage of ME as a pedagogical tool. This transformation was largely due to the immersive, gamified experience of ME. The engaging, visual, and interactive elements of ME helped to make abstract STEM concepts more real and relatable, allowing teachers to communicate these concepts in a way that was easier for students to understand. GPCK was a particularly salient area for improvement given its representation of teachers' skills in integrating game-based tools with content knowledge to produce lessons with meaningfulness and impact. One example was a chemistry lesson where students created periodic tables using ME, which included virtual representations of elements for the students to identify and interact with. This innovative teaching approach not only enhanced the teacher's understanding of the subject matter, but also demonstrated the potential of ME to enhance STEM education. Another important factor was the practice of collaborative feedback. Group gatherings allowed teachers to share their lesson plans with one another and receive what was usually constructive criticism of their ideas so that they could hone a more precise understanding of game-based pedagogy. This matches up well with the role of game knowledge in serving as a bridge between pedagogy and content to meet educational objectives (Mishra & Koehler, 2006), which is such an important part of the TPACK-G framework.

To address Research Question 2, we conducted a repeated measures ANOVA to compare the pre-test and post-test scores of the three digital proficiency components: GK, GPK, and GPCK. The results demonstrate a significant improvement in the digital proficiency of science teachers

International Journal of Education, Psychology and Counseling
IJEPC
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Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016
following the intervention. The intervention effectively addressed various aspects of digital competence, as evidenced by the observed enhancement across all three components of digital proficiency. The repeated measures ANOVA showed a strong main effect of time, which means that from the pre-test to the post-test, the participants' overall digital competence went up (Koehler et al., 2014). The research findings for all three components (GK, GPK, and GPCK) showed similar positive mean score increments in the post-test (refer to Tables 4, 5, and 6). Teachers showed an increase in GK from a pre-test mean score of 22.05 to a post-test mean score of 26.67 (refer to Table 4), with a total increment of 4.62. From the perspective of the GK component, teachers showed increased confidence in digital usage with ME. Confidence levels significantly influence teachers' ability to enhance their digital proficiency and successfully use ME in science teaching (Koehler et al., 2014; Angeli & Valanides, 2009).

On the other hand, for GPK, teachers exhibited the highest total increase in mean score of 10.03, from 20.23 (pre-test) to 30.26 (post-test) (Table 4). After the intervention, teachers employed high confidence in their digital knowledge and were more adept at integrating ME in their teaching (Bebell et al., 2010). Through lesson plan development that integrated ME, teachers gained a strong belief in the method of using gamification in science lessons. The engaging and interactive characteristics of ME align well with specific science topics, enhancing conceptual understanding. Therefore, GPK plays a critical role in determining teachers' readiness to use digital tools appropriately in the classroom (Mishra & Koehler, 2006). For GPCK, teachers showed the second-highest mean score increase of 6.87, from 22.67 (pre-test) to 29.54 (post-test) (Table 3). Notably, before the intervention, the standard deviation for GPCK was the highest (8.24), indicating substantial variability in how teachers approached the pedagogical application of ME in teaching science. After the intervention, the standard deviation for the post-test GPCK was the lowest (2.69), showing that teachers had significantly improved their understanding of how to integrate appropriate pedagogy with digital tools, specifically ME. The teachers' digital comprehension was evident in their ability to design appropriate science learning activities using suitable ME games (Schmidt et al., 2009).

Previous studies have shown that teachers' digital proficiency with digital tools is associated with game-based teaching in the classroom (Hsu et al., 2013; Hamari et al., 2016). Therefore, this study examines teachers' attitudes, preferences, and understanding of how ME functions within the TPACK-G framework. The results demonstrate that teachers' intention to use games like ME in teaching plays an important role in increasing their confidence in GK and GPK, which, in turn, contribute to GPCK (Davis et al., 1989). The findings align with the Technology Acceptance Model (TAM), which states that teachers' attitudes toward technology usage influence their intention to use it (Davis et al., 1989). Consequently, positive, fun learning experiences strengthened GK and GPK among participants in the Minecraft workshop. Teachers demonstrated increased capability in producing lesson plans that integrated ME, signifying a significant association between their digital proficiency with ME and their GPCK (Bebell et al., 2010). The Minecraft workshop provided valuable game experience that contributed to GK and GPCK development. More exposure to ME may enhance teachers' GK and GPCK, aligning with Hsu et al. (2013), who explored the relationship between preschool teachers' acceptance of educational games and their attitudes and exposure.

The study clearly articulates the positive effects of ME, but it also highlights its challenges and limitations. The context of the challenge When we first rolled it out, the teachers faced skepticism about using digital tools to teach. Teachers with minimal prior experience with ME,

Volume 9 Issue 56 (December 2024) PP. 250-268
DOI 10.35631/IJEPC.956016
for example, struggled to contextualize it within their practice and identify potential uses in interdisciplinary STEM teaching. A significant standard deviation of 15.92 showed that the pre-test results were not all the same. This meant that different people in the small group had different proficiency scores and different levels of digital competence. s. The need for teachers to receive ME training posed another challenge. Several teachers pointed out the strong learning effort involved in adopting ME for lesson design, particularly when trying to adapt around curriculum objectives. As an example, teachers had found it difficult to design STEM lessons that were both hands-on and in line with the learning goals.

## Conclusion

The significant improvements in all three components of digital proficiency among science teachers underscore the effectiveness of the intervention. These findings have important implications for teacher education and professional development training. By incorporating strategies focused on GK, GPK, and GPCK, teacher training programs can better equip teachers to leverage digital tools and resources for enhancing student learning. The observed improvements have significant implications for teacher education and professional development. By incorporating strategies focused on these three components, teacher training programs can better equip teachers to effectively integrate digital technologies into their classrooms. Although this report provides important insights, it should be regarded considering some limitations. Findings reflect a sample of science teachers; thus the generalizability of findings should be tested in other educational contexts and teacher populations. Future research can however assess other determinants of digital competence, including intrinsic motives from teachers, extrinsic support from others, as well as organizational policies driving technology use. Additionally, studies could evaluate how STEM curricula use ME and other digital tools for teaching and professional development. Such a study would shed more clarity on the possible avenues of integration between ME-like gamified platforms and traditional or mainstream education.To address the challenges associated with implementing Minecraft Education (ME) in diverse educational contexts, it is recommended that customized training programs are developed to cater to educators' varying levels of digital proficiency in integrating ME into STEM lessons, as well as ME accessibility by increasing funding and infrastructural support to facilitate the adoption of ME.

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