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AlgorithmAce: Development and Evaluating a Spatial-Unity Metaverse Platform to Foster Computational Thinking in Secondary Education

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Abstract. Computational Thinking (CT) is recognised as an essential skill for today's society, vital for addressing multidisciplinary challenges and equipping students to face future challenges. However, students' ability to understand the abstract nature of CT has been limited by a lack of immersive digital resources and the continued use of outdated teaching techniques. While efforts to incorporate CT into education have evolved, few learning tools are closely aligned with the national curriculum and make use of immersive technology, like the metaverse. This highlights a critical gap in both research and classroom practice. The Fundamental Computer Science curriculum served as a framework for developing *AlgorithmAce*. This study employed a Design and Development Research (DDR) approach to develop and evaluate *AlgorithmAce*, an immersive learning platform built using Unity and Spatial.io, designed to enhance CT skills among lower secondary school students in Southern Malaysia. A total of 180 students participated in the evaluation. The USE Questionnaire assessed four main aspects of usability, including usefulness, ease of use, ease of learning, and user satisfaction. Quantitative data were analysed using descriptive statistics and Pearson correlation via SPSS v27. The results indicated a strong correlation between perceived usefulness and user satisfaction ($r = 0.692$), while ease of use ($r = 0.660$) and ease of learning ($r = 0.556$) also showed significant positive relationships with satisfaction. These results demonstrated that metaverse-based environments can significantly improve student engagement and offer innovative pathways for CT instruction. This study supports the advancement of inclusive and equitable quality education in Malaysia by making abstract ideas more accessible through immersive and contextualised learning, which contributes to Sustainable Development Goal 4 (SDG 4).

Keywords: Computational Thinking (CT); Metaverse; Immersive Learning; Spatial-Unity; Computer Science Education

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1. Introduction

Computational Thinking (CT) enables students to deconstruct complex issues, observe patterns, and formulate systematic, sequential solutions, establishing it as a fundamental aspect of contemporary problem-solving across various fields (Fei et al., 2025; Shute et al., 2017). This skill is recognised as an essential cognitive capability in the digital era, relevant not only in computer science but also in any field requiring abstraction, analytical thinking, and algorithmic reasoning (Anderson, 2016; Rafli et al., 2024; Supiarmo et al., 2022). However, despite its recognised value, the effective integration of CT into classroom practices remains uneven.

Many students may provide answers to the problems they face. However, a more critical question arises: are these solutions as resilient and systematically organised as those derived from established problem-solving methodologies? The objective should not merely be to produce an answer but to ensure its quality, clarity, and transferability, which are hallmarks of genuine mastery. This underscores the need to train Computational Thinking (CT) as a structured cognitive skill. As emphasised by Muthmainnah et al. (2025), individuals with strong cognitive capacity are better equipped to solve problems, make informed decisions, understand complex topics, and make arguments supported by strong evidence, all of which are essential for producing effective and transferable solutions.

CT has been formally introduced into Malaysia's national curriculum since 2017 through courses such as Fundamentals of Computer Science and Digital Technology (Kusnan et al., 2020). Nevertheless, research indicates that numerous students, particularly in disadvantaged or rural regions, continue to struggle with fundamental concepts of computational thinking due to limited access to digital resources, reliance on outdated teaching methods, and the abstract nature of the subject (Akil & Matore, 2023; Ariffin et al., 2022). Although the integration of CT into the curriculum represents a beneficial advancement, students may still struggle to connect CT principles with real-world contexts, particularly when learning experiences are not sufficiently engaging or contextualised.

Immersive technologies, like the metaverse, present a promising solution to these challenges. Platforms such as Unity and Spatial.io provide dynamic, gamified settings that enable students to explore, collaborate, and address challenges through experiential learning (Wu et al., 2025; Zhang et al., 2025). While serious games and block-based platforms (e.g., Scratch) have shown educational advantages, few studies have investigated how these pedagogical ideas can be applied to 3D metaverse settings, especially for primary-level CT teaching (Gerini et al., 2025; Holstein & Cohen, 2025). This highlights the growing need to explore how immersive, interactive environments can be effectively designed and implemented to support meaningful computational thinking development in younger learners.

Although interest in Computational Thinking (CT) has expanded across various fields, its incorporation into early education remains uneven, particularly in relation to immersive teaching methodologies (Robledo-Castro et al., 2025; Zhang et al., 2025). Existing approaches, such as unplugged activities, robotics, and screen-based programming, have shown positive effects on engagement and cognitive development (Chevalier et al., 2022; Gundersen & Lampropoulos, 2025; Murcia et al., 2024). However, these methods often lack the interactivity and sense of presence offered by immersive experiences. As a result, students may struggle to internalise abstract CT concepts when instruction remains detached from experiential and context-rich environments.

Furthermore, although the metaverse shows significant potential for facilitating Computational Thinking (CT) education, empirical evidence regarding its practical efficacy remains scarce, particularly in fostering essential CT elements such as decomposition, abstraction, and algorithmic reasoning (Gerini et al., 2025; Gundersen & Lampropoulos, 2025). A significant gap also exists in the design frameworks for developing CT activities that are both aligned with national curricular requirements and are developmentally suitable (Holstein & Cohen, 2025; Murcia et al., 2024). While global literature affirms the promise of immersive platforms for teaching computational thinking, studies in Malaysia indicate that practical implementation of CT activities remains fragmented and underdeveloped, especially when aligned with the national curriculum (Mohmad & Maat, 2024; Subramaniam et al., 2023).

Although international literature has expanded the discussion on immersive technologies in education, local research on the use of metaverse platforms to teach computer science remains limited, especially among secondary school students (Selamat & Adnan, 2025). Research shows that incorporating Virtual Reality (VR) to transform conventional classroom activities into interactive, game-based experiences can significantly enhance student motivation and engagement.

Such immersive environments not only support learning but also foster higher-order skills such as creativity, communication, and critical thinking, which are skills that are equally crucial in computational thinking education (Muthmainnah et al., 2025). Consequently, the aim of this study was to address this gap by developing and accessing a metaverse-based educational game that serves as a teaching aid for computational thinking. The game integrates the principles of game-based learning, immersive technology, and CT pedagogy to improve student engagement and conceptual comprehension.

The findings from this study are expected to offer meaningful implications for educational practice, particularly in enhancing the quality of instruction through immersive technology. By aligning game-based metaverse environments with the national curriculum, the results can inform future curriculum design and support more effective integration of digital tools in science and computer education (Choi et al., 2025; Wang, 2024). Despite its educational potential, the integration of metaverse technology still faces significant challenges, including high technical demands, usability concerns, and the immaturity of platform development for instructional contexts (Choi et al., 2025).

This study was guided by the following objectives:
1. To develop *AlgorithmAce*, a metaverse learning platform to assist secondary school students in learning Computational Thinking (CT).
2. To conduct a usability evaluation of the *AlgorithmAce* platform using the USE Questionnaire.
3. To examine the relationships between usability dimensions (usefulness, ease of use, and ease of learning) and user satisfaction in the context of the AlgorithmAce platform.

2. Literature Review

2.1 Computational Thinking

Computational Thinking (CT) is a problem-solving approach that enhances creativity, reasoning, interdisciplinary flexibility, and a variety of technical abilities. By teaching techniques such as decomposition, abstraction, and the formulation of proactive solutions, CT helps students to handle complex problems (Chevalier et al., 2022; Gundersen & Lampropoulos, 2025; Shute et al., 2017). CT is often presented in educational contexts as a way of thinking and as a fundamental skill that links to higher-order thinking and digital literacy (Fei et al., 2025; Holstein & Cohen, 2025; Zhang et al., 2025). While higher-order thinking skills are heavily emphasised in school curricula to produce quality future leaders, the extent to which these skills are developed depends on how effectively they are taught and contextualised, especially through structured approaches like computational thinking.

Murcia et al. (2024), Robledo-Castro et al. (2025), and Zhang et al. (2025) highlight the importance of aligning CT instruction with developmentally appropriate methods, especially in early and primary education. Tools such as interactive visual programming environments, robotics kits, and tactile coding devices are often employed to make CT engaging and cognitively accessible for young students. For example, activities involving structured programming have been shown to improve executive functions such as inhibitory control and cognitive flexibility, which are critical for learning across domains (Chevalier et al., 2022; Murcia et al., 2024; Zhang et al., 2025). However, the effectiveness of these approaches in fostering a deep conceptual understanding of CT still depends on whether they are delivered through structured, continuous, and context-rich learning experiences.

Moreover, CT is increasingly promoted through constructivist and experiential learning models. Teachers are encouraged to incorporate CT into problem-based, collaborative, and creative situations rather than treating coding as an isolated skill (Gerini et al., 2025; Gundersen & Lampropoulos, 2025; Holstein & Cohen, 2025). Game-based learning and design-oriented approaches are also gaining traction, as they allow students to experiment, debug, and reflect in authentic scenarios that resemble real-world problem-solving (Gerini et al., 2025; Gundersen & Lampropoulos, 2025; Wu et al., 2025).

Although some researchers argue that over-reliance on low-fidelity technologies may limit students' ability to fully understand, others highlight the lack of curriculum alignment and teacher readiness for successful CT implementation (Chevalier et al., 2022; Holstein & Cohen, 2025; Murcia et al., 2024). This highlights the need to investigate more interactive and immersive modalities, particularly those that can offer meaningful feedback, adaptability, and collaborative opportunities to support the development of CT skills in diverse educational settings (Gundersen & Lampropoulos, 2025; Robledo-Castro et al., 2025; Wu et al., 2025). Without intentional pedagogical design, even advanced technologies risk becoming low experiences that fail to foster deep and transferable computational thinking abilities.

2.2 Metaverse

The metaverse is a three-dimensional (3D) virtual environment where the digital and real worlds converge (Zhang et al., 2022). According to Naim and Hua (2024), this technology is becoming widely recognised as a versatile platform with potential applications across all stages of education. In educational contexts, the metaverse is viewed as an interactive digital environment that provides immersive learning experiences, encouraging active student engagement and real-time peer interactions, thereby creating a more dynamic and participatory learning atmosphere (Chen et al., 2023).

Through metaverse platforms, students can connect and collaborate in virtual environments, enabling participation in virtual simulations, role-playing activities, and collaborative projects regardless of geographic boundaries (Pari-Bedoya et al., 2023). The integration of metaverse-based virtual reality may enhance learning outcomes in cognitive and physical domains, including improvements in confidence, motivation, and motor skills (Utamayasa et al., 2025).

Research in sustainability education has shown that immersive metaverse experiences may facilitate the integration of theoretical knowledge with practical problem-solving by providing realistic, interactive settings that enhance student engagement (Choi et al., 2025). However, researchers advise that excessive immersion without good instructional design might lead to cognitive overload, highlighting the need for a balanced combination of interaction, usability, and pedagogical techniques in metaverse-based learning (Choi et al., 2025; Ldokova et al., 2025). Given the diversity of students, digital learning experiences must be tailored to each student's learning style and psychological profile in order to optimise engagement and outcomes (Ldokova et al., 2025).

Recent empirical evidence supports this potential. Muthmainnah et al. (2025) found that students engaged in immersive VR-based metaverse learning not only improved their motivation and engagement but also developed transferable skills such as computational thinking, creativity, and problem-solving. Through VR content creation and reflective storytelling, learners demonstrated enhanced logical reasoning, abstraction, and decomposition, skills that are essential to computational thinking.

Building upon the need for more context-rich and engaging CT instruction, the metaverse holds substantial promise for making learning more accessible, engaging, and personalised, while also fostering critical cognitive, social, and emotional skills within an innovative digital context. Previous studies have shown that virtual reality and metaverse-based applications significantly improve student confidence, motor development, and engagement compared to traditional methods (Utamayasa & Mardhika, 2024; Liang et al., 2023).

In the context of Computational Thinking (CT) education, these immersive and experiential affordances provide a compelling solution to persistent challenges, including students' struggles with abstract concepts, a lack of contextual relevance, and disengagement with conventional instructional approaches. By enabling students to explore simulated real-world problems through interactive, student-driven tasks, the metaverse has the potential to make CT instruction more concrete, engaging, and pedagogically effective.

2.3 Spatial-Unity

To operationalise the affordances of the metaverse for CT instruction, this study utilised Spatial.io, integrated with Unity to design an immersive learning platform tailored to address the core CT challenges outlined earlier. The Spatial.io platform combines the cross-platform Unity game engine with its Spatial Creator Toolkit to facilitate the development of virtual worlds (Sriworapong et al., 2022). Through avatar-based interactions, Spatial.io presents immersive learning environments that enhance digital literacy and social skills while enhancing student engagement (Pujasari et al., 2024).

Game-Based Learning (GBL) within Spatial.io has also proven effective in boosting academic performance through interactive learning and gamification elements (Vate-U-Lan & Cahill, 2024). For instance, students' scores improved after using an English module created in a Spatial.io virtual environment (Vate-U-Lan & Cahill, 2024). Avatar systems, like Ready Player Me, further reinforce students' sense of presence and identity, improving their interactions with digital instructional material (Seo et al., 2017).

The Spatial Creator Toolkit, created in Unity, enhances immersive experiences by enabling dynamic visual elements such as multi-layered animations and shaders. For example, a Mars exploration project demonstrated the integration of intricate animation and lighting to create lifelike settings (Alabau et al., 2024). Despite some technical limitations, creative design strategies have effectively leveraged Spatial.io to enhance engagement and interactivity (Jover et al., 2025).

Overall, the virtual learning environments developed with Unity and the Spatial Creator Toolkit serve not only as instructional aids but also as platforms that encourage interaction, teamwork, and cognitive immersion in online learning (Wu et al., 2024). These features make Spatial.io an attractive tool for creating innovative, learner-focused virtual learning environments. Therefore, this study adopts Spatial.io as the primary development platform for *AlgorithmAce*, designed to support CT learning through immersive and gamified experiences.

3. Methodology

This study used the Design and Development Research (DDR) approach, which combines design, development, and evaluation processes to develop and evaluate educational products (Richey & Klein, 2014). This study employed the first category of DDR, focusing on the development and evaluation of a metaverse-based learning tool to improve students' computational thinking abilities (Richey & Klein, 2007).

As emphasised by Wang (2024), teaching designs for e-learning must be grounded in a rigorous theoretical foundation and incorporate appropriate technologies and tools to achieve optimal learning outcomes. This principle guided the development of *AlgorithmAce,* ensuring that the platform not only leveraged immersive technologies but also aligned with pedagogical objectives to enhance CT learning experiences meaningfully.

To address these issues, this project explored how immersive technologies, specifically the Metaverse, might make CT training more interactive, engaging, and accessible for Malaysian secondary school students. Therefore, it was necessary not only to develop innovative CT learning platforms using immersive technologies but also to evaluate their usability and effectiveness from the students' perspective. This study addressed to this need by developing a metaverse-based CT learning platform and assessing its usability using the USE Questionnaire.

However, this study only focused on the following stages, including designing and implementing the *AlgorithmAce* metaverse platform using Unity and Spatial.io, as well as assessing secondary school students' usability. The overall process of this study, which follows the phases of needs analysis, design and development, and usability evaluation, is illustrated in Figure 1.

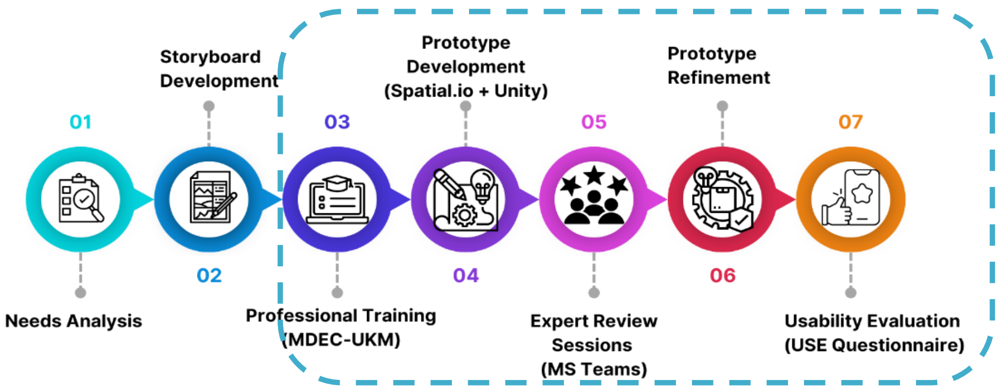

Figure 1: Research Flow

3.1 Design and Development Phase

Following the requirements analysis phase, the design and development of the *AlgorithmAce* prototype were systematically guided by the ADDIE instructional design model. According to Feng and Sangsawang (2023), the ADDIE model is a widely adopted instructional design framework comprising five stages, including

Analysis, Design, Development, Implementation, and Evaluation. This model provides a structured process for designing curricula and instructional strategies, making it particularly relevant for technology-enhanced learning. This phase focused on the Design and Development components, ensuring that pedagogical goals were well aligned with technological execution.

During the Design stage, a comprehensive storyboard was created to guide the structure of learning activities, the spatial arrangement within the metaverse, and the sequencing of content delivery. As noted by Lisboa et al. (2024), storyboards help the systematic development of educational materials by providing a clear sequence that guides the creation of content and learning activities, making them an essential tool in constructing educational technologies (Lisboa et al., 2024). This systematic method enables educators and designers to visualise learning paths, ensuring logical consistency and pedagogical alignment throughout the design process.

To strengthen the technical aspects of development, the researcher participated in a professional training course conducted by the Malaysia Digital Economy Corporation (MDEC) in collaboration with the National University of Malaysia (UKM). The training emphasised the use of the Spatial Creator Toolkit, which is increasingly employed to develop immersive and interactive learning environments (Wu et al., 2024).

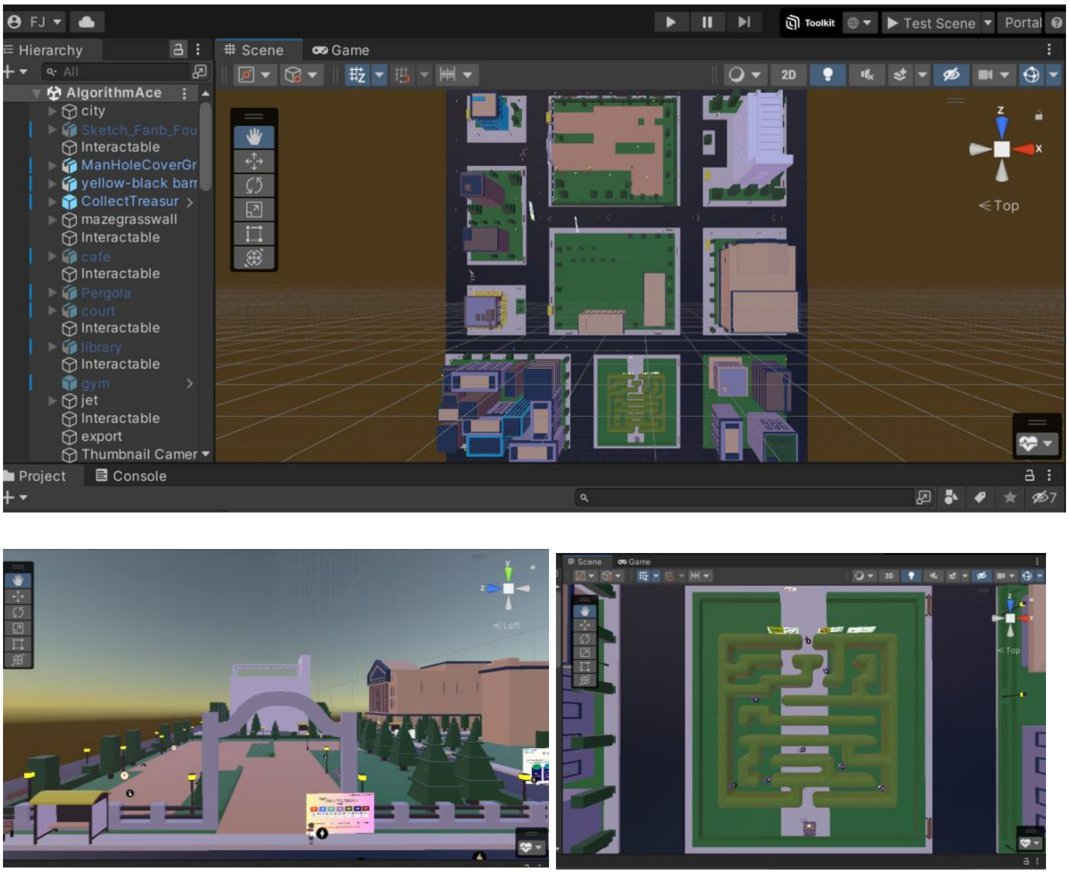

Figure 2: Screenshots from the Development Process of *AlgorithmAce* in Unity and Spatial.io.

As part of the Development process, the platform was constructed using Unity's Scene and Game views, with environment elements built using the Spatial Creator Toolkit. Figure 2 illustrates the Development stages, including the top-down city layout, park entrance, and maze-based learning structure created for exploratory missions. In *AlgorithmAce*, each mission was structured in a specific sequence, reflecting algorithmic principles in computational thinking. To enhance engagement, gamification elements such as badges for mission completion, star collection for guidance, and visual cues were embedded. This approach is consistent with prior research showing that scoring systems, feedback mechanisms, and gamification strategies can effectively support learner motivation, progress, and interaction in VR-based CT environments (Sukirman et al. 2024; del Olmo-Muñoz et al., 2023).

The preliminary prototype of *AlgorithmAce* was then presented to the Metaskool Teacher team, a group of educators collaborating with MDEC, during two review sessions conducted using Microsoft Teams. Gathering expert opinion in the early development stages is considered an effective approach to improve usability and strengthen pedagogical alignment in educational technology initiatives (Utamayasa et al., 2025). Feedback from these sessions focused on increasing engagement, clarifying task instructions, and strengthening the integration of key computational thinking skills.

To provide robust pedagogical and practical validation, 14 experts participated in the assessment process, including pedagogy professionals, pioneer teachers, and research fellows involved in the MetaSkool project. Table 1 summarises the composition of the expert panel and their respective roles in validating the prototype.

Table 1: Summary of Expert Involvement in *AlgorithmAce* Prototype Review

No.	Expert Category	Numbers	Affiliation	Role in Validation
1	Metaskool Pedagogy Specialists	2	UKM	Evaluated pedagogical alignment and CT integration
2	Metaskool Pioneer Teachers	9	MDEC-affiliated schools	Provided classroom-focused feedback on clarity and interactivity
3	Metaskool Research Fellows (including the researcher)	3	MDEC - UKM	Contributed to the design, coherence, and alignment with curriculum goals

The ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation, provides a systematic framework for designing and refining instructional tools. Previous studies have confirmed its effectiveness in guiding technology-enhanced learning and professional development programmes (Feng & Sangsawang, 2023; Zulkepli et al., 2024). Building on this framework, several refinements were made to enhance the platform's pedagogical strength, students' engagement, and overall usability. These modifications addressed issues such as task clarity, instructional flow, and interactive design elements. This iterative and collaborative approach, situated within the Design and Development stages of the ADDIE model, ensured that *AlgorithmAce* was pedagogically aligned, technically robust, and theoretically grounded for use in secondary education. The final prototype integrated key computational thinking components, including decomposition, pattern recognition, and algorithmic problem-solving, consistent with national computational thinking curriculum standards.

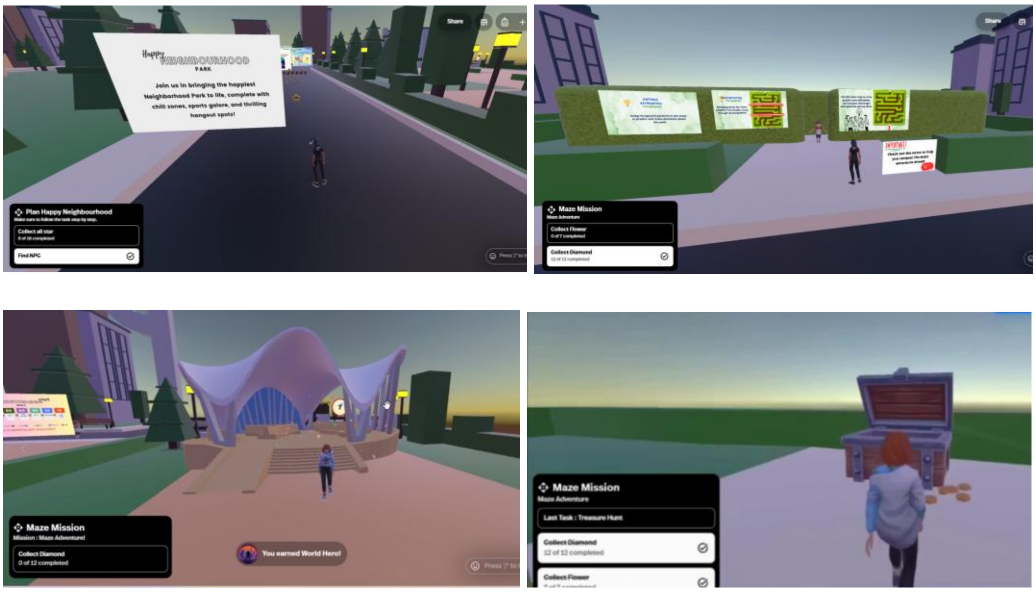

Figure 3: Final World of *AlgorithmAce*

Figure 3 shows the completed metaverse environment of *AlgorithmAce*, featuring two structured missions, which are "Happy Neighbourhood Park" and "Maze Adventure". Each mission integrates computational thinking tasks arranged in sequence, along with gamification elements such as collectible stars, mission progress indicators, and achievement badges to enhance learner motivation and engagement within an immersive virtual setting.

3.2 Usability Evaluation Phase

The objective of the usability evaluation was to assess students' perceptions of the *AlgorithmAce* platform regarding its usefulness, ease of use, ease of learning, and overall satisfaction. The main instrument used for data collection was the USE Questionnaire (Sukirman et al., 2024), which focuses on usefulness, ease of use, ease of learning, and satisfaction. For this study, the questionnaire items were adapted by replacing the original application name "CT Saber" with "AlgorithmAce" to suit the study context, while retaining the original constructs and response scale.

Students engaged with the *AlgorithmAce* platform by completing two interactive missions within a metaverse environment built using Spatial.io. These missions were carefully designed to embed core Computational Thinking (CT) components such as decomposition, pattern recognition, and algorithmic thinking into exploratory, game-based learning tasks. The immersive nature of the activities aimed to boost student engagement and develop conceptual comprehension through experiential learning. Before completing the missions and answering the questionnaire, all participant students attended a brief metaverse workshop facilitated by the researcher. This orientation introduced the basic functions of navigating the virtual environment, controlling avatars, and interacting with objects. The training ensured that participants, particularly those unfamiliar with metaverse platforms, were adequately prepared to complete the *AlgorithmAce* missions smoothly and to focus on the intended learning objectives.

After completing both missions, students were automatically prompted to answer an adapted version of the USE Questionnaire, embedded directly within the platform. This approach ensured the collection of prompt and authentic user feedback while the learning experience was still fresh. The original questionnaire was designed and verified by Sukirman et al. (2024) for undergraduate computer science students in a virtual reality scenario. However, as this research targeted a different target population, Malaysian secondary school students, the questionnaire required the instrument to be linguistically and contextually altered to meet the students' cognitive level, curricular context, and experience with metaverse-based settings.

To ensure accurate comprehension of the questionnaire items, the researcher and the respective school computer science teachers were present during the session to provide clarifications when necessary. These explanations focused primarily on boosting item understandings and did not influence the student's responses, thereby preserving the objectivity and reliability of the data collected. The findings from this usability evaluation provide valuable insights into the strengths and areas for improvement of *AlgorithmAce* as a pedagogical tool for CT learning in immersive environments.

3.2.1 Sampling

This study employed a purposive sampling approach to select students whose characteristics were directly related to the research objectives. Purposive sampling, as described by Andrade (2021), involves choosing participants based on specified characteristics relevant to the study's aims. According to Zickar and Keith (2023), this approach allows researchers to apply expert judgement in choosing participants who are likely to provide rich and meaningful data due to their relevance to the topic.

In this study, 180 students from Form 1 to Form 3, all enrolled in the Fundamental Computer Science curriculum, were chosen. These students had already been exposed to Computational Thinking (CT) concepts through the national curriculum, making them suitable candidates for evaluating the *AlgorithmAce* platform. This aligns with the expert sampling subtype of purposive sampling, where individuals are chosen because of their familiarity and relevance to the domain being studied (Etikan et al., 2016; Zickar & Keith, 2023).

The participants were selected from three secondary schools in Negeri Sembilan, located in Southern Malaysia, providing a contextually relevant sample for measuring usability in the Malaysian secondary education setting. This sampling technique ensured that the evaluation responses were grounded in actual user experience and educational relevance. The sample comprised a mixed-gender group of students aged between 13 and 15 years. Ethical clearance was obtained from the Ministry of Education Malaysia, and informed consent was secured from both the students and their guardians prior to participation.

3.2.2 Reliability Test

The reliability analysis indicated that all four items had a high degree of internal consistency, with Cronbach's alpha values exceeding the recommended threshold of 0.70 (Hair et al., 2019; Pituch & Stevens, 2016). This demonstrates a high level of internal consistency. Among these, ease of use received the greatest reliability (α = 0.886), followed by satisfaction (α = 0.880), usefulness (α = 0.863), and ease of learning (α = 0.833). These findings demonstrate that the adapted questionnaire was reliable for assessing the usability of *AlgorithmAce* among Malaysian secondary school students.

Table 2: Reliability Test (N = 180)

Construct	No. of Items	Cronbach's Alpha
Usefulness	8	0.863
Ease of Use	11	0.886
Ease of Learning	4	0.833
Satisfaction	8	0.880

3.2.3 Data Analysis

The quantitative data collected in this study were analysed using SPSS version 27.0. Descriptive statistics were computed to summarise the participants' demographic profiles, including gender, age group (13 to 15 years old), and prior exposure to metaverse technologies. Prior to conducting Pearson correlation analysis, the required assumptions were tested. Normality was assessed using skewness and kurtosis values, all of which fell within acceptable ranges (skewness ±3, kurtosis ±10) as suggested by Kline (2015), indicating that the data were normally distributed (see Table 3 in Section 4.1). Linearity was verified visually through scatterplots (Figure 6), which demonstrated linear relationships between the independent variables and the dependent variable. These results confirmed the suitability of the data for parametric correlation analysis.

To evaluate the internal consistency of the instrument, reliability analysis was conducted using Cronbach's Alpha. A threshold value of 0.70 was considered appropriate, as indicated by Hair et al. (2019) and Pituch and Stevens (2016). Subsequently, Pearson correlation analysis was conducted to investigate the relationships between three independent variables, including perceived usefulness (X_1), ease of use (X_2), and ease of learning (X_3), and the dependent variable, user satisfaction (Y), in the context of the AlgorithmAce metaverse platform. Specifically, the correlation analysis focused on the following relationships:

1. Perceived usefulness (X_1) and satisfaction (Y).
2. Ease of use (X_2) and satisfaction (Y).
3. Ease of learning (X_3) and satisfaction (Y).

From data collection and preprocessing (including data cleaning and coding) to descriptive statistical analysis (including demographics and normality checks) and correlation analysis based on the theoretical framework, Figure 4 illustrates the overall data analysis process used in this study.

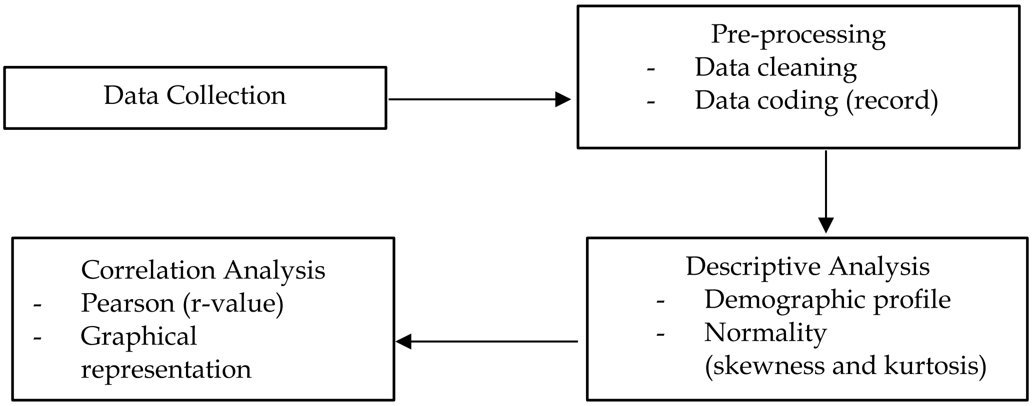

Figure 4: Data Analysis Flowchart of the Study

Figure 5 illustrates the theoretical framework underpinning this study. It outlines the hypothesised relationships between the independent variables, including perceived usefulness (X_1), ease of use (X_2), and ease of learning (X_3), and the dependent variable, user satisfaction (Y), with regard to the *AlgorithmAce* platform.

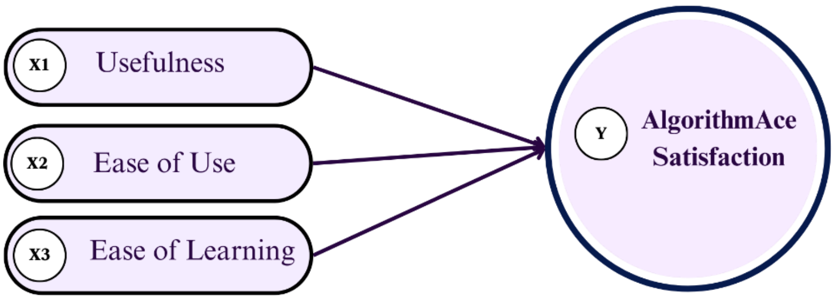

Figure 5: Theoretical Framework

This step was important in determining how each usability dimension contributes to student satisfaction when using *AlgorithmAce*.

3.3 Ethical Considerations

Ethical principles were strictly observed throughout this study, including informed consent, voluntary participation, risk minimisation, privacy protection, and data confidentiality (Bell et al., 2018; Saunders et al., 2019). All participants were clearly informed about the purpose of the study and gave their voluntary consent to participate. Although face-to-face contacts occurred while students were using the *AlgorithmAce* platform, the researcher and computer science professors only provided explanations when required, ensuring that student responses remained uninfluenced.

Given the participants' age range (13–15 years), care was taken to explain procedures clearly and review the questionnaire for any sensitive content. All responses were anonymous, with no identifying information collected. Data were securely stored on a password-protected device and could only be accessed by the research team.

4. Findings

The findings revealed significant insights into how usability dimensions, including perceived usefulness, ease of use, and ease of learning, affect students' satisfaction in using the *AlgorithmAce* metaverse learning platform.

A total of 180 secondary school students participated in this study. Of these, 36.1% were male (n = 65), while the majority were female (63.9%, n = 115). In terms of age, most students were 13 years old (40.6%), followed by 14 years old (34.4%) and 15 years old (25.0%). Regarding ICT use, 70.6% of students reported using ICT daily, 20.6% several times a week, 5.0% several times a month, and 3.9% infrequently. Interestingly, 61.7% of students said this was their first time using a metaverse platform for studying, while 38.3% had previous experience.

This implies that although most students were active ICT users, the majority had limited experience with metaverse-based learning settings. As a result, their responses provide valuable insights regarding *AlgorithmAce's* usability and engagement potential as an innovative teaching tool to enhance computational thinking abilities.

4.1 Normality Test

A normality analysis was conducted using skewness and kurtosis values to assess the suitability for performing parametric statistical tests. According to Kline (2015), skewness values within ±3 and kurtosis values within ±10 were considered acceptable levels for assuming normal distribution in behavioural research.

Table 3: Normality Test

Variable	Skewness	Std. Error (Skewness)	Kurtosis	Std. Error (Kurtosis)	Normality Status
Usefulness	–0.264	0.181	0.157	0.360	Normal
Ease of Use	–0.535	0.181	0.000	0.360	Normal
Ease of Learning	–0.876	0.181	0.489	0.360	Normal
Satisfaction	–0.612	0.181	–0.096	0.360	Normal

All variables showed skewness and kurtosis values within the acceptable range, indicating that the normality assumption was met. In addition, scatterplots confirmed that the relationships between the variables were linear and homoscedastic, while independence of observations was ensured through the sampling design. Hence, the assumptions required for Pearson's correlation were satisfied, and parametric tests were considered appropriate for further analysis.

4.2 Pearson Correlation Analysis

This study employed Pearson correlation analysis to examine the relationships between the independent variables, perceived usefulness (X_1), ease of use (X_2), and ease of learning (X_3), and the dependent variable, user satisfaction (Y), in relation to the development of a metaverse-based learning platform.

Table 4: Pearson Correlation Analysis between Perceived Usefulness, Ease of Use, Ease of Learning, and User Satisfaction (N = 180)

Independent Variable	Pearson Correlation (r)	Sig. (2-tailed)	Strength of Relationship	Significance Level
Usefulness	0.692	< .001	Strong positive	Significant
Ease of Use	0.660	< .001	Strong positive	Significant
Ease of Learning	0.556	< .001	Moderate positive	Significant

All three independent variables, perceived usefulness, ease of use, and ease of learning, showed statistically significant positive correlations with user satisfaction ($p < .001$). Perceived usefulness ($r = 0.692$) and ease of use ($r = 0.660$) exhibited strong positive relationships, indicating that as users perceived the platform to be more useful and easier to use, their satisfaction levels increased accordingly and substantially. These strong correlations suggest that both factors are highly influential in determining overall satisfaction with the *AlgorithmAce* platform.

In contrast, ease of learning ($r = 0.556$) showed a moderate positive relationship with user satisfaction. While still significant, this indicates that perceived ease of learning contributes positively to satisfaction but to a lesser extent compared to usefulness and ease of use. This finding suggests that although usability and usefulness play dominant roles, simplifying the learning curve remains an important factor in enhancing the overall user experience.

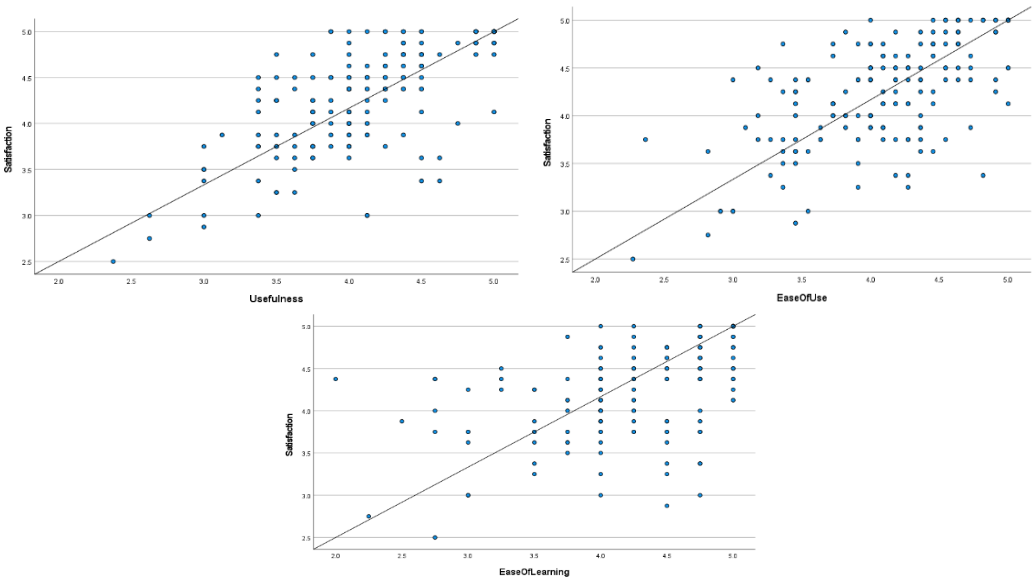

Figure 6: Scatterplots Showing the Relationship between Usability Dimensions and User Satisfaction

Figure 6 presents scatterplots illustrating the relationships between each of the three independent variables, perceived usefulness, ease of use, and ease of learning, and the dependent variable, user satisfaction. The graphical representation complements the Pearson correlation results by providing a visual indication of the direction and strength of each association without statistical inference.

5. Discussion

The findings of the Pearson correlation study showed statistically significant positive associations between user satisfaction with the *AlgorithmAce* platform and perceived usefulness, ease of use, and ease of learning. Among these three independent variables, perceived usefulness demonstrated the strongest correlation ($r = 0.692$), followed by ease of use ($r = 0.660$) and ease of learning ($r = 0.556$). These findings suggest that students' satisfaction with the metaverse-based learning environment is significantly influenced by all usability factors.

These findings align with previous research emphasising the influence of usability dimensions on learning satisfaction within immersive or gamified environments. Wang (2024) identified interaction design, interface intuitiveness, and alignment between content and learning objectives as critical factors that significantly enhance the effectiveness and perceived usefulness of VR-based educational materials. Sukirman et al. (2024) discovered similar trends when evaluating virtual reality education tools for computational thinking.

Also, Fei et al. (2025) and Holstein and Cohen (2025) highlighted that intuitive interface design, straightforward navigation, and scaffolded content delivery contribute significantly to students' engagement and satisfaction, especially in technology-enhanced learning environments. Choi and Yang (2025) further stressed the need to balance involvement with cognitive manageabilityClick or tap here to enter text., noting that students' willingness to use metaverse platforms for sustainability education was strongly influenced by ease of use and enjoyment, though excessive immersion could reduce usability.

The strong relationship between perceived usefulness and satisfaction may be attributed to how *AlgorithmAce* integrates real-world problem-solving tasks with interactive activities that resemble students' everyday experiences. The two missions, "Build a Happy Neighbourhood Park" and "Maze Adventure", enabled students to apply decomposition and pattern recognition in visual and relatable scenarios.

This practical relevance likely strengthened students' perception of the platform's value, reinforcing its usefulness in their learning journey. Similar findings were reported by Sukirman et al. (2024), who found that VR-based CT learning games increased perceived usefulness by situating abstract concepts in interactive contexts. Likewise, Wu et al. (2025) and Gerini et al. (2025) noted that immersive and gamified environments enhance engagement and satisfaction when learning tasks are aligned with real-world experiences.

Additionally, the significant influence of ease of use and ease of learning underscored the importance of cognitive accessibility, especially for younger learners aged 13 to 15. Developed in Unity and Spatial.io, *AlgorithmAce's* design facilitates natural exploration and minimises educational burden. In metaverse-based learning environments, these characteristics are crucial for avoiding cognitive overload and disengagement (Gundersen & Lampropoulos, 2025; Wu et al., 2025).

In Malaysia, where immersive education research remains unexplored, this study contributes to the limited body of research on metaverse learning materials. Although various efforts have been established in computer education, students' exposure to immersive platforms like the metaverse remains limited. These findings highlight the need for educators to employ more interactive and relevant teaching practices aligned with students' digital experiences. Platforms like *AlgorithmAce* offer engaging and relevant educational experiences by immersing students in gamified environments, thereby promoting deeper understanding of computational thinking. Moreover, the platform provides insights into how immersive, gamified design may connect abstract computer science ideas with students' real-life experiences.

Importantly, these findings also align with global education objectives, including Sustainable Development Goal 4 (SDG 4), which advocates inclusive and equitable quality education. Through immersive platforms, *AlgorithmAce* helps bridge the gap in learning experiences and provides students with the necessary skills for the future by increasing access and engagement in computational thinking, a subject often perceived as abstract and challenging. Ldokova et al. (2025) further argue that immersive digital technologies may be more effective when tailored to the cognitive profiles of particular learners. While *AlgorithmAce* did not directly personalise experiences based on learner psychotypes, its visual and exploratory design may support neurodiverse engagement.

Despite these contributions, this study has several limitations. The sample was limited to a specific age group and geographic region, which may restrict the generalisability of the findings. Furthermore, the research focused only on user perceptions of usability and satisfaction, without assessing knowledge acquisition or long-term effects on computational thinking proficiency. Future research should investigate the interactions of students with varying personality or cognitive profiles with metaverse-based learning platforms and assess whether adaptive pathways, as suggested by Choi et al. (2025), might enhance engagement. Longitudinal research investigating learning outcomes and integration across various educational environments is also recommended.

6. Conclusion

This research developed and evaluated *AlgorithmAce*, a metaverse platform that incorporates game-based learning to enhance Computational Thinking (CT) among Malaysian secondary school students. The results indicated that perceived usefulness, ease of use, and ease of learning were significantly associated with user satisfaction, affirming that well-designed immersive environments can facilitate meaningful learning experiences. The missions enabled students to use decomposition and pattern recognition techniques in relatable situations, connecting abstract computational thinking concepts with practical problem-solving.

This study presented a conceptual framework in which usability factors are essential to satisfaction and engagement in immersive learning. Grounded in the USE framework, the results validate and extend current theory by highlighting that usability transcends a simple technological characteristic and becomes a pedagogical factor in metaverse design. The findings also support the proposed theoretical framework, confirming that usability dimensions, particularly perceived usefulness, ease of use, and ease of learning, significantly influence user satisfaction. This reinforces the applicability of the framework for evaluating metaverse-based learning environments.

The research, conducted in Southern Malaysia, acknowledged the potential influence of cultural and infrastructural elements on students' experiences. However, these factors were not directly measured in this study and are noted as contextual considerations. Future research should systematically collect and analyse such data to better understand their role in the adoption and effectiveness of metaverse-based learning platforms. Many participants had not previously engaged with metaverse platforms, indicating a digital exposure gap that might influence uptake in various educational settings.

Limitations of the study included its focus on short-term usability without assessing long-term learning outcomes and the limited demographic variety. Theoretically, the findings reinforce the applicability of the USE framework in the context of metaverse-based learning, highlighting the significant role of usability dimensions in shaping user satisfaction. Practically, these results can guide educators, curriculum designers, and policymakers in integrating immersive technologies into teaching strategies to enhance student engagement and computational thinking skills, particularly in contexts where abstract concepts need to be visualised and contextualised.

Future studies should investigate adaptive characteristics tailored to students' psychological types and conduct longitudinal assessments across various educational settings. Another limitation of this study was its exclusive use of quantitative methods. Although the USE Questionnaire provided structured insights, future studies should consider incorporating open-ended questions or qualitative techniques such as interviews or focus group discussions to capture more nuanced perspectives from learners. In this study, four core usability dimensions were evaluated using the USE Questionnaire. However, future research should consider examining additional aspects such as accessibility for diverse learners and the instructional effectiveness of the platform.

This study focused solely on student feedback to evaluate usability. Future research should also involve teachers to capture expert pedagogical perspectives and implementation challenges, which would provide a more holistic understanding of the platform's educational value. These insights contribute to the evolving body of research on immersive education and support the global push for inclusive, engaging learning aligned with Sustainable Development Goal 4. Educators and policymakers may use these insights to create scalable and culturally appropriate teaching materials. Further research should enhance the theoretical framework by incorporating diverse educational approaches and digital engagement within the metaverse environment.

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