International Journal of Learning, Teaching and Educational Research
Vol. 24, No. 5, pp. 90-113, May 2025
https://doi.org/10.26803/ijlter.24.5.5
Received Feb 27, 2025; Revised Apr 17, 2025; Accepted May 8, 2025

Enhancing Computational Thinking through Metaverse-Based Learning: Expert Consensus on Challenges, Pedagogical Strategies, and Future Directions

F. Alifah M. Jaaffar* **and Nor Hafizah Adnan**
Faculty of Education
Universiti Kebangsaan Malaysia (UKM), Bangi, Malaysia

Abstract. This study investigates the integration of Computational Thinking (CT) and Metaverse technologies as a means of addressing instructional challenges in Malaysian secondary schools. Specifically, it aims to identify the key barriers in CT instruction and explore how immersive technologies can enhance learning. CT, a vital 21st-century skill, is difficult to teach due to its abstract nature, low student engagement, and infrastructural limitations, particularly in rural areas. Using the Nominal Group Technique (NGT), selected to gain expert consensus on the challenges faced in teaching CT, six experienced computer science educators participated in structured virtual sessions to identify and prioritise key instructional issues. The data were categorised into five principal constructs, including difficulties with abstraction, lack of student motivation, limited problem-solving abilities, absence of real-world applications, and infrastructural constraints. Experts unanimously agreed (100%) that gamified, real-life projects significantly increase student motivation and understanding of CT concepts. The findings suggest that immersive environments utilising Spatial.io and Unity can enhance CT instruction by visualising abstract concepts, promoting engagement, and enabling collaborative, gamified learning experiences. Moreover, the study aligns with Malaysia's Digital Education Policy (DEP) by addressing the digital divide. A Metaverse-based learning storyboard is proposed to promote CT components such as decomposition, pattern recognition, and algorithmic thinking. The study contributes to the growing body of research on immersive pedagogy and offers a scalable model for CT education using virtual environments, with implications for both educators and policymakers.

Keywords: Computational Thinking (CT); Metaverse; Immersive Learning; Nominal Group Technique (NGT); Spatial-unity

* Corresponding author: *F. Alifah M. Jaaffar*, p131421@siswa.ukm.edu.my*

1. Introduction

Computational thinking (CT) is a crucial cognitive ability in the modern digital world. It is not only required in computer science but in any field where problem-solving, abstractions, and the use of algorithms are vital (Supiarmo et al., 2022; Anderson, 2016; Rafli et al., 2024). Educational reforms aimed at fostering higher-order thinking and preparing students for a technology-driven future are placing a greater emphasis on CT, much like literacy in reading and writing (Anderson, 2016; Zhu & Deng, 2024).

In recognition of its importance, Malaysia began integrating CT into its national curriculum in 2017, through the Primary School Standard Curriculum and the Secondary School Standard Curriculum (Kusnan et al., 2020). However, many students reportedly struggle to understand CT concepts, resulting in low interest in the subject (Asarani & Mohd Yassin, 2020). CT concepts are progressively taught in subjects such as Fundamentals of Computer Science and Computer Science, with a curriculum that emphasises logic and algorithm-based problem-solving (Napiah & Hashim, 2021; Ministry of Education Malaysia, 2017). Despite these efforts, many students still find it hard to apply CT effectively due to a weak understanding of the basic concepts (Ariffin et al., 2022). They also lack sufficient opportunities to practise higher-order thinking, especially in traditional classrooms (Halim & Mahmood, 2024).

In rural areas, the problem is much more severe due to the absence of internet, outdated pedagogical techniques, and limited information and communication technology (ICT) hardware and software, all of which hinder effective CT teaching (Anuar et al., 2021; Akil & Matore, 2023). Although the Ministry of Education has provided various initiatives to support CT integration, achieving equitable implementation remains a challenge (Akil & Matore, 2023; Han et al., 2024). The consistently poor performance of secondary school pupils in computer science classes, argue Halim and Mahmood (2024), highlights the urgent need for improved instructional strategies that foster computational thinking.

Transitioning from conventional methods to pedagogies that engage the younger generation through technology comes with its own challenges (Cilliers, 2017). A systematic, engaging, and culturally relevant learning environment is essential to ensure learning objectives are met, particularly in online or hybrid learning modes (Halim and Mahmood, 2024). According to Sidek et al. (2020), incorporating elements of local culture into classes significantly enhances student engagement and motivation.

To address these challenges, immersive technologies such as the Metaverse offer promising alternatives. Platforms like Spatial.io and Unity provide interactive, collaborative, and gamified learning environments that can simulate real-world scenarios, making CT concepts more accessible and meaningful (Zhang et al., 2022; Kaddoura & Al Husseiny, 2023). The immersive and dynamic nature of these platforms facilitates deeper learning, supports teamwork, and promotes motivation through game-based experiences (Menezes et al., 2023; Said, 2023). These virtual environments not only transcend physical infrastructure limitations but also create engaging learning spaces that are adaptable to students' diverse needs.

Despite the theoretical benefits, few empirical studies have explored how Metaverse-based learning environments can address the specific instructional challenges of teaching CT in Malaysian schools, especially in rural contexts. This research seeks to fill that gap.

The objectives of this study are to:
i. Identify challenges in traditional teaching methods for fostering computational thinking skills.
ii. Explore the potential of Spatial.io and Unity in creating immersive and interactive learning environments.
iii. Propose innovative approaches for enhancing student engagement and understanding of computational thinking through gamification and Metaverse integration.

2. Literature Review

2.1 Computational Thinking Skill

Computational Thinking (CT) has emerged as a core 21st-century skill that empowers students with analytical, problem-solving, and algorithmic thinking abilities (Supiarmo et al., 2022; Rafli et al., 2024). In line with the global trend of incorporating CT into interdisciplinary learning, Malaysia formally introduced CT into the national curriculum in 2017 through courses such as Computer Science and Fundamentals of Computer Science (Napiah & Hashim, 2021). CT is now commonly taught in schools through four main pillars, including deconstruction, abstraction, pattern recognition, and algorithmic thinking (Ministry of Education Malaysia, 2016).

Despite this integration, recent studies report that students demonstrate only moderate levels of CT mastery, particularly in translating theoretical understanding into real-world problem solving (Liu et al., 2023). Curriculum inclusion alone is insufficient without appropriate instructional techniques, as many students still lack the ability to solve complex problems systematically (Zhu & Deng, 2024). Additionally, most CT programmes focus heavily on content delivery, often overlooking learner diversity and failing to provide authentic, contextualised experiences (Ezeamuzie et al., 2022; Yosepha et al., 2023). This emphasises the gap between curriculum development and actual student results, especially in rural and low-resource areas. The lack of immersive, relatable, and student-centred methods further hinders the development of CT proficiency, underscoring the need for pedagogical innovation.

This study responds to these identified gaps by examining instructional challenges through expert consensus and exploring Metaverse-based approaches as a novel intervention to strengthen CT instruction. It contributes to the existing literature by focusing on the underexplored intersection between immersive learning technologies and CT pedagogy within the Malaysian school context.

2.2 Challenges of Traditional Teaching Methods in Fostering Computational Thinking

Computational Thinking (CT) is a way of addressing problems based on computer science principles. It is increasingly recognised as a crucial skill for students in today's digital age (Molina-Ayuso et al., 2024; Tsai et al., 2021). CT teaches students to think analytically and gain a better understanding of systemic processes, going beyond linear problem-solving approaches (Falloon, 2024; Supiarmo et al., 2022). The application of CT has extended beyond its original domain of computer science into other areas of education. Skills such as decomposition, pattern recognition, and algorithmic reasoning have been shown to improve learning in other fields (Saidin et al., 2021; Kastner-Hauler et al., 2022). However, mastering CT poses significant challenges, especially for young learners. The abstract nature of CT concepts often leads to difficulties, particularly among students who have not been exposed to computing from an early age. This is largely due to their cognitive developmental stage and the inherent complexity of CT tasks (Su & Yang, 2023). Additionally, educators still find it challenging to teach CT effectively, as students are often disengaged, and conventional methods, such as textbook exercises and lectures, fail to make abstract concepts tangible (Tsai et al., 2021; Zhu & Deng, 2024).

In many cases, students' engagement with CT is also influenced by their own perceptions and identities. For example, whether they consider themselves "tech-savvy". This can lead to self-exclusion from computing-related learning opportunities. As highlighted by Aslan et al. (2024), supporting students from under-represented or less confident backgrounds requires intentional instructional planning that fosters inclusiveness and relevance.

In addition, there is a concerning trend in the performance of Malaysian students in international assessments like PISA 2022. Only 41% of Malaysian students reached Proficiency Level 2 in mathematics, well below the OECD average of 69%, while reading scores stood at 42% compared to the OECD average of 74% (Department of Educational Planning and Policy Research, 2023). These findings suggest that students continue to struggle with higher order thinking skills, including those associated with CT.

Many educators still rely on conventional teaching methods that emphasise rote learning and algorithm memorisation, offering limited opportunities for collaborative and exploratory problem solving (Supiarmo et al., 2022). To address these issues, CT instruction must evolve beyond lecture-based approaches. Immersive platforms like Spatial.io offer promising alternatives by transforming abstract CT concepts into interactive experiences, making learning more accessible, engaging, and relevant to today's learners.

Despite the growing recognition of CT as a foundational skill, current instructional approaches remain largely traditional and insufficient in addressing the challenges faced by diverse learners. Limited student engagement, difficulties in abstract reasoning, and infrastructural constraints, especially in rural contexts, highlight the need for innovative pedagogical solutions. Therefore, this study seeks to explore how immersive technologies, particularly the Metaverse, can address these challenges and enhance the teaching and learning of Computational Thinking in Malaysian secondary schools.

3. Methodology

3.1 Nominal Technique Group

The research implemented Nominal Group Technique (NGT) as a qualitative approach to collect expert evaluation on challenges that Malaysian schools face when teaching CT. The researchers picked NGT because its systematic evaluation process allows participants to maintain equal input while obtaining mutual consensus during expert evaluations (Vahedian-Shahroodi et al., 2023). The participatory method NGT was first developed by Van de Ven and Delbecq (1971) and has since become a widely used technique which active across education institutions and public policy development as well as health institutions. The research approach combines qualitative brainstorming with semi-quantitative prioritization because of its effectiveness in instructional space detection and evidence-based solution building (Andre et al., 1975; Mullen et al., 2021).

The systematic design of NGT supports balanced participant interaction and eliminates dominance bias and reinforces valid research conclusions (Olsen, 2019). This research method is perfect for educational investigations because it grants practitioners from intricate educational environments the ability to share vital practical knowledge. In their research the researchers used NGT to evaluate CT education obstacles while analysing Metaverse-based teaching approaches as possible educational answers.

The research implemented purposive sampling methods to recruit six Malaysian computer education teachers from diverse geographic areas thus achieving participant representation across metropolitan and country areas. Six participants were picked by the research team through three preselected criteria which included more than five years of experience and both expertise in CT teaching and prior digital interactive tool experience. The participant demographic selected based on specific criteria obtained effective results that identified infrastructure problems as well as teaching challenges present in various Malaysian educational facilities (MacPhail, 2001; Lloyd-Jones et al., 1999). These participants demonstrated complete expertise for conducting research about innovative CT instruction through their combined experience in education systems and extensive teaching backgrounds.

The virtual session of NGT took place on Google Meet due to accessibility problems and geographical boundary restrictions. The session lasted two hours which researchers deem sufficient for productive interactions between groups according to Gibson and Soanes (2000). Research participants encountered study goals followed by the initial question "What are the major challenges in teaching computational thinking in Malaysian schools?" at the beginning of the first stage. The NGT process implemented four sequential phases beginning with private ideas followed by collective sharing and next moving to clarification and consolidation before a final step involved ranking based on importance evaluation (Vahedian-Shahroodi et al., 2023; Dang, 2015).

The participants individually created initial challenge prevention ideas at the beginning of the session before moving onto peer exchanges. Each participant provided their first ideas through round-robin sharing without receiving any evaluation during this step. The participants spent time discussing the generated ideas to minimize confusion and exclusivity of similar concepts. Group members evaluated the challenges in their last step for determining challenges where all members found mutual agreement. The researchers collected detailed discussion records by employing audio recordings and shared Google Forms as their recording system. A thematic coding system following Mullen et al. (2021) was used to review and understand analytical research data.

The research analysis revealed five fundamental elements which consist of (1) irregular access to digital equipment and (2) inadequate training for CT instructors along with (3) students displaying low interest and (4) theoretical CT concepts being abstract and (5) insufficient indigenous content in educational materials. Both immersion-based learning attributes and virtual characters and simulation models in gamified interfaces create better student involvement and conceptual understanding of CT according to the full agreement of research members.

Multiple evaluation procedures were implemented by the researchers in order to establish findings validity. The authors used the member checking process which supported participants in verifying their recognized patterns of constructs. An audit record kept for process oversight along with predictable coding protocols ensured the reliability of the NGT process. Research ensured validity of transferability by presenting detailed descriptions about participants alongside their teaching environments alongside their session management practices (Olsen, 2019; Mullen et al., 2021). Every procedure in this study obtained official ethical authorization through proper governing institutions after participants provided their consent. Both privacy protections of anonymity and confidentiality remained active during the entire investigation duration.

The research findings delivered practical implications although the investigation acknowledges its limitations. The study's small participant number is reasonable because it focuses on intensive expert analysis regardless of broad statistical reach. The virtual communication method that became mandatory introduced changes to group interactions because necessary technological prerequisites existed. The method generated findings grounded in reality that offer significant valuable input to create immersive CT learning solutions suitable for Malaysian educational contexts.

3.2 Sampling

The research selected six expert teachers through purposive sampling because all participants specialized in both computer education and digital pedagogy. Four expert teachers qualified for selection through having five years of teaching experience combined with both CT instruction experience and knowledge of technology-enhanced learning spaces (Vahedian-Shahroodi et al., 2023). The researchers selected these participants because they brought a deep understanding of CT education challenges along with valuable insights about solutions for the field. The representative sample consisted of education settings across Malaysia featuring both schools from urban and rural areas to obtain various insights about structural and teaching and sociocultural learning obstacles (MacPhail, 2001; Lloyd-Jones et al., 1999).

The experts shared valuable field experience to help solve the research issue that examines traditional teaching problems and potential Metaverse opportunities in CT education. Teachers working directly with students in classrooms could pinpoint challenges that included their specific learning contexts and recognize whether technology solutions would be feasible in these environments (O'Neil & Jackson, 1983; Duggan & Thachenkary, 2004). The research engaged a group of practitioners who already worked with innovative teaching approaches and digital learning tools in limited resource environments thus establishing data credibility based on real educational experiences. The research findings reached high validity and practical values because the study designed selection of domain-specialist participants who matched perfectly with its objectives (Andre et al., 1975; Abdullah & Islam, 2011).

Table 1: Participant Profile

Expert	Position	Experience
E1	School ICT Coordinator	5 years
E2	Computer Science Teacher	10 years
E3	Computer Science Teacher	10 years
E4	School ICT Coordinator	8 years
E5	Head of Computer Science Panel	11 years
E6	Head of Technical and Vocational Department	16 years

4. Findings

Using the Nominal Group Technique (NGT), all expert participants agreed on the 25 items presented as challenges in teaching and learning Computational Thinking in the Fundamental Computer Science subject. These items were then grouped into five main constructs, as pictured below. In line with the study's aim, all five constructs were extensively discussed in a two-hour NGT session with the six expert teachers.

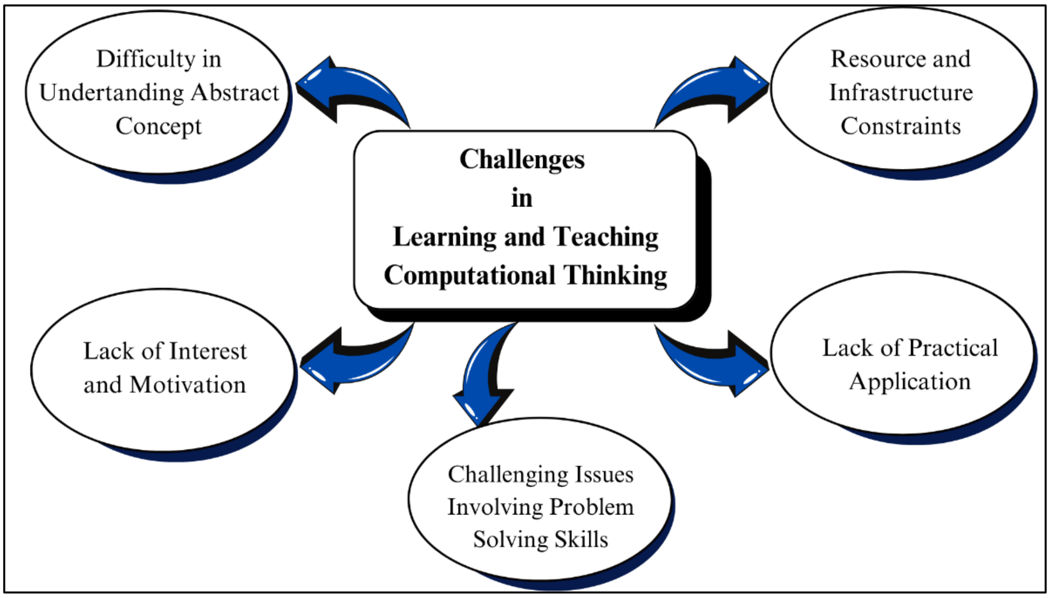

Figure 1: Construct Challenges in Learning and Teaching Computational Thinking Agreed by Experts

Table 2: Expert concensus on challenges faced by students in learning CT.

Items / Elements	**Percentage**	**Rank Priority**	**Voter Acceptance Status**
1. Construct Difficulty in Understanding Abstract Concepts			
Understanding problem decomposition in computational thinking is something students typically struggle with.	72.22	6	Accepted
Abstraction is a confusing concept for most students as they do not understand how it is applied to real life.	94.44	2	Accepted
Students spend a great deal of time trying to comprehend the abstract concepts of computational thinking.	94.44	2	Accepted
Providing an abstract concept alongside a visualisation or concrete example can make the concept more comprehensible.	100	1	Accepted
By providing less complex problems to be solved, teachers can assist students in comprehending abstract concepts.	88.89	3	Accepted
2. Construct Lack of Interest and Motivation			
Students display a lack of interest in computational thinking due to it being perceived as overly complex and difficult.	72.22	6	Accepted
Students tend to be more active participants when they work on projects that require them to practice their computational thinking skills.	100	1	Accepted
Challenge-based or game-like activities can enhance students' motivation for learning computational thinking concepts.	100	1	Accepted

Students are more motivated to learn computer science when its applications in everyday life are made visible to them.	100	1	Accepted
By allowing students the choice of the topic or project, teachers are likely to enhance their students' interest in learning.	83.33	4	Accepted
3. Construct Challenging Issues Involving Problem Solving Skills			
Students experience stress when faced with tasks that require integration of several elements of computational thinking.	72.22	6	Accepted
Students tend to give up on complex problems with no apparent direction for tackling them.	72.22	6	Accepted
Teachers need to provide more exercises that guide students in breaking down and solving complex problems.	94.44	2	Accepted
Students find it easier to solve complex problems when given step-by-step examples.	94.44	2	Accepted
Students need additional tools or resources to help them overcome problems involving many steps.	94.44	2	Accepted
4. Construct Lack of Practical Applications			
Students are more interested in learning when they see how computational thinking can be used in their daily lives.	100	1	Accepted
Practical applications in computational thinking help students understand theory better.	100	1	Accepted
Projects involving real-world problem-solving provide more meaningful learning experiences for students.	100	1	Accepted
Computational thinking will be easier to understand if students can see examples of how it is used in the technology industry.	100	1	Accepted
The use of easily accessible tools and software can help students apply computational thinking concepts more effectively.	100	1	Accepted
5. Construct Resource and Infrastructure Constraints			
A lack of resources such as computers and software make it difficult to teach computational thinking in schools.	77.78	5	Accepted
Students face difficulties accessing online learning materials due to insufficient digital infrastructure.	83.33	4	Accepted
Providing more digital learning resources can improve the effectiveness of teaching computational thinking.	94.44	2	Accepted
Limited internet connectivity in schools affects the online learning process for computational thinking topics.	94.44	2	Accepted

Improving infrastructure support, such as better computer rooms or internet access, can help enhance computational thinking learning in schools.	100	1	Accepted

Note: Acceptance percentages ≥70%

The results based on the Nominal Group Technique (NGT) session, attended by six experts in Computer Science, are presented in this section. Twenty-five elements were discovered and categorised into five primary constructs. These results are directly aligned with the objectives of the study and inform the recommended actions. In relation to the first objective, to identify the challenges in conventional teaching strategies for developing computational thinking (CT) skills, five key constructs emerged. These include difficulty in understanding abstract concepts, lack of interest and motivation, challenges in problem-solving skills, lack of practical application, and resource and infrastructure constraints.

According to the experts, many students have issues with understanding abstract concepts in CT, such as decomposition and abstraction, especially when these are not grounded in real-world scenarios. This difficulty is exacerbated by the use of conventional teaching methods that rely heavily on verbal explanations and textbook-based learning. Students' lack of interest was also associated with perceptions of CT as too complicated and unimportant. The experts found that students engagement improved significantly when CT was taught through interactive, gamified exercises or real-world projects that align with students' interests. In terms of problem-solving, many students said that integrated or multi-step assignments were too much for them. In order to help students understand and solve complicated issues, the experts emphasised the importance of using more guided, scaffolded teaching methodologies.

The experts also highlighted the limited application of CT in meaningful, everyday applications, which leads to a disconnect between theory and practice. When students cannot relate CT to real life, their motivation and understanding decline. Lastly, infrastructural limitations, especially in rural schools, continue to hinder the effective implementation of CT, as many students lack access to devices, software, and reliable internet. Experts noted that the lack of essential resources such as computers and educational software significantly impedes the delivery of CT instruction effectively. Insufficient internet access, especially in rural places, further restricts the use of the full potential of online Metaverse platforms and services (Tan et al., 2024). This condition exacerbates the uneven learning opportunities and the digital gap in CT education.

The results of the second objective, which investigates the potential of Unity and Spatial.io to establish immersive and interactive learning environments, indicate that these platforms are capable of resolving a variety of the challenges identified. The need for visual and interactive representations of abstract CT concepts can be met through the use of 3D visualisations and simulations in Spatial.io. Furthermore, Unity's capabilities in developing game-based learning experiences align with expert recommendations for enhancing student motivation through engaging and challenge-based tasks. Additionally, the interactive nature of these platforms enables students to investigate CT principles in real-time, collaborative, and scenario-based environments, thereby bridging the gap between theoretical knowledge and practical application.

The findings also provide a clear direction for the third objective, which is to propose innovative approaches to improve student engagement and comprehension of CT through the integration of the Metaverse and the gamification. Experts unanimously agreed on the effectiveness of project-based and gamified learning strategies. These strategies can be integrated within a Metaverse learning environment, allowing students to engage with simulated real-world challenges, collaborate on problem-solving, and investigate virtual worlds. In addition, the Metaverse environment enables greater student agency, where learners can choose tasks based on interest, thus increasing motivation and participation. To address these infrastructure issues, the study proposes a lightweight and adaptable Metaverse design that enables content usage both online and offline, with the potential to be hosted on local school servers.

In summary, the findings highlight a strong alignment between the instructional challenges identified and the immersive strategies proposed. Each construct identified through expert consensus is directly addressed by elements embedded in the Metaverse storyboard, ensuring that the intervention is both contextually relevant and pedagogically effective.

5. Proposed Solution

5.1 Metaverse

The Metaverse, defined as a virtual 3D environment where digital and physical realities combine, offers transformative potential in education (Zhang et al., 2022). In the Malaysian context, where challenges such as limited infrastructure in rural areas and traditional instructional approaches persist, the Metaverse emerges as a strategic response to educational barriers (Naim & Hua, 2024). As shown by Chen et al. (2023), Metaverse environments promote learner engagement and peer interaction, critical elements for improving students’ motivation and participation in Computational Thinking (CT) instruction.

The immersive nature of the Metaverse supports simulations, virtual role-playing, and collaborative tasks that help students understand abstract CT concepts such as decomposition and pattern recognition, skills often difficult to teach using traditional methods. These environments allow students to manipulate virtual objects and receive real-time feedback, offering a more tangible learning experience (De La Asuncion Pari-Bedoya et al., 2023). In Malaysian classrooms, where students have shown low engagement and difficulty with abstraction, such experiences directly respond to these challenges.

Recent studies have further demonstrated the effectiveness of Metaverse-based learning in improving academic engagement and problem-solving skills. Lam and Norman (2024) report improvements in student performance and interest when science content is delivered through Metaverse platforms. Similarly, Pyae et al. (2023) highlight how Metaverse use promotes 21st-century skills such as collaboration and critical thinking, key components of CT pedagogy. In line with this, Kamsulbahri and Norman (2024) found that integrating the Metaverse in subjects like history increases student attention and knowledge retention.

From an accessibility perspective, Metaverse technologies can help bridge gaps for rural students by creating equitable, gamified learning spaces. Platforms like Spatial.io and Gather.Town support learner interaction through avatars, team projects, and gamification elements such as leaderboards and badges, enhancing motivation even in under-resourced settings (Krishnan et al., 2021; Pyae et al. 2023). These features are particularly relevant in the Malaysian context, where uneven ICT distribution and internet access hinder equitable access to quality education.

Moreover, the Malaysian government's commitment through the Digital Education Policy (DEP) 2023 supports the integration of digital technologies, such as the Metaverse, into education (Ministry of Education Malaysia, 2023). This policy reflects a broader national strategy to prepare students for the digital economy, making the adoption of immersive and student-centred methods both timely and necessary. As Camilleri (2024) and López-Belmonte et al. (2023) suggest, Metaverse environments not only simulate real-world contexts but also serve as bridges between academic knowledge and practical skills.

Nevertheless, adoption must be supported by teacher training and appropriate policy safeguards. As noted by Makrakis (2024), enhancing teacher self-efficacy is crucial for effective use of Metaverse-based tools. Without suitable training and pedagogical frameworks, the potential benefits of Metaverse integration may not be fully realised. Tan et al. (2024) also emphasise the need to adapt instructional methods to digital learners, particularly in language and CT-related domains.

In conclusion, the Metaverse offers a viable, immersive solution that directly addresses key issues identified in CT instruction, such as low motivation, difficulty with abstraction, and infrastructural inequality, particularly in the Malaysian context. While challenges such as digital access and privacy remain, the Metaverse provides a scalable and innovative pedagogical approach aligned with both global trends and local educational needs (Ibrahim et al., 2025).

While the Metaverse holds considerable promise for addressing issues such as geographical isolation and digital engagement, significant challenges remain, particularly around access to technology, privacy concerns, and societal readiness for rapid technological change. As with any emerging innovation, it is essential to acknowledge these limitations while strategically deploying Metaverse capabilities to maximise future opportunities for inclusive and transformative education.

5.2 Spatial-Unity Integration for Immersive Learning

Unity and Spatial.io are powerful platforms that, when integrated, offer immersive and interactive learning environments aligned with 21st-century educational needs. Unity, a globally recognised game engine, provides real-time rendering and interactive simulation capabilities that educators can utilise to design engaging learning content across subjects (Lin et al., 2022). Through Unity's functionality, teachers can develop simulations and virtual experiences that support students' understanding of computational concepts.

On the other hand, Spatial.io enables the creation of immersive virtual worlds using the Spatial Creator Toolkit, which is directly compatible with Unity (Sriworapong et al., 2022). Within this environment, students benefit from engaging with content through gamified learning tasks, avatars, and collaboration spaces that promote motivation and enhance learning outcomes (Vate-U-Lan & Cahill, 2024; Pujasari et al., 2024). For example, learning modules on English spatial prepositions delivered in Spatial.io led to significantly improved test scores, illustrating its effectiveness as a pedagogical tool (Vate-U-Lan & Cahill, 2024).

The integration of Ready Player Me avatars allows learners to personalise their digital identity, contributing to increased social presence and motivation (Seo et al., 2017). Avatars provide a more engaging way to participate in discussions, collaborate on assignments, and explore abstract CT concepts in a contextualised manner (Abdullah & Norman, 2024). Additionally, Spatial.io promotes digital literacy and social interaction, as students engage with content through avatars in a shared environment, thereby enhancing collaborative learning experiences (Pujasari et al., 2024).

The Spatial Creator Toolkit further allows educators to embed dynamic visual elements such as shaders and animated assets into their virtual environments. Alabau et al. (2024) demonstrated how this was used to simulate Mars exploration, offering a rich learning experience that supports inquiry-based and problem-solving instruction. This reinforces the importance of gamified and visual learning for making abstract CT concepts tangible.

In summary, integrating Unity with Spatial.io creates an immersive and interactive platform that directly addresses key challenges identified in this study, such as difficulties with abstract thinking, lack of student motivation, and the need for contextualised CT learning. This integration is particularly relevant in the Malaysian education context, where digital tools are being increasingly explored to overcome traditional pedagogical limitations.

Proposed Storyboard for Metaverse-Based CT Learning

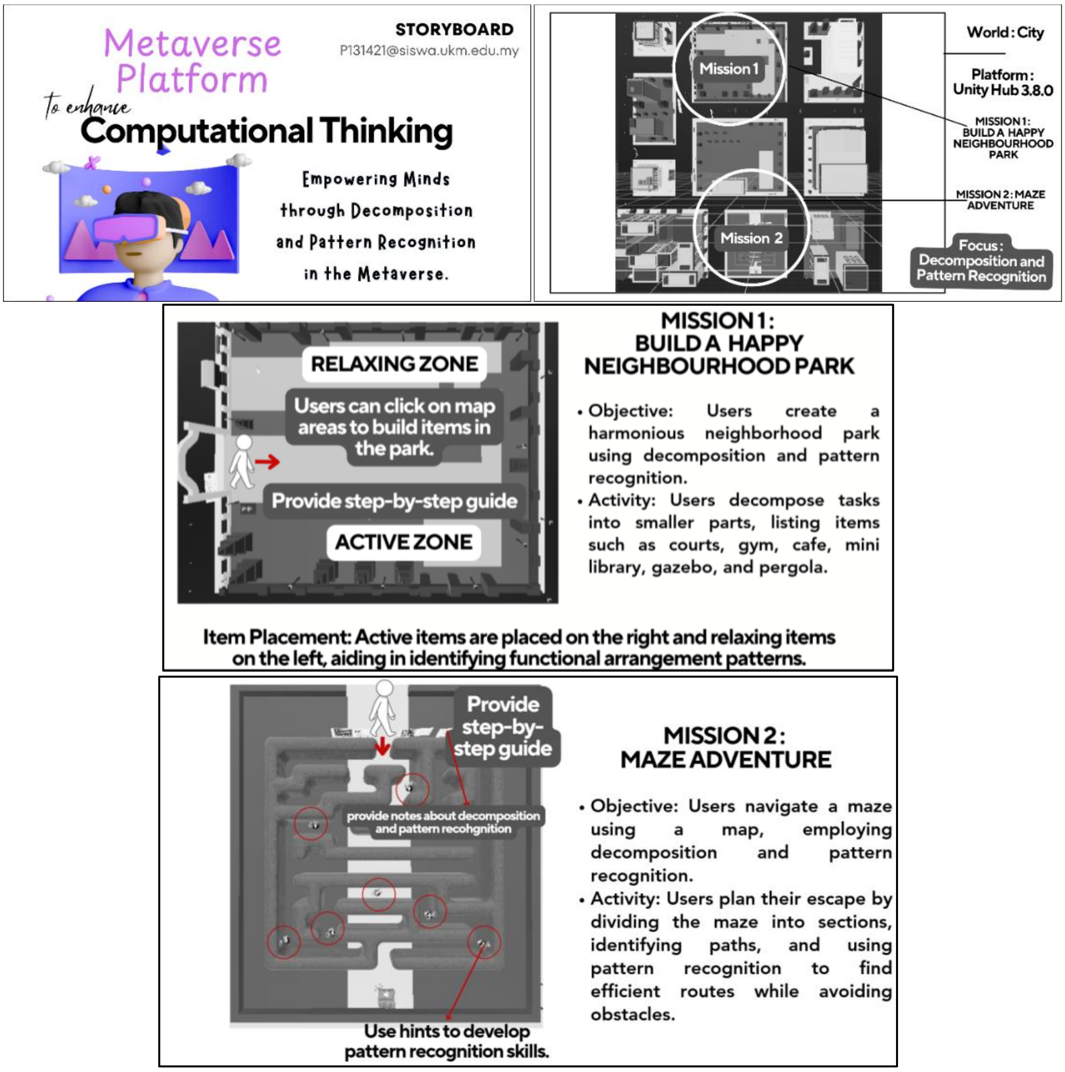

Figure 2: Storyboard using Metaverse to Learn Computational Thinking

The proposed storyboard outlines two immersive missions designed in Spatial.io using Unity, aimed at addressing the specific Computational Thinking (CT) challenges identified during the NGT session, including difficulty with decomposition, pattern recognition, and low motivation, particularly among non-IT learners.

In Mission 1: Build a Happy Neighbourhood Park, students are instructed to plan and design a virtual park that includes elements such as a gym, café, reading room, and court. This task intentionally applies the CT skill of decomposition by requiring learners to break down the overall task into smaller sub-tasks (e.g., organising active vs. relaxing zones). The park layout, with active items (gym and court) on the right and relaxing items (café and reading room) on the left, supports pattern recognition, allowing learners to identify spatial logic through repeated structural arrangements. This mirrors real-life planning skills and was created in response to expert feedback that abstract CT concepts need to be supported by visualisation and relatable contexts (Ding & Zainudin, 2024; Choi & Yang, 2025).

In Mission 2: Maze Adventure, learners apply CT by navigating a maze using decomposition and pattern recognition. They analyse the layout, plan escape routes, eliminate dead ends, and adapt their path using hint prompts. These mechanisms directly address the NGT findings, where experts highlighted students' stress and disengagement when faced with multi-step problems (Halim & Mahmood, 2024). The gamified design increases motivation, aligning with Pyae et al. (2023), who advocate for Metaverse-based learning games to enhance CT engagement.

The storyboard's user-friendly structure makes it accessible to learners with no computing background. This addresses the concern that non-IT students often struggle with CT due to the abstract nature of its concepts. Choi and Yang (2025) emphasise that Problem-Based Learning (PBL), embedded in real-world scenarios, supports concept acquisition across disciplines. The missions provide exactly this, using project-based challenges to foster engagement and improve understanding.

Gamification elements, such as avatar design, social interaction, and task progression, further enhance motivation and collaboration. Platforms like Ready Player Me allow learners to personalise avatars, which has been shown to increase ownership and participation in digital learning (Seo et al., 2017). The use of avatars in discussions and group activities reinforces digital identity and social presence (Abdullah & Norman, 2024), which are critical for increasing engagement among disengaged learners.

The integration of Unity and Spatial.io through the Spatial Creator Toolkit allows educators to design interactive environments with layered animations, shaders, and dynamic scenes. For example, Alabau et al. (2024) demonstrated how Mars exploration simulations using this toolkit provided an immersive learning experience, illustrating its broader educational potential. Similarly, the avatar-based interaction and immersive world-building in Spatial.io improve both collaboration and digital literacy (Pujasari et al., 2024; Vate-U-Lan & Cahill, 2024).

Together, these missions support the CT components of decomposition and pattern recognition while simultaneously addressing low motivation and accessibility for non-technical students. As supported by Onu et al. (2024) and Ajang and Yasin (2024), such interactive and gamified designs significantly boost learning motivation and performance. This storyboard, based on expert consensus and pedagogical theory, offers a practical model for future Metaverse-based CT learning environments in Malaysian secondary schools.

6. Discussion

This study examined the integration of Metaverse technologies in enhancing the teaching and learning of Computational Thinking (CT) in Malaysian secondary schools. The results from the Nominal Group Technique (NGT) session revealed five key challenges with current CT instruction, including difficulty in understanding abstract concepts, lack of motivation, weak problem-solving skills, insufficient real-life applications, and infrastructure limitations. Experts confirmed that immersive, gamified environments, particularly those developed using platforms such as Spatial.io and Unity, could potentially address these issues. These findings align with prior studies supporting the use of immersive technologies to enhance problem-solving, student engagement, and conceptual understanding (Pyae et al., 2023; Lam & Norman, 2024).

Traditional methods of CT often rely on textbook-driven tasks, static explanations, and limited interactivity. These methods are inadequate in conveying abstract and procedural CT concepts to students with diverse learning needs. In contrast, Metaverse-based environments offer multi-sensory engagement, real-time feedback, and interactive simulations. For example, in this study's prototype missions, students explored virtual parks and mazes where CT skills such as decomposition and pattern recognition were embedded into gameplay. These learning experiences simulate real-world challenges in a way that traditional classroom teaching cannot, thereby fostering deeper engagement and understanding, an improvement noted by experts during the NGT session.

The study's findings suggest that immersive virtual environments offer meaningful alternatives to conventional pedagogies. Students' motivation increased when they were allowed to make choices in their learning and exposed to game-based challenges. In Mission 1 (Neighbourhood Park) and Mission 2 (Maze Adventure), students were required to apply CT skills to solve context-based problems, thereby practising higher-order thinking in a simulated environment. These scenarios align with gamified and exploratory learning approaches discussed in literature (Zhang et al., 2022; Menezes et al., 2023; Pyae et al., 2023)**.** The challenge of "difficulty with abstraction", identified in the NGT findings, was also addressed through the use of 3D visualisations that allow learners to manipulate virtual elements, a significant advantage over passive lecture methods.

Furthermore, the ability to create and personalise avatars enhances students' sense of agency and social presence, contributing to increased engagement. Platforms such as Ready Player Me allow learners to design digital identities that reflect their preferences, thereby fostering greater motivation and ownership in the learning process. Seo et al. (2017). In addition, the Metaverse offers a unique opportunity to democratise access to high-quality educational resources. Technologies within this environment are often cross-platform compatible, enabling students from diverse backgrounds to engage in learning beyond hardware limitations (Sriworapong et al., 2022). Nevertheless, teacher preparedness remains essential. As highlighted by Makrakis (2024), digital integration alone is insufficient unless teachers are equipped with the necessary skills and confidence to facilitate learning in these new environments.

While this study focuses on student outcomes, teacher readiness is equally vital. The transition to Metaverse-based learning requires teachers to be trained not only in digital tools but also in the instructional design of immersive environments. According to Makrakis (2024), teacher self-efficacy is a crucial factor in successful digital integration. Educators need professional development in areas such as gamification, facilitation within 3D environments, and the assessment of student performance in non-traditional settings. The Metaverse does not replace the teacher, but it repositions them as facilitators and experience designers.

Despite the benefits, implementation challenges remain. As the findings show, schools, especially in rural areas, face infrastructure limitations such as lack of computers and internet connectivity. These barriers may hinder the equitable deployment of Metaverse-based strategies. To address this, the proposed solution includes modular, lightweight experiences that can function offline or on local servers. As supported by Tan et al. (2024), addressing infrastructure readiness is essential to prevent further widening of the digital gap. Furthermore, privacy and accessibility concerns were raised during the NGT session, reflecting the importance of ethical and inclusive design in digital education tools.

This study focused on expert feedback gathered through the NGT method, which, while insightful, is limited by the small number of participants (six teachers). The study did not collect direct student performance data or conduct classroom observations, which limits the generalisability of the findings. Additionally, the missions tested (e.g., Park and Maze) were prototype simulations that require further empirical testing in real classroom environments to comprehensively evaluate learning outcomes.

Future studies should involve a larger, more diverse sample of teachers and include student voices through surveys or focus groups. Experimental studies could be designed to measure the effectiveness of Metaverse-based CT instruction on student performance, motivation, and cognitive development. Moreover, collaboration with policymakers is encouraged to explore how national digital education strategies, such as Malaysia's Digital Education Policy (DEP 2023), can integrate Metaverse learning into mainstream curricula. Research should also explore differentiated Metaverse environments for students with special needs or low digital literacy to ensure inclusivity and universal applicability.

Integrating Metaverse technologies with CT pedagogy presents both opportunities and responsibilities. This study provides early evidence that such integration, when informed by expert consensus and grounded in immersive learning theory, can address the core challenges of CT instruction. However, its success depends on thoughtful design, equitable access, and sustained support for teachers and learners.

7. Conclusion

This study explored the integration of Metaverse technologies into Computational Thinking (CT) instruction in Malaysian secondary schools, identifying five major challenges, including difficulty with abstract concepts, low motivation, weak problem-solving skills, limited real-life applications, and infrastructure gaps. Expert consensus, gathered through the Nominal Group Technique (NGT), revealed that immersive and gamified environments, developed using platforms such as Spatial.io and Unity, have strong potential to address these barriers by offering interactive, visual, and engaging learning experiences.

These findings affirm that Metaverse platforms can serve as alternative pedagogical tools, particularly in contexts where traditional methods fail to support student engagement and higher-order thinking. However, implementation requires more than technology alone. Teacher readiness, equitable infrastructure, and curriculum integration are crucial. Aligning with Malaysia's Digital Education Policy (DEP), this study underscores the need for supportive policies, including professional development for educators and targeted funding to reduce the digital gap, especially in rural areas.

Future efforts should prioritise large-scale, classroom-based pilot studies to evaluate the actual impact of Metaverse learning on student achievement and engagement. Research should also examine how local culture can be embedded into virtual environments to enhance relatability and motivation. Moreover, conceptual models involving stakeholders, including teachers, policymakers, and tech developers, must be further refined to ensure the scalability and sustainability of Metaverse-based learning.

While this study provides early expert-based insights, it acknowledges its limitations, particularly the small sample size and absence of student data. Nonetheless, the findings offer a practical foundation for reimagining CT education. With collaborative support from all sectors, immersive technologies have the potential to equip students with the cognitive skills and digital fluency required in today's fast-evolving world.

8. Acknowledgements

This study is supported by the research grant GG-2024-004 from the Faculty of Education, National University of Malaysia.

9. References

Abd Halim, N. D., & Mahmood, M. (2024). Kesan Pendekatan Inkuiri 5E Dalam Persekitaran PdP STEM Terhadap Pencapaian Dan Pemikiran Komputasional Bagi Subjek Sains Komputer Tingkatan Empat . *Seminar Kebangsaan Majlis Dekan Pendidikan Universiti Awam 2024 Inovasi Dalam Pendidikan Ke Arah Matlamat Pembangunan Lestari (Sdg)* , 93.

Abdullah, K., & Norman, H. (2024). Perceptions And Acceptance Of Matriculation Students Towards Metaverse For Chemistry. *Journal of Research, Innovation, and Strategies for Education*. ttps://doi.org/https://doi.org/10.70148/rise.15

Ajang, E. E., & Mohammad Yasin, R. (2024). Keberkesanan Penggunaan Aplikasi Pembelajaran Interaktif dalam Meningkatkan Motivasi serta Pencapaian Pelajar dalam Mata Pelajaran Fizik. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, *9*(1), e002469. https://doi.org/10.47405/mjssh.v9i1.2469

Alabau, A., Fabra, L., Martí-Testón, A., Muñoz, A., Solanes, J. E., & Gracia, L. (2024). Enriching User-Visitor Experiences in Digital Museology: Combining Social and

Virtual Interaction within a Metaverse Environment. *Applied Sciences (Switzerland)*, *14*(9). https://doi.org/10.3390/app14093769

Anderson, N. D. (2016). A Call for Computational Thinking in Undergraduate Psychology. *Psychology Learning & Teaching*, *15*(3), 226–234. https://doi.org/10.1177/1475725716659252

Andre L Delbecq, Andrew H. Van de Ven, & David Gustafson. (1975). *Group Techniques for Program Planning; a guide to nominal group and Delphi processes.* 108.

Anuar, N. H., Mohamad, F. S., & Minoi, J.-L. (2021). Art-Integration in Computational Thinking as an Unplugged Pedagogical Approach at A Rural Sarawak Primary School. *International Journal of Academic Research in Business and Social Sciences*, *11*(14). https://doi.org/10.6007/IJARBSS/v11-i14/8328

Aslan, U., Horn, M., & Wilensky, U. (2024). Why are some students "not into" computational thinking activities embedded within high school science units? Key takeaways from a microethnographic discourse analysis study. *Science Education*, *108*(3), 929–956. https://doi.org/10.1002/sce.21850

Camilleri, M. A. (2024). Metaverse applications in education: a systematic review and a cost-benefit analysis. *Interactive Technology and Smart Education*, *21*(2), 245–269. https://doi.org/10.1108/ITSE-01-2023-0017

Cao, Y. (2023). Design and Development of Machine Learning Curriculum for Middle School Students' Computational Thinking Development. *Advances in Computer and Communication*, *4*(5), 283–288. https://doi.org/10.26855/acc.2023.10.004

Chen, W., Zhang, J., & Yu, Z. (2023). A Bibliometric Analysis of the Use of the Metaverse in Education Over Three Decades. *International Journal of Information and Communication Technology Education*, *19*(1), 1–16. https://doi.org/10.4018/IJICTE.322101

Cheong Tau Han, Nurul Ainin Sofia Binti Atan, Mohd Shafie Rosli, Joseph Boon Zik Hong, Harrini Md Noor, & Juan Li. (2024). Global Education: Computational Thinking's Role and Relationships Explored. *Environment-Behaviour Proceedings Journal*, *9*(27), 361–367. https://doi.org/10.21834/e-bpj.v9i27.5709

Choi, J. I., & Yang, S. (2025). Effectiveness and Design of PBL-Based Project Approach for Non-Major University Computing Courses. *Applied Sciences (Switzerland)*, *15*(1). https://doi.org/10.3390/app15010050

Choy, S. C., Yim, J. S. C., & Sedhu, D. S. (2019). Pre-service Teachers' Reflection on Reflective Practices: A Malaysian Perspective. *Universal Journal of Educational Research*, *7*(12A), 18–26. https://doi.org/10.13189/ujer.2019.071903

Cilliers, E. J. (2017). The Challenge Of Teaching Generation Z. *People: International Journal of Social Sciences*, *3*(1), 188–198. https://doi.org/10.20319/pijss.2017.31.188198

Criollo-C, S., Uzcategui, J. E. C., Guerrero-Arias, A., Anita Yanez, T., Samala, A. D., Rawas, S., & Lujan-Mora, S. (2024). Use of Virtual Reality as an Educational Tool: A Comparison Between Engineering Students and Teachers. *IEEE Access*, *12*, 86662–86674. https://doi.org/10.1109/ACCESS.2024.3416673

Dang, V. H. (2015). The Use of Nominal Group Technique: Case Study in Vietnam. *World Journal of Education*, *5*(4). https://doi.org/10.5430/wje.v5n4p14

De La Asuncion Pari-Bedoya, I. N. M., Vargas-Murillo, A. R., Palacios, R. J., Guevara-Soto, F. D. J., & Ypanaque-Pereira, I. L. (2023). Smart Learning in Virtual Worlds: A Systematic Literature Review on the Usage and Applications of Metaverse in Education. In *International Journal of Learning, Teaching and Educational Research* (Vol. 22, Issue 9, pp. 85–101). Society for Research and Knowledge Management. https://doi.org/10.26803/ijlter.22.9.5

Department of Educational Planning and Policy Research. (2023). *Preliminary report on Malaysia's performance in the Programme for International Student Assessment (PISA) 2022*.

Dowling, K. L., & St. Louis, R. D. (2000). Asynchronous implementation of the nominal group technique: is it effective? *Decision Support Systems*, *29*(3), 229–248. https://doi.org/10.1016/S0167-9236(00)00073-7

Duggan, E. W., & Thachenkary, C. S. (2004). Integrating nominal group technique and joint application development for improved systems requirements determination. *Information & Management*, *41*(4), 399–411. https://doi.org/10.1016/S0378-7206(03)00080-6

Ezeamuzie, N. O., Leung, J. S. C., Garcia, R. C. C., & Ting, F. S. T. (2022). Discovering computational thinking in everyday problem solving: A multiple case study of route planning. *Journal of Computer Assisted Learning*, *38*(6), 1779–1796. https://doi.org/10.1111/jcal.12720

Falloon, G. (2024). Advancing young students' computational thinking: An investigation of structured curriculum in early years primary schooling. *Computers and Education*, *216*. https://doi.org/10.1016/j.compedu.2024.105045

Gibson, F., & Soanes, L. (2000). The development of clinical competencies for use on a paediatric oncology nursing course using a nominal group technique. *Journal of Clinical Nursing*, *9*(3), 459–469. https://doi.org/10.1046/j.1365-2702.2000.00404.x

Harvey, N., & Holmes, C. A. (2012). Nominal group technique: An effective method for obtaining group consensus. *International Journal of Nursing Practice*, *18*(2), 188–194. https://doi.org/10.1111/j.1440-172X.2012.02017.x

Ibrahim, N. H., Norman, H., & Nasir, M. K. M. (2025). A Review of the Metaverse in Nursing Education: A SCORE Model Evaluation. *International Journal of Learning, Teaching and Educational Research*, *24*(1), 209–224. https://doi.org/10.26803/ijlter.24.1.11

Kaddoura, S., & Al Husseiny, F. (2023). The rising trend of Metaverse in education: challenges, opportunities, and ethical considerations. *PeerJ Computer Science*, *9*, e1252. https://doi.org/10.7717/peerj-cs.1252

Kamsulbahri, K. F. K., & Norman, H. (2024). Online Learning with Metaverse for History Education At Primary School Education Level. *International Journal of Academic Research in Progressive Education and Development*, *13*(2). https://doi.org/10.6007/ijarped/v13-i2/21502

Kastner-Hauler, O., Tengler, K., Sabitzer, B., & Lavicza, Z. (2022). Combined Effects of Block-Based Programming and Physical Computing on Primary Students' Computational Thinking Skills. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.875382

Khair Naim, M., & Kim Hua, T. (2024). Metaverse in Language Learning on Communicative Competencies-Mini Review. *International Journal of Arts Humanities and Social Sciences Studies* , *9*(4). www.ijahss.com

Krishnan, S. D., Norman, H., & Yunus, M. M. (2021). Online gamified learning to enhance teachers' competencies using classcraft. *Sustainability (Switzerland)*, *13*(19). https://doi.org/10.3390/su131910817

Lam, M. W., & Norman, H. (2024). Keberkesanan Pembelajaran Berasaskan Metaverse Melalui Aplikasi Zepeto bagi Subjek Sains di kalangan Murid Sekolah Rendah. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, *9*(4), e002792. https://doi.org/10.47405/mjssh.v9i4.2792

Lin, H., Wan, S., Gan, W., Chen, J., & Chao, H.-C. (2022). *Metaverse in Education: Vision, Opportunities, and Challenges*. http://arxiv.org/abs/2211.14951

Liu, S., Peng, C., & Srivastava, G. (2023). What influences computational thinking? A theoretical and empirical study based on the influence of learning engagement on computational thinking in higher education. *Computer Applications in Engineering Education*, *31*(6), 1690–1704. https://doi.org/10.1002/cae.22669

Lloyd-Jones, Fowell, & Bligh. (1999). The use of the nominal group technique as an evaluative tool in medical undergraduate education. *Medical Education*, *33*(1), 8–13. https://doi.org/10.1046/j.1365-2923.1999.00288.x

Lomax, P., & McLeman, P. (1984). The uses and abuses of nominal group technique in polytechnic course evaluation. *Studies in Higher Education*, *9*(2), 183–190. https://doi.org/10.1080/03075078412331378834

López-Belmonte, J., Pozo-Sánchez, S., Moreno-Guerrero, A.-J., & Lampropoulos, G. (2023). Metaverse in Education: a systematic review. *Revista de Educación a Distancia (RED)*, *23*(73). https://doi.org/10.6018/red.511421

MacPhail, A. (2001). Nominal Group Technique: A useful method for working with young people. *British Educational Research Journal*, *27*(2), 161–170. https://doi.org/10.1080/01411920120037117

Madi Bin Abdullah, M., & Islam, R. (2011). Nominal Group Technique and its Applications in Managing Quality in Higher Education. In *Soc. Sci* (Vol. 5, Issue 1).

Makrakis, V. (2024). Teachers' Resilience Scale for Sustainability Enabled by ICT/Metaverse Learning Technologies: Factorial Structure, Reliability, and Validation. *Sustainability*, *16*(17), 7679. https://doi.org/10.3390/su16177679

Menezes, J., Schlemmer, E., & Di Felice, M. (2023). Developing Computational Thinking in the City through an OnLIFE Education and Digital Citizenship perspective. *Research, Society and Development*, *12*(7), e18612742732. https://doi.org/10.33448/rsd-v12i7.42732

Ministry of Education Malaysia. (2016). *Buku Teks Asas Sains Komputer Tingkatan 3* (1st ed.). Pan Asia. https://apdm.my/buku-teks-asas-sains-komputer-tingkatan-3/

Ministry of Education Malaysia. (2023). *Digital Education Policy*. https://www.moe.gov.my/policies/digital-education-policy

Mohd Ariffin, N. A., Ariffin, A. H., Suhaimi, S., Rosli, A. N., & Abd Wahab, M. H. (2022). Pembangunan Permainan Berkomputer Pintar-II Bagi Mata Pelajaran

Asas Sains Komputer Tingkatan 1. *Journal of Engineering, Technology, and Applied Science*, *4*(3), 114–121. https://doi.org/10.36079/lamintang.jetas-0403.394

Mohd Asarani, U. H., & Mohd Yassin, S. F. (2020). Pengintegrasian Pemikiran Komputasional Dalam Aktiviti Pengaturcaraan Dan Robotik. *International Journal of Education and Pedagogy (IJEAP)*, *2*(2), 124.

Mohd Kusnan, R., Tarmuji, N. H., & Omar, M. K. (2020). Sorotan Literatur Bersistematik: Aktiviti Pemikiran Komputasional dalam Pendidikan di Malaysia. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, *5*(12), 112–122. https://doi.org/10.47405/mjssh.v5i12.581

Mohd Napiah, A. S., & Hashim, M. (2021). Tahap kesediaan guru pelatih terhadap pelaksanaan pemikiran komputasional. *Journal of ICT in Education*, *8*(4), 81–103. https://doi.org/10.37134/jictie.vol8.sp.2.9.2021

Molina-Ayuso, Á., Adamuz-Povedano, N., Bracho-López, R., & Torralbo-Rodríguez, M. (2024). Computational Thinking with Scratch: A Tool to Work on Geometry in the Fifth Grade of Primary Education. *Sustainability (Switzerland)*, *16*(1). https://doi.org/10.3390/su16010110

Mullen, R., Kydd, A., Fleming, A., & McMillan, L. (2021). A practical guide to the systematic application of nominal group technique. Nurse researcher, 29(1).

O'Neil, M. J., & Jackson, L. (1983). Nominal Group Technique: A process for initiating curriculum development in higher education. *Studies in Higher Education*, *8*(2), 129–138. https://doi.org/10.1080/03075078312331378994

Olsen, J. (2019). The Nominal Group Technique (NGT) as a tool for facilitating pan-disability focus groups and as a new method for quantifying changes in qualitative data. International Journal of Qualitative Methods, 18, 1609406919866049.

Onu, P., Pradhan, A., & Mbohwa, C. (2024). Potential to use metaverse for future teaching and learning. *Education and Information Technologies*, *29*(7), 8893–8924. https://doi.org/10.1007/s10639-023-12167-9

Pokorny, L. J., Lyle, K., Tyler, M., & Topolski, J. (1988). Introducing a modified nominal group technique for issue identification. *Evaluation Practice*, *9*(2), 40–44. https://doi.org/10.1016/S0886-1633(88)80063-1

Pujasari, R. S., Fatimah, A. S., Sri, M., & Sulastri, F. (2024). Potential Benefits of Metaverse Concept Implementation in English for Tourism Course: A Case Study in Indonesian Higher Education Contexts. *International Journal of Language Education*, *8*(3), 520–532. https://doi.org/10.26858/ijole.v8i3.66494

Pyae, A., Ravyse, W., Luimula, M., Pizarro-Lucas, E., Sanchez, P. L., Dorado-Diaz, I. P., & Thaw, A. K. (2023). Exploring User Experience and Usability in a Metaverse Learning Environment for Students: A Usability Study of the Artificial Intelligence, Innovation, and Society (AIIS). *Electronics (Switzerland)*, *12*(20). https://doi.org/10.3390/electronics12204283

Rafli, M., Sutarno, H., & Wihardi, Y. (2024). Implementation of Computational Thinking in Data Structure Subject Using Problem-based Learning Models. *Jurnal Guru Komputer*, *4*(2), 66–75. https://doi.org/10.17509/jgrkom.v4i2.30450

Said, G. R. El. (2023). Metaverse-Based Learning Opportunities and Challenges: A Phenomenological Metaverse Human–Computer Interaction Study. *Electronics*, *12*(6), 1379. https://doi.org/10.3390/electronics12061379

Saidin, N. D., Khalid, F., Martin, R., Kuppusamy, Y., & Munusamy, N. A. P. (2021). Benefits and challenges of applying computational thinking in education. *International Journal of Information and Education Technology*, *11*(5), 248–254. https://doi.org/10.18178/ijiet.2021.11.5.1519

Seo, Y., Kim, M., Jung, Y., & Lee, D. (2017). Avatar face recognition and self-presence. *Computers in Human Behavior*, *69*, 120–127. https://doi.org/10.1016/j.chb.2016.12.020

Sidek, S. F., Mohamad Yatim, M. H., & Said, C. S. (2020). Characterizing Computational Thinking for Tertiary Education Learning. *Journal of Contemporary Issues and Thought*, *10*, 58–69. https://doi.org/10.37134/jcit.vol10.sp.6.2020

Siti Farhah A.Aziz, & Saedah Siraj. (2015). Pembangunan Model Objektif Kurikulum Berasaskan Taman Buah-Buahan Dan Sayur-Sayuran Berkhasiat Untuk Sekolah Rendah Orang Asli. *Jurnal Kurikulum & Pengajaran Asia Pasifik*, *3*(3), 1–13.

Solanes, J. E., Montava-Jordà, S., Golf-Laville, E., Colomer-Romero, V., Gracia, L., & Muñoz, A. (2023). Enhancing STEM Education through Interactive Metaverses: A Case Study and Methodological Framework. *Applied Sciences*, *13*(19), 10785. https://doi.org/10.3390/app131910785

Sriworapong, S., Pyae, A., Thirasawasd, A., & Keereewan, W. (2022). Investigating Students' Engagement, Enjoyment, and Sociability in Virtual Reality-Based Systems: A Comparative Usability Study of Spatial.io, Gather.town, and Zoom. *Communications in Computer and Information Science*. https://doi.org/https://doi.org/10.1007/978-3-031-14832-3_10

Su, J., & Yang, W. (2023). A systematic review of integrating computational thinking in early childhood education. *Computers and Education Open*, *4*, 100122. https://doi.org/10.1016/j.caeo.2023.100122

Supiarmo, M. G., Hadi, H. S., & Tarmuzi, T. (2022). Student's Computational Thinking Process in Solving PISA Questions in Terms of Problem Solving Abilities. *(JIML) Journal Of Innovative Mathematics Learning*, *5*(1), 01–11. https://doi.org/10.22460/jiml.v5i1.p01-11

Tan, K. H., Mohd Khair Naim, Wahiza Wahi, Ahmad Firdaus Arham, & Yunos, N. (2024). Metaverse-Based Activities for Enhancing Communicative Competencies among Young Learners. *International Journal of Interactive Mobile Technologies (IJIM)*, *18*(21), 4–25. https://doi.org/10.3991/ijim.v18i21.47867

Tsai, M. J., Liang, J. C., & Hsu, C. Y. (2021). The Computational Thinking Scale for Computer Literacy Education. *Journal of Educational Computing Research*, *59*(4), 579–602. https://doi.org/10.1177/0735633120972356

Van De, A., & Delbecq, A. L. (1971). Nominal Versus Interacting Group Processes for Committee Decision-Making Effectiveness. *Academy of Management Journal*, *14*(2), 203–212. https://doi.org/10.2307/255307

Vate-U-Lan, P., & Cahill, D. (2024). Advancing academic achievement: integrating society 5.0 and game-based learning in metaverse space for undergraduates in Bangkok, Thailand. *Cogent Education*, *11*(1). https://doi.org/10.1080/2331186X.2024.2385239

Vahedian-Shahroodi, M., Mansourzadeh, A., Shariat Moghani, S., & Saeidi, M. (2023). Using the nominal group technique in group decision-making: A review. Medical Education Bulletin, 4(4), 837-845.

Wan Mohamad Akil, W. N. H., & Mohd Matore, M. E. @ E. (2023). Shocking Truths About Three Factors That Influenced Computational Thinking (I Wish I Learned Earlier!). *International Journal of Academic Research in Progressive Education and Development*, *12*(2). https://doi.org/10.6007/IJARPED/v12-i2/17205

Wang, X., Saito, D., Washizaki, H., & Fukazawa, Y. (2023). Facilitating Students' Abstract and Computational Thinking Skills Using Virtual Reality. *2023 IEEE Integrated STEM Education Conference (ISEC)*, 243–246. https://doi.org/10.1109/ISEC57711.2023.10402125

Williams, P. L., White, N., Klem, R., Wilson, S. E., & Bartholomew, P. (2006). Clinical education and training: Using the nominal group technique in research with radiographers to identify factors affecting quality and capacity. *Radiography*, *12*(3), 215–224. https://doi.org/10.1016/j.radi.2005.06.001

Xue, C., & Liu, Y. (2021). The Analysis of Research Hotspots and Frontiers of Computational Thinking Based on CiteSpace. *Open Journal of Social Sciences*, *09*(09), 1–16. https://doi.org/10.4236/jss.2021.99001

Yanfang Ding, & Hassan Zainudin. (2024). Enhancing Critical Thinking in China's Virtual Learning Environments: Developing a Model for University Education. *International Journal of Advanced Research in Education and Society*. https://doi.org/10.55057/ijares.2024.6.1.34

Yosepha, A., Ali, M., Wahyudin, D., & Rusman. (2023). The Role of Multi-dimensional Curriculum Design in Improving Higher-Order Thinking Skills. *International Journal of Learning, Teaching and Educational Research*, *22*(7), 219–239. https://doi.org/10.26803/ijlter.22.7.12

Zhang, X., Chen, Y., Hu, L., & Wang, Y. (2022). The metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics. In *Frontiers in Psychology* (Vol. 13). Frontiers Media S.A. https://doi.org/10.3389/fpsyg.2022.1016300

Zhu, H., & Deng, P. (2024). This Paper Discusses the Current Situation and Training Strategies of Primary School Students' Computational Thinking Ability. *Advances in Education, Humanities and Social Science Research*, *10*(1), 74. https://doi.org/10.56028/aehssr.10.1.74.2024

Zhu Meijuan. (2022). CiteSpace Map Analysis of Computational Thinking Research in China. *Journal of Educational Research and Policies*, *4*(12). https://doi.org/10.53469/jerp.2022.04(12).20