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Exploring the Use of Minecraft Education Edition to Support Computational Thinking, Coding Skills, and AI Literacy: A Case Study in an Indonesian Madrasah Informatics Classroom

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Abstract: *This study investigates how Minecraft Education Edition supports the development of computational thinking (CT), coding skills, and foundational artificial intelligence (AI) literacy within the Grade 10 Phase E Informatics curriculum at MAN 9 Jakarta, Indonesia. The study employed a qualitative case study design involving 204 students across six Informatics classes, one Informatics teacher, and the madrasah principal. Data were gathered through non-participant classroom observations, semi-structured interviews with 30 focal students (five per class), interviews with the teacher and principal, and documentation of student artefacts (Minecraft worlds and in-game code). To strengthen the claim of effectiveness across all six classes, rubric-based observation and artefact indicators for the three focal outcomes (CT, coding skills, and AI literacy) were additionally summarized using descriptive statistics (frequencies and percentages), complementing the thematic analysis. Findings indicate that Minecraft Education promoted CT through decomposition and iterative debugging, supported coding skill growth via visual block-based programming and immediate feedback, and helped students conceptualize AI as a rule-based system through programmable agents. The study highlights Minecraft Education as a contextually responsive approach for developing CT, coding skills, and AI literacy in a faith-based public-school setting when implemented with intentional scaffolding and reflective pedagogy.*

Keywords: *minecraft education, computational thinking, coding skills, AI literacy, madrasah Informatics*

Introduction

Digital transformation has become a strategic imperative for education systems worldwide as societies respond to rapidly evolving socio-technical realities. Systematic reviews show that successful digital transformation depends not only on infrastructure, but also on leadership, professional capacity, and pedagogical innovation at the school level (Aditya et al., 2022; Benavides et al., 2020). Within this broader context, Informatics education plays a pivotal role because it explicitly cultivates computational thinking (CT), programming skills, and emerging artificial intelligence (AI) literacy—a triad of competencies increasingly seen as foundational for participation in a data-driven economy and civic life (Li et al., 2020; Shute et al., 2017). Positioning AI literacy alongside CT and coding from the outset is therefore essential for understanding the significance of Informatics learning in contemporary schools.

Contemporary research conceptualizes CT as a family of cognitive practices that include decomposition, pattern recognition, abstraction, algorithmic design, and systematic debugging (Andrian & Hikmawan, 2021; Nouri et al., 2020; Tang et al., 2020). When these practices are well supported, CT is linked to improved problem solving in both STEM and non-STEM contexts. Yet, in many classrooms, Informatics is still experienced as abstract and intimidating, particularly when instruction is lecture-based, textbook-driven, or heavily focused on symbolic notation. Difficulties in understanding control flow, conditional logic, and iterative structures often lead to frustration and disengagement (Shute et al., 2017; Tang et al., 2020).

In parallel, AI literacy has emerged as a complementary construct that captures what learners need to understand about AI systems: what they are, how they work, and what their limitations and societal implications might be (Li et al., 2020; Long & Magerko, 2020). School-based AI literacy initiatives typically begin with concrete experiences, such as block-based programming and simple agent-based scenarios, that help students' reason about rules, data, and decision flows (T.-Y. Liu & Jeong, 2022). When CT, coding, and AI literacy are developed together, Informatics can move beyond narrow technical skills to provide a broader preparation for life in AI-mediated societies.

In Indonesia, these challenges are sharpened by uneven access to digital resources, disparities in teacher readiness, and institutional differences between general schools and faith-based institutions such as madrasahs. Studies on digital transformation in Indonesian education highlight that technology initiatives frequently stall at the level of hardware provision when not accompanied by sustained pedagogical support and contextually grounded models of practice (Aditya et al., 2022; Alam & Hidayah, 2025). Madrasahs are expected to align with national curricula while simultaneously maintaining religious and cultural commitments, which creates both constraints and opportunities for innovation in Informatics learning.

At MAN 9 Jakarta—the bounded case in this study—Informatics in Phase E is delivered to a full Grade 10 cohort organized into six parallel classes (n = 204). Classroom observations and initial teacher reflections in this setting pointed to three recurring instructional constraints: (1) students' prior experience with formal programming constructs (e.g., loops and conditionals) varied widely despite high everyday exposure to digital media; (2) early coding lessons tended to become overly abstract when detached from visible outputs, making it difficult for learners to articulate decomposition and algorithmic reasoning; and (3) opportunities to discuss AI-related concepts (rules, inputs/outputs, automation, and limitations) were limited in routine lessons, even though students frequently encountered AI-mediated features in their digital lives. These contextual characteristics motivated the choice of an immersive, artifact-rich learning environment that could make thinking visible and support structured reflection.

Minecraft Education Edition was selected as a pedagogical response to these constraints because it offers an accessible bridge from concrete action to formal reasoning: students can observe immediate in-world consequences of code, collaborate on shared builds, and iteratively revise solutions. Crucially, the platform's Code Builder (e.g., MakeCode block programming) and agent-based tasks allow learners to externalize algorithmic steps, test conditional rules, and reason about automated behavior—features that align directly with CT practices and early AI literacy (rule-based decision-making, input–process–output, and the need for human oversight). In this way, Minecraft Education is positioned not merely as an engaging medium, but as a contextual solution for making CT, coding, and AI concepts learnable and assessable in the MAN 9 Jakarta classroom ecology.

One promising response is digital game-based learning (DGBL), especially through open-ended sandbox environments such as Minecraft Education Edition. Research indicates that sandbox games can support CT by allowing learners to iteratively design, test, and refine computational artefacts in visually rich environments (Hébert & Jenson, 2020; Pan et al., 2022). Empirical studies demonstrate that learning with Minecraft can enhance CT, coding practices, and STEM dispositions across age groups and disciplines (Kutay & Öner, 2022; Sarıçam & Yıldırım, 2021; Tseng & Pan, 2024). In science education, Minecraft Education has been shown to provide powerful affordances for modelling complex phenomena and supporting collaborative inquiry (Nkadimeng & Ankiewicz, 2022). Indonesian studies likewise report that Minecraft-based activities can foster immersion, creativity, and 21st-century skills in local contexts (Handak et al., 2024).

Affective dimensions of learning are equally important. Work on game-based learning consistently reports that challenging, well-designed games can foster engagement, flow, and persistence, which in turn support conceptual understanding (Hamari et al., 2016; Hébert & Jenson, 2020). Indonesian scholarship has introduced the intertwined notions of meaningful, mindful, and joyful learning—emphasising metacognitive awareness, contextual relevance, and positive emotional experiences as conditions for deep learning (Feriyanto & Anjariyah, 2024). Studies in Islamic elementary schools similarly document how joyful learning designs help sustain attention and participation (Donasari et al., 2023). Game-based environments such as Minecraft can naturally support these conditions by combining autonomy, feedback, and collaborative problem solving.

Despite the emerging international and national evidence base, at least three important research gaps remain. First, most Minecraft Education and digital game-based learning studies focus on general or STEM classrooms, with very limited attention to faith-based public schools such as Indonesian madrasahs, where digital transformation is shaped by distinctive institutional, cultural, and policy expectations (Aditya et al., 2022; Alam & Hidayah, 2025; Handak et al., 2024). Second, prior research tends to examine computational thinking or coding in isolation, whereas far fewer studies explicitly investigate how CT, coding skills, and AI literacy are developed together within a single, coherent Informatics programme (T.-Y. Liu & Jeong, 2022; Tseng & Pan, 2024). Third, many existing designs rely on short-term quantitative interventions and report test scores or attitude scales, leaving a shortage of in-depth qualitative accounts that document how students and teachers actually experience joyful, mindful, and meaningful learning processes in game-based environments (Donasari, Rofiah, et al., 2023; Feriyanto & Anjariyah, 2024; Hamari et al., 2016; Hébert & Jenson, 2020). The present study addresses these gaps through a qualitative case study of a Minecraft-based Informatics programme in an Indonesian madrasah, examining how CT, coding, and AI literacy develop in tandem and how learners and educators experience this innovation within a broader SDG-oriented digital transformation agenda. Against this backdrop, the present study addresses the following research questions:

1. How does Minecraft Education mediate the development of computational thinking and coding skills among Grade 10 Informatics students in a madrasah context?

2. How do students conceptualize AI when learning with programmable agents in Minecraft Education?
3. How do students and teachers experience the affective dimensions of this learning environment (joyful, mindful, meaningful), and what contextual challenges arise?

By foregrounding AI literacy alongside CT and coding from the beginning, this study contributes situated evidence to the broader literature on DGBL, AI literacy, and digital transformation in education, particularly in faith-based public schools.

Method

Research design

This study employed a qualitative case study design to capture the complex interplay between technology, pedagogy, and context in a single bounded setting. Qualitative case studies are particularly suited to examining contemporary educational phenomena in real-world environments where the boundary between the intervention and its context is porous (Aspers & Corte, 2019). Here, the case is MAN 9 Jakarta's implementation of Minecraft Education within the Grade 10 Informatics curriculum.

The study adopted an interpretivist stance, viewing learning processes and experiences as socially constructed and best understood through participants' perspectives. The design emphasized iterative engagement with empirical material and analytical refinement, in line with contemporary conceptions of qualitative inquiry as an iterative process aimed at deepening understanding of the phenomenon studied (Aspers & Corte, 2019).

Research site and participants

MAN 9 Jakarta is a state Islamic senior high school (madrasah aliyah) in Indonesia that has positioned itself as an early adopter of Minecraft Education in the national Phase E Informatics curriculum. The implementation involved 204 Grade 10 students organized into six Informatics classes, one Informatics teacher whose Minecraft-based lessons were observed, and the madrasah principal.

For the interview component, 30 students (five from each of the six classes) were selected as focal participants to provide perspectives from across the cohort. Purposive sampling focused on these three participant groups—

students, teacher, and principal—because they were directly involved in, or responsible for, the Minecraft implementation and could offer rich insights into learning processes, pedagogical strategies, and institutional conditions.

Focus of the study

The conceptual focus of the study can be summarized as a triad of.

1. Learning environment – the Minecraft Education platform and associated tasks;
2. Pedagogical mediation – teacher-designed missions, scaffolding, and peer collaboration;
3. Learning outcomes – cognitive (CT, coding, AI literacy) and affective (joyful, mindful, meaningful engagement).

Operational definitions and indicators

Each indicator was scored using a four-level analytic rubric (1 = beginning, 2 = developing, 3 = proficient, 4 = advanced) during classroom observations and artefact review. Class-level summaries were computed by aggregating student-level scores within each class and reporting (i) class means (1–4) and (ii) the proportion of students at Level 4; the proportion at or above Level 3 (proficient) was also calculated and is reported narratively.

Table 1. Operational definitions and assessment indicators for the three focal outcome domains

Focal outcome domain	Indicators (analytic rubric 1–4)	Primary evidence sources	Derived descriptive statistics
Computational Thinking (CT)	Decomposition & problem framing; Pattern recognition & abstraction; Algorithm design (sequencing/planning); Debugging & iterative refinement.	Classroom observation rubric; student Minecraft mission artefacts; student reflections/interviews.	Class mean (1–4), SD; % of students at Level 4 (advanced) per class and overall; narrative confirmation of Level ≥3 attainment.
Coding Skills	Sequencing & events; Conditionals; Loops/iteration; Debugging (testing, revising).	Artefact analysis of in-game code (MakeCode); observation notes on coding processes; interviews.	Class mean (1–4), SD; % of students at Level 4 per class and overall; frequency of key constructs (e.g., loops) from artefact review.

Focal outcome domain	Indicators (analytic rubric 1–4)	Primary evidence sources	Derived descriptive statistics
AI Literacy (foundational)	Explaining agent behavior as rule-based; Input–process–output reasoning; Translating tasks into explicit rules; Recognizing limitations and need for human oversight.	Interviews and student explanations; agent code artefacts; observation of decision-rule discussions.	Class mean (1–4), SD; % of students at Level 4 per class and overall; frequency of AI-related explanations in interviews (n=30).

Data collection

Data were collected through three main techniques: classroom observation, semi-structured interviews, and documentation/artefacts.

Classroom observations

Non-participant observations were conducted during Minecraft-based Informatics lessons across the six Grade 10 classes. A structured observation protocol captured interaction patterns, task sequences, visible CT behaviors (e.g., decomposition, debugging), and affective indicators (e.g., persistence, collaborative talk, visible frustration or relief).

Semi-structured interviews

Semi-structured interviews were conducted with 30 focal students (five representatives from each of the six Grade 10 classes), the Informatics teacher, and the principal. Student interviews explored prior experience with coding and games, perceptions of Minecraft-based learning, understandings of CT and AI concepts, and experiences of motivation and challenge. The teacher interview focused on lesson design, assessment strategies, perceived benefits and difficulties, and digital leadership within the madrasah. The principal interview addressed institutional priorities, resource allocation, and the school's vision for digital transformation.

Documentation and artefacts

Student-created Minecraft worlds, in-game code (e.g., MakeCode scripts), screenshots, and short video clips were collected as artefacts. Internal documents describing the school's digital innovation initiatives and participation in Minecraft Education pilot programmes were reviewed to provide contextual background.

Data analysis

Data analysis followed a thematic approach aligned with trustworthiness criteria (Nowell et al., 2017). The process unfolded in iterative cycles.

Familiarization and initial coding

Observation notes, interview transcripts, and artefact descriptions were read repeatedly. Segments related to CT, coding, AI understanding, engagement, and contextual challenges were inductively coded. Descriptive quantification (a qualitatively driven “quantitizing” step) was applied to strengthen cross-class claims: rubric scores from observations and artefact reviews were converted into frequencies, percentages, and class-level means. These descriptive statistics do not replace the qualitative interpretation; rather, they provide transparent numerical support for the distribution of CT, coding, and AI literacy indicators across the six classes (reported in Table 2).

Developing and refining themes

Codes were clustered into candidate themes such as “emerging decomposition strategies,” “debugging as reflective practice,” “AI as rule-based system,” and “joyful but demanding learning.” Themes were refined through comparison across data sources (students, teacher, principal; observations vs. interviews vs. artefacts).

Triangulation and verification

A triangulation matrix was constructed to map themes against data sources and data types. Negative cases and tensions (for example, highly engaged but technically constrained sessions) were examined to avoid overly simplistic interpretations.

Reporting

Themes were elaborated into narrative accounts supported by illustrative quotes and connected to the existing literature in the Discussion. Throughout the analysis, analytic memorizing documented evolving interpretations, and preliminary findings were discussed with the teacher (member checking) to enhance credibility.

Trustworthiness

Multiple strategies were used to enhance trustworthiness (Nowell et al., 2017). Credibility was supported through triangulation of data sources and methods and through member checking with the teacher and selected students. Dependability was strengthened by systematic documentation of data collection and analysis decisions and use of a codebook. Confirmability was addressed via reflexive memos and an audit trail of analytic decisions. Transferability was facilitated through thick description of the context, participants, and instructional design, allowing readers to judge applicability to other madrasahs or schools.

Result

Development of computational thinking

Across interviews, observations, and artefacts, students showed notable growth in CT. Many described explicitly breaking down complex missions into sub-tasks. One learner explained that they began by clarifying the mission goal, then dividing it into "fondasi, dinding, atap, dan dekorasi," illustrating concrete decomposition. Classroom observations confirmed that learners often sketched plans or verbally negotiated sub-tasks before building.

Pattern recognition emerged as students connected new missions to prior experiences. They reported "melihat pola dari tugas sebelumnya" in navigation or resource-gathering challenges and reusing solution strategies across missions. Observationally, students transferred movement sequences, resource management routines, and build patterns from earlier tasks to more complex scenarios.

Algorithmic thinking was evident when students described imagining step-by-step sequences before assembling code blocks: they mentally simulated agent paths and actions, then translated them into ordered commands. Many adopted an incremental strategy—running small segments of code to test their logic before extending it—which aligns with research on block-based programming and CT development (Li et al., 2020; Pan et al., 2022).

Debugging became a systematic, reflective practice. Students narrated how they checked blocks "satu-satu" when an agent misbehaved, adjusting conditions or loop boundaries until the behavior matched their intent. Observations captured cycles of run–inspect–revise, with learners discussing possible causes of errors and testing alternative solutions. The teacher noted clear growth in students' willingness to confront errors and view debugging as part of learning rather than a sign of failure, echoing contemporary CT literature (Shute et al., 2017; Tang et al., 2020).

Improvement in coding skills

Students' coding fluency improved as they moved from viewing code as a mysterious artefact to understanding it as a precise language for expressing logic. In interviews, several students framed coding as "cara memberi perintah supaya komputer ngerti," indicating a conceptual grasp of deterministic execution.

Learners increasingly leveraged sequences, conditionals, and loops. One student explained using repeat blocks to avoid writing long, repetitive sequences, reflecting an appreciation of efficiency and structure. In classroom observations, students iteratively refined conditional statements to handle different in-game situations, such as detecting obstacles or triggering actions when a resource was encountered.

The teacher reported that, over time, more students could independently design simple algorithms and reason about why a particular arrangement of blocks produced a given behavior. These findings align with studies showing that block-based programming in game contexts can scaffold conceptual understanding of core programming constructs (Kutay & Öner, 2022; Tseng & Pan, 2024).

Emerging AI literacy

Missions involving programmable agents created a natural context for early AI literacy. Students were asked to design and debug agents to perform tasks such as navigating mazes or automating construction. In interviews, many learners emphasized that the agent "ngikutin instruksi, bukan mikir sendiri," indicating recognition of its rule-based nature rather than anthropomorphic assumptions.

When agents failed, students typically attributed the problem to incomplete or incorrect code rather than to the agent itself. Statements such as "kalau salah, berarti kodenya yang salah, bukan agennya" reveal causal reasoning about system behavior. Observations captured student dialogues about "kenapa agennya milih jalan itu," reflecting an emerging understanding of decision flows and conditions. These patterns resonate with recent work defining AI literacy as understanding how computational systems perceive, represent, and act on information (Long & Magerko,

2020) and with studies showing that block-based AI tasks can enhance conceptual clarity (Z. Liu & Jeong, 2022).

Joyful, mindful, and meaningful learning environment

Students consistently described the Minecraft-based Informatics lessons as enjoyable and motivating_"kayak main tapi tetap belajar." Classroom observations showed high energy coupled with substantial task focus: learners frequently continued experimenting with code even after completing the required mission.

Meaningfulness emerged in several ways. Students recognised that coding and CT skills were relevant beyond the game, mentioning applications in future jobs or everyday problem solving. The teacher noted that learners who previously viewed Informatics as abstract began to ask more "why" and "how" questions about algorithmic behaviour and digital systems. These affective outcomes align with research on engagement and flow in game-based learning (Hamari et al., 2016) and with Indonesian scholarship on meaningful, mindful, and joyful learning (Donasari et al., 2023; Feriyanto & Anjariyah, 2024).

Challenges and opportunities

Despite positive learning outcomes, several challenges emerged. Technical issues—such as device limitations, intermittent connectivity, and login problems—occasionally disrupted class flow and required ad hoc solutions (for example, hotspot sharing, device rotation). These constraints mirror broader findings on infrastructure as a critical factor in digital transformation efforts in schools (Aditya et al., 2022; Alam & Hidayah, 2025; Benavides et al., 2020).

Learners also entered the programmed with varied prior experience in coding and digital games. Some students advanced quickly, while others required more structured scaffolding. The teacher highlighted the need to differentiate tasks and support, especially at the beginning of the unit, to prevent less experienced students from feeling overwhelmed. Students expressed interest in more collaborative, long-term projects (for example, building shared worlds or simulations linked to real community issues). This points to an opportunity to expand from mission-based tasks toward project-based learning that bridges Informatics with other subjects and SDG-related themes, in line with recent studies on Minecraft-based STEM projects (Nkadimeng & Ankiewicz, 2022; Sarıçam & Yıldırım, 2021).

Class-Level Descriptive Statistics Across Six Classes

To respond to the request for statistical support from all six classes, the rubric scores and artefact codes were aggregated into descriptive summaries. Table 2 reports the class-level distribution for the three dependent outcomes (CT, coding skills, and AI literacy), including the number of students per class (n) and the proportion of students reaching at least the proficient level (≥ 2) on the analytic rubric. These statistics are presented to transparently support the qualitative claims of learning success and to show consistency of outcomes across the six Grade 10 classes.

Table 2. Descriptive summary of CT, coding skills, and AI literacy rubric levels across six Grade 10 classes (MAN 9 Jakarta)

Class	n students	CT (Mean; % Level 4)	Coding (Mean; % Level 4)	AI literacy (Mean; % Level 4)	Notes (evidence basis)
X.A	34	Mean 3.12; L4 11.8%	Mean 3.32; L4 32.4%	Mean 3.12; L4 11.8%	Rubric recap (1–4) derived from coded artefacts + observation records
X.B	34	Mean 3.00; L4 0.0%	Mean 3.24; L4 23.5%	Mean 3.00; L4 0.0%	Rubric recap (1–4) derived from coded artefacts + observation records
X.C	34	Mean 3.15; L4 14.7%	Mean 3.15; L4 14.7%	Mean 3.00; L4 0.0%	Rubric recap (1–4) derived from coded artefacts + observation records
X.D	34	Mean 3.12; L4 11.8%	Mean 3.21; L4 20.6%	Mean 3.12; L4 11.8%	Rubric recap (1–4) derived from coded artefacts + observation records
X.E	34	Mean 3.06; L4 5.9%	Mean 3.21; L4 20.6%	Mean 3.09; L4 8.8%	Rubric recap (1–4) derived from coded artefacts + observation records
X.F	34	Mean 3.15; L4 14.7%	Mean 3.21; L4 20.6%	Mean 3.32; L4 32.4%	Rubric recap (1–4) derived from coded artefacts +

Class	n students	CT (Mean; % Level 4)	Coding (Mean; % Level 4)	AI literacy (Mean; % Level 4)	Notes (evidence basis)
					observation records
Overall (six classes)	204	Mean 3.10; L4 9.8%	Mean 3.22; L4 22.1%	Mean 3.11; L4 10.8%	Aggregated across classes

Note: Replace bracketed values with computed results from the rubric recap (1–4) and artefact coding described in the Method section.

Summary tables and visual models

The manuscript includes a series of tables and figures that summarize the triangulated findings across data sources and indicators. In line with the intention to preserve existing charts and tables, their structure and formatting remain unchanged.

Table 3. Triangulation of findings across data sources

Thematic Category	Evidence from Student Interviews	Evidence from Classroom Observations	Evidence from Teacher Reflections
Computational Thinking (CT)	Students consistently described breaking tasks into smaller parts (decomposition), identifying repeated structures, visualizing algorithmic sequences, and correcting errors through debugging.	Students were observed planning builds on paper, discussing logical steps, and modifying their actions based on trial-and-error sequences.	Teacher noted students' growing ability to reason systematically, test assumptions, and adopt structured approaches to problem solving.
Improvement in Coding Skills	Students articulated clearer understanding of coding as giving precise instructions; many described debugging as central to success.	Learners actively experimented with Code Builder, revising loops and conditionals while observing live system responses.	Teacher observed increased independence in coding tasks and improved logical structuring among previously struggling learners.
Understanding of Artificial Intelligence (AI)	Students stated that AI behaves "sesuai instruksi," recognizing its reliance on logical rules rather than autonomy.	Observers documented discussions about why agents behave a certain way and how rules govern outcomes.	Teacher noted that AI missions prompted deeper conversations about decision flow, system logic, and reliability.
Joyful, Mindful, and Meaningful	Students reported enjoyment, motivation, and emotional	Observations showed high engagement,	Teacher reported a lively yet purposeful atmosphere where

Thematic Category	Evidence from Student Interviews	Evidence from Classroom Observations	Evidence from Teacher Reflections
Learning Environment	engagement; many felt learning "lebih menyenangkan dan serius."	collaborative dialogue, and focused attention during challenging tasks.	students demonstrated ownership and curiosity.
Challenges and Opportunities	Students mentioned device lag, login issues, and varying comfort with coding; some requested more collaborative projects.	Observers noted pacing disruptions due to technical issues and uneven coding readiness among students.	Teacher highlighted the need for differentiated support and infrastructure improvements, while recognizing strong potential for expanded project-based learning.

Table 4. Detailed triangulation matrix for computational thinking indicators

CT Indicator	Evidence from Student Interviews	Evidence from Classroom Observations	Evidence from Teacher Reflections
Decomposition	"Saya memecahkan masalah besar menjadi beberapa bagian kecil…" (Siswa A)	Siswa membuat sketsa proyek, membagi tugas antar kelompok	Guru melihat peningkatan kemampuan siswa menyusun langkah sistematis
Pattern Recognition	Siswa menghubungkan pola misi sebelumnya dengan tugas baru	Siswa cepat mengenali pola navigasi dan struktur tantangan	Guru mencatat bahwa siswa semakin cepat memahami struktur masalah
Algorithmic Thinking	"Saya membayangkan dulu urutannya sebelum menyusun code."	Siswa menguji urutan langkah secara bertahap dan memperbaiki struktur	Guru menilai siswa lebih runtut dan logis dalam menjelaskan alur
Debugging	"Kalau agennya salah, saya cek lagi bloknya satu-satu…"	Siswa melakukan iterasi: run → error → revisi → run ulang	Guru melihat peningkatan ketelitian dan ketekunan siswa

Table 5. Detailed triangulation matrix for coding skill indicators with micro-quotes

Coding Skill Indicator	Direct Student Quote	Evidence from Observation	Teacher Reflection
Sequence & Logic	"Coding itu ngatur langkah-langkah supaya urut dan bener."	Siswa menyusun blok perintah step-by-step sebelum dieksekusi	Guru melihat siswa semakin paham hubungan sebab-akibat dalam kode

Conditional Reasoning	"Kalau kondisi ini terjadi, baru agennya jalan…"	Siswa mencoba blok *if–then* dalam skenario sederhana	Guru mencatat pemahaman awal tentang logika bercabang
Looping	"Supaya nggak cape ulang, saya pakai repeat…"	Siswa menggunakan *repeat* untuk membuat pola otomatis	Guru menilai konsep *loop* sangat membantu efisiensi kerja siswa
Debugging (Error Fixing)	"Waktu salah, saya cek bloknya satu-satu sampai nemu yang keliru."	Siswa sering membandingkan output dan memperbaiki kesalahan	Guru melihat perkembangan besar pada kemampuan evaluatif siswa

Table 6. Detailed triangulation matrix for ai understanding with micro-quotes

AI Literacy Indicator	Direct Student Quote	Observation Evidence	Teacher Reflection
AI as Rule-Based System	"AI itu ngikutin instruksi, bukan mikir sendiri."	Siswa menyimpulkan perilaku agen setelah kode dijalankan	Guru menilai siswa mulai memahami konsep dasar sistem cerdas
Error Attribution	"Kalau salah, berarti kodenya yang salah, bukan agennya."	Siswa memperbaiki perintah setelah agen tidak bekerja sesuai harapan	Guru melihat kemampuan analitis siswa meningkat
Decision Flow Understanding	"AI jalan sesuai alur perintah yang kita buat."	Diskusi tentang mengapa agen memilih jalur tertentu	Guru mencatat tumbuhnya kesadaran siswa tentang bagaimana sistem mengambil Keputusan

Table 7. Triangulation with micro-quotes for joyful–mindful–meaningful learning

Learning Dimension	Direct Student Quote	Observation Evidence	Teacher Reflection
Joyful Engagement	"Belajarnya seru, kayak main tapi tetap belajar."	Suasana kelas antusias, ekspresi positif siswa	Guru mencatat motivasi siswa jauh lebih tinggi
Mindful Focus	"Pas coding harus fokus banget supaya urutannya bener."	Periode hening ketika siswa debugging secara mandiri	Guru menilai siswa masuk 'flow state' ketika menyelesaikan misi
Meaningful Learning	"Baru tahu kalau coding itu dipakai juga di kehidupan nyata."	Siswa menghubungkan konsep dengan situasi dunia nyata	Guru mencatat pemahaman konsep semakin mendalam

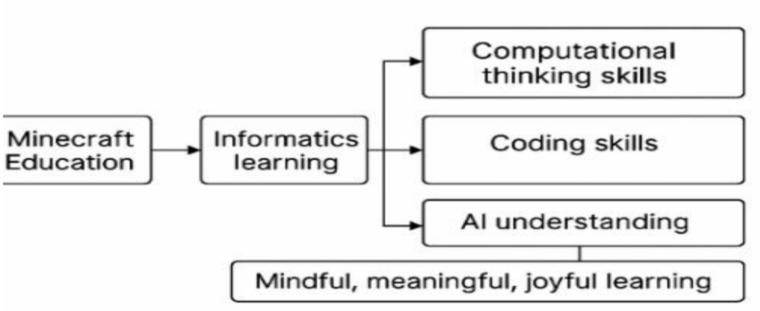

Figure 1. C`onceptual model

Conceptual Model of the Study Diagram illustrating the relationship between the learning environment (Minecraft Education), the pedagogical mediation processes, and the targeted cognitive and affective learning outcomes.

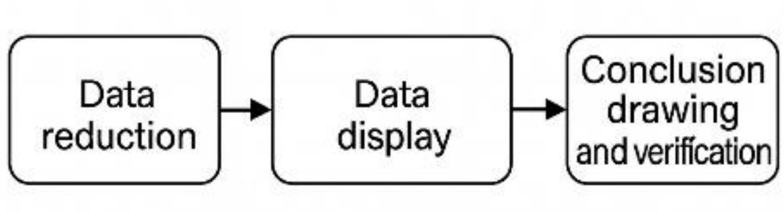

Figure 2. Miles and Huberman's data analysis model

Miles and Huberman Interactive Model Diagram illustrating the iterative process of qualitative data analysis involving data reduction, data display, and conclusion drawing/verification.

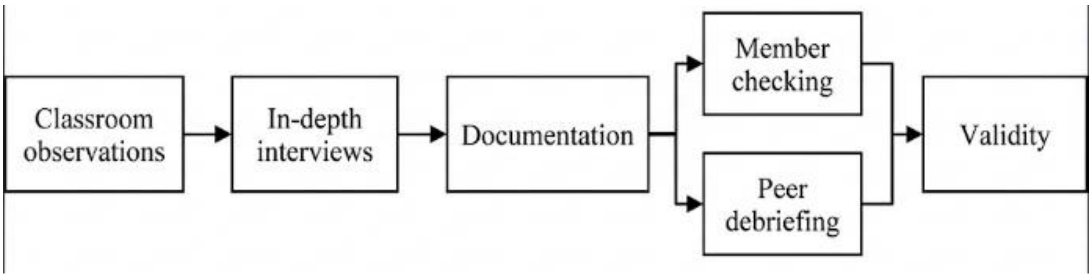

Figure 3. Data validity and triangulation flow

Data Validity and Triangulation Flow Flowchart depicting the sequence and structure of triangulation and verification procedures used to ensure the validity of the qualitative findings.

Discussion

The findings show that Minecraft Education Edition can serve as a powerful mediator for developing CT, coding skills, and AI literacy within a madrasah Informatics curriculum. Students' increasingly sophisticated use of decomposition, pattern recognition, algorithmic reasoning, and debugging indicates that they were not simply "playing a game," but engaging in core CT practices described in recent frameworks (Andrian & Hikmawan, 2021; Nouri et al., 2020; Tang et al., 2020) . Rather than treating CT as a separate, decontextualized topic, the Minecraft environment embedded these practices in meaningful tasks that required planning, iteration, and reflection.

In addition to thematic evidence, the descriptive summaries (Table 2) indicate that the attainment of CT, coding skills, and AI literacy indicators was not confined to a single high-performing class; rather, patterns were observable across all six Grade 10 classes. This strengthens the argument that Minecraft Education can function as a scalable classroom innovation in MAN 9 Jakarta when supported by consistent scaffolding, stable infrastructure, and teacher facilitation.

Improved coding fluency reinforces evidence that block-based programming, particularly in game contexts, lowers barriers to entry and supports conceptual understanding of core constructs (Kutay & Öner, 2022; x`x`Tseng & Pan, 2024). Students in this study moved from tentative block manipulation to more deliberate design of loops and conditional structures, aligning with findings that visual representations help learners' reason about flow of control and logic (Li et al., 2020; Pan et al., 2022). The observed shift in attitude—from fearing syntax errors to embracing debugging as exploration—suggests that Minecraft can reshape students' emotional relationship with programming in pedagogically valuable ways.

Affective outcomes are another important contribution. The combination of enjoyment, challenge, and perceived relevance observed in this study aligns with prior work on flow and engagement in DGBL (Hamari et al., 2016; Hébert & Jenson, 2020). Indonesian discourses on meaningful, mindful, and joyful learning provide a locally resonant lens for interpreting these affective dynamics (Donasari et al., 2023; Feriyanto & Anjariyah, 2024). Minecraft Education appears to naturally support these dimensions by offering autonomy, immediate feedback, and opportunities for collaborative problem solving. For madrasahs that seek to cultivate holistic learner development, such environments can be especially attractive.

At the same time, the study highlights the realities of implementing game-based digital innovation in resource-constrained contexts. Technical issues and variable prior experience underscore that enthusiastic adoption of tools like Minecraft Education must be accompanied by strategic investment in infrastructure, capacity-building, and instructional design support (Aditya et al., 2022; Alam & Hidayah, 2025; Benavides et al., 2020). In this case, the teacher's willingness to experiment, reflect, and adjust was crucial—illustrating the central role of teacher leadership in digital transformation.

The madrasah context adds further nuance. As a faith-based public school, MAN 9 Jakarta operates within both national policy frameworks and religious values. The findings suggest that Minecraft Education can be harmonised with this context by aligning missions and projects with themes such as stewardship, collaboration, and community service, thereby linking Sustainable Development Goal 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure) to local educational aims. This complements international evidence that Minecraft Education can support STEM and 21st-century skills (Handak et al., 2024; Hébert & Jenson, 2020; Nkadimeng & Ankiewicz, 2022; Sarıçam & Yıldırım, 2021).

Methodologically, the study demonstrates the value of rigorous, triangulated qualitative analysis for understanding technology-rich learning environments. By combining observations, interviews, and artefacts, and by applying systematic thematic analysis procedures (Aspers & Corte, 2019; Nowell et al., 2017), the research moves beyond surface descriptions of "engagement" to unpack how specific design features of Minecraft-based tasks supported CT, coding, and AI literacy. Overall, the results suggest that Minecraft Education can serve as a practical model for integrating CT, coding, and AI literacy into the Phase E Informatics curriculum in Indonesian madrasahs, provided that implementation is supported by appropriate infrastructure, teacher professional development, and curricular alignment.

Conclusion

This qualitative case study examined the use of Minecraft Education Edition in Grade 10 Phase E Informatics at MAN 9 Jakarta and found that the platform can meaningfully support three intended learning outcomes: computational thinking, coding skills, and foundational AI literacy. Triangulated qualitative evidence, complemented by class-level descriptive summaries (Table 2), suggests that these outcomes were observable across the six participating classes. For computational thinking, students increasingly demonstrated decomposition, pattern recognition, abstraction, algorithm design, and iterative debugging while completing Minecraft-based missions. For coding skills, learners progressed from basic sequencing toward more confident use of conditionals, loops, and debugging as they built and refined in-game solutions using block-based programming with immediate feedback.

Foundational AI literacy emerged when students interpreted programmable agents as rule-based systems, articulated input–process–output reasoning, and recognised the limitations of automated behaviour (e.g., the need for precise instructions and human oversight). Overall, Minecraft Education Edition offers a coherent, assessable pathway for developing CT, coding skills, and early AI literacy in the MAN 9 Jakarta context, provided that teachers intentionally scaffold missions and ensure minimum technical readiness.

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