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Is Elementary Science Education Ready for Unplugged Coding? Teachers' Knowledge, Perceptions, and Readiness

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Abstrak

Integrasi berpikir komputasional dalam pendidikan dasar penting untuk mendukung penalaran dan pemecahan masalah siswa, khususnya dalam pembelajaran sains. Namun, keterbatasan akses komputer di banyak sekolah dasar menjadi kendala implementasi pembelajaran koding. Unplugged coding menawarkan pendekatan non-digital yang potensial, tetapi kesiapan guru masih belum banyak dikaji. Penelitian ini bertujuan menganalisis pengetahuan, persepsi, dan kesiapan guru sekolah dasar terhadap penerapan unplugged coding dalam pembelajaran sains. Penelitian menggunakan desain eksploratif dengan pendekatan campuran terhadap 18 guru sekolah dasar negeri di Jakarta. Data kuantitatif dikumpulkan melalui kuesioner dan dianalisis secara deskriptif, sedangkan data kualitatif diperoleh melalui wawancara semi-terstruktur dan dianalisis secara tematik. Hasil penelitian menunjukkan bahwa pengetahuan guru berada pada tingkat sedang, terutama terbatas pada konsep inti berpikir komputasional. Guru memiliki persepsi positif, namun kesiapan implementasi masih sedang hingga rendah, khususnya dalam perancangan, penyelarasan kurikulum, dan penilaian.

Abstact

The integration of computational thinking in elementary education is essential to support students' reasoning and problem-solving skills, particularly in science learning. However, limited access to computers in many elementary schools remains a barrier to the implementation of coding-based instruction. Unplugged coding offers a promising non-digital approach, yet teachers' readiness has not been widely examined. This study aims to analyze elementary school teachers' knowledge, perceptions, and readiness regarding the implementation of unplugged coding in science learning. An exploratory mixed-methods design was employed involving 18 public elementary school teachers in Jakarta. Quantitative data were collected through questionnaires and analyzed descriptively, while qualitative data were obtained through semi-structured interviews and analyzed thematically. The results indicate that teachers' knowledge is at a moderate level, with limitations in core computational thinking concepts. Teachers hold positive perceptions; however, their readiness to implement unplugged coding remains moderate to low, particularly in lesson design, curriculum alignment, and assessment.

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INTRODUCTION

The development of twenty-first-century education positions computational thinking as a key competence that should be introduced from the elementary level. Computational thinking is not merely related to the ability to use computers, but rather to a way of thinking that is systematic, logical, and structured in solving problems (Abdul Hanid et al., 2022; Babazadeh & Negrini, 2022; Bati, 2022; Buitrago-Flórez et al., 2021). As a cognitive skill, computational thinking supports learners in decomposing problems, recognizing patterns, designing step-by-step procedures, and evaluating solutions—abilities that are closely aligned with the nature of scientific inquiry.

In the context of elementary science learning, this competence is particularly relevant because science requires students to observe phenomena, identify regularities, formulate procedures, and draw evidence-based conclusions (Setiawan, Barokah, et al., 2025; Setiawan, Kurnia, et al., 2025; Setiawan, Mukhlis, et al., 2025). However, science learning practices in many elementary schools continue to face challenges in consistently fostering higher-order thinking skills. Instruction often remains focused on factual knowledge acquisition, with limited opportunities for students to engage in reasoning, problem solving, and structured thinking processes that are central to scientific literacy (Galimova et al., 2025; Yulianto et al., 2025).

International evidence reinforces this concern. Data from the Programme for International Student Assessment (PISA) 2022 indicate that Indonesian students' science literacy achievement remains below the OECD average. Most students have not yet reached the minimum proficiency level, particularly in aspects related to reasoning and context-based problem solving (OECD, 2023). These findings suggest that science learning at the elementary level still requires substantial reorientation toward strengthening thinking processes rather than emphasizing content mastery alone. Such reorientation is increasingly urgent as twenty-first-century education demands the integration of cross-disciplinary competencies, including computational thinking and digital literacy.

At the same time, efforts to integrate technology-based learning into elementary classrooms face persistent structural challenges. Various national reports show that access to computers and digital infrastructure at the elementary level has not been evenly distributed, particularly in schools outside urban areas (Badan Standar, Kurikulum, dan Asesmen Pendidikan, 2025; Elliyani & Nurhasanah, 2025; Norfika, 2025). Limited availability of devices, inadequate infrastructure, and insufficient technical support constrain the implementation of computer-based learning. Under these conditions, instructional approaches that rely heavily on digital technology risk widening disparities in educational quality between schools (Nsabayezu et al., 2022; Tang et al., 2024; Timotheou et al., 2023).

In response to these constraints, unplugged coding has emerged as a pedagogical alternative that is increasingly discussed in the literature. Unplugged coding refers to learning activities that introduce computational thinking and basic programming concepts through non-digital means, such as games, simulations, physical activities, discussions, and the manipulation of concrete objects (Dağ et al., 2023; Rati et al., 2024; Walstra, 2024). A growing body of international research has shown that unplugged activities can support students' understanding of algorithmic thinking, logic, and problem solving, particularly at the elementary education level (Brackmann et al., 2017; Chen et al., 2023; Li et al., 2022; Lin et al., 2024). Beyond cognitive benefits, this approach is considered more inclusive because it can be implemented in schools with limited access to technological devices.

Nevertheless, the existing literature reveals important limitations. Most studies on unplugged coding have examined its effects on student learning outcomes or have positioned it primarily within the domain of computer science education (AYTEKİN & TOPÇU, 2024; Chen et al., 2023; Dağ et al., 2023; Liu & Hu, 2025; Moreno-Palma et al., 2024; Zhang et al., 2024). Research that explicitly situates unplugged coding within elementary science learning remains relatively limited. Moreover, teachers' knowledge, perceptions, and readiness to implement unplugged coding are often underexplored, even though teachers play a central role in determining the success of instructional innovations. Without adequate conceptual understanding, teachers may encounter difficulties in aligning unplugged activities with science learning objectives and curricular expectations.

e urgency of strengthening teacher competence is further reinforced by recent national policy developments. The Regulation of the Minister of Primary and Secondary Education Number 13 of 2025 formally introduces coding and artificial intelligence within the school curriculum and provides flexibility for implementation based on school readiness and student needs (Peraturan Menteri Pendidikan Dasar Dan Menengah Nomor 13 Tahun 2025 Tentang Perubahan Atas Peraturan Menteri Pendidikan, 2025). While this policy creates opportunities for innovation, its implementation at the elementary level cannot be separated from actual classroom conditions, including limited access to computers and diverse teacher competency backgrounds (Tazkya Misbachul Jannah et al., 2025; Tutik Lestari & Arni Retno Mariana, 2024). In this context, unplugged approaches become strategically important; however, their effectiveness depends largely on teachers' understanding, perceptions, and readiness as the primary agents of instruction.

Based on the literature review, several research gaps can be identified. First, there is still limited research that explicitly connects unplugged coding with elementary science learning. Second, studies that examine teachers' knowledge and readiness toward unplugged coding prior to instructional implementation remain scarce, particularly in developing-country contexts with unequal access to technology. Third, few studies have systematically explored how teachers conceptualize unplugged coding and perceive its relevance to science learning and the development of students' computational thinking. Mapping these aspects is essential as a foundation for teacher professional development, instructional material design, and sustainable policy implementation.

This study contributes novelty by empirically examining elementary school teachers' knowledge, perceptions, and readiness toward unplugged coding specifically within the context of science learning, rather than computer science instruction. By foregrounding teachers' perspectives under conditions of limited technological access, this study extends existing unplugged coding research and provides evidence that is directly aligned with current curriculum and policy demands.

Accordingly, this study aims to: (1) analyze elementary school teachers' knowledge of unplugged coding, (2) explore their perceptions of its relevance for science learning and the development of students' computational thinking, and (3) examine their readiness to implement unplugged coding activities in elementary science classrooms. The findings are expected to contribute to the development of more inclusive and context-sensitive science learning practices, while also informing teacher training programs and policy decisions related to the implementation of coding and artificial intelligence education at the elementary level.

METHOD

Research Design

This study employed an exploratory mixed-methods design integrating quantitative and qualitative approaches to obtain a comprehensive understanding of elementary school teachers' knowledge, perceptions, and readiness regarding unplugged coding in science learning. An exploratory design was selected because unplugged coding had not yet been formally implemented in science instruction at the research sites. The quantitative component was used to describe general patterns of teachers' knowledge, perceptions, and readiness, while the qualitative component provided deeper insights into teachers' conceptual understanding, concerns, and contextual considerations related to unplugged coding. The integration of both approaches enabled data triangulation and strengthened the interpretation of findings (Creswell & Creswell, 2020; Fraenkel & Wallen, 1990).

Participants

The participants consisted of 18 elementary school teachers from several public elementary schools in Jakarta, Indonesia. All participants were actively involved in teaching science at the elementary level. Teachers were selected using purposive sampling based on their instructional responsibilities in science and their involvement in implementing the current curriculum.

The relatively small sample size reflects the exploratory nature of the study and its focus on in-depth examination rather than statistical generalization. This scope is considered appropriate for early-stage investigations aimed at mapping baseline conditions, particularly teachers' knowledge and readiness prior to instructional implementation. While the findings are not intended to be generalized to all elementary school teachers, they provide contextualized insights that may inform further large-scale or confirmatory studies.

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Data Collection Instruments

Data were collected using two main instruments: a structured questionnaire and semi-structured interviews.

The questionnaire was designed to measure teachers' knowledge of unplugged coding concepts, perceptions of its relevance to science learning, and readiness to implement unplugged coding activities. The instrument employed a Likert-scale format and was developed based on relevant literature on computational thinking, teacher readiness, and unplugged coding. To ensure content validity, the questionnaire was reviewed by two experts in science education and one expert in educational technology. Their feedback was used to refine item clarity, relevance, and alignment with the research objectives.

A pilot test was conducted with a small group of teachers outside the main sample to examine internal consistency. The reliability analysis yielded acceptable Cronbach's alpha coefficients for all questionnaire dimensions, indicating satisfactory internal consistency and suitability for descriptive analysis.

Semi-structured interviews were conducted with selected teachers to explore their understanding of unplugged coding in greater depth, including perceived benefits, challenges, and support needs. Interview participants were selected purposively to represent variation in teaching experience and questionnaire response patterns. Interviews were conducted until thematic saturation was reached, indicated by the absence of new substantive themes in successive interviews.

Data Analysis Techniques

Quantitative data from the questionnaires were analyzed using descriptive statistics, including means and standard deviations, to identify overall trends in teachers' knowledge, perceptions, and readiness. Given the exploratory focus and sample size, inferential statistical analysis was not employed.

Qualitative data from the interviews were analyzed using thematic analysis. The analysis followed an iterative process of familiarization, coding, and theme development. To enhance qualitative rigor, coding was reviewed through peer debriefing with another researcher experienced in qualitative analysis. Data triangulation between questionnaire results and interview findings was also applied to strengthen the credibility of interpretations. Emerging themes were continuously refined to ensure consistency and coherence with the research objectives.

The quantitative and qualitative findings were then integrated at the interpretation stage to provide a comprehensive explanation of teachers' readiness toward unplugged coding in elementary science learning.

Ethical Considerations

This study was conducted in accordance with ethical principles for research involving human participants. Informed consent was obtained from all participants prior to data collection. Participants were informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any time without consequences. To ensure confidentiality, all identifying information was

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removed from the dataset, and pseudonyms or numerical codes were used in place of real names. All data were securely stored and accessible only to the research team. The study adhered to generally accepted ethical standards for educational research and complied with national regulations governing research involving human subjects.

RESULT AND DISCUSSION

Quantitative Results

Quantitative data were collected through a questionnaire completed by 18 elementary school teachers from several public elementary schools in Jakarta, Indonesia. The instrument measured three main aspects: teachers' knowledge of unplugged coding, teachers' perceptions of unplugged coding in elementary science learning, and teachers' readiness to implement unplugged coding. All questionnaire items were rated using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

1. Teachers' Knowledge of Unplugged Coding

This aspect examined teachers' understanding of unplugged coding concepts and their relationship with computational thinking and elementary science learning. As shown in Table 1, the overall mean score for this aspect was 3.21, indicating a moderate level of knowledge. However, analysis at the indicator level revealed uneven understanding across different conceptual components.

Table 1. Teachers' Knowledge of Unplugged Coding

Indicator Statement	Mean	SD	Interpretation
I understand the concept of unplugged coding.	3.06	0.52	Moderate
Unplugged coding can be conducted without using computers or digital devices.	3.67	0.48	Moderately high
I understand the relationship between unplugged coding and computational thinking.	3.00	0.50	Moderate
I am familiar with algorithmic thinking concepts used in unplugged coding.	2.94	0.56	Moderate to low
I understand how sequencing activities relate to unplugged coding.	3.11	0.49	Moderate
I understand abstraction in the context of unplugged coding.	2.83	0.58	Moderate to low
I can distinguish unplugged coding from general learning games.	3.17	0.47	Moderate
I understand how unplugged coding can be integrated into science learning.	3.06	0.51	Moderate

The results indicate that teachers were relatively aware that unplugged coding does not require computers or digital devices. However, lower mean scores were observed on indicators related to algorithmic thinking, abstraction, and the integration of unplugged coding into elementary science learning. This pattern suggests that teachers' knowledge was largely superficial and not yet supported by a clear conceptual framework.

2. Teachers' Perceptions of Unplugged Coding in Science Learning

This aspect measured teachers' views regarding the relevance, usefulness, and potential contribution of unplugged coding to elementary science education. As presented in Table 2, this dimension obtained the

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highest overall mean score (3.74), reflecting generally positive perceptions among teachers from different schools.

Table 2. Teachers' Perceptions of Unplugged Coding in Science Learning

Indicator Statement	Mean	SD	Interpretation
Unplugged coding is relevant to elementary science learning.	3.83	0.39	Moderately high
Unplugged coding can support students' logical thinking skills.	3.89	0.34	High
Unplugged coding can increase student engagement in science lessons.	3.78	0.41	Moderately high
Unplugged coding is suitable for schools with limited computer access.	4.06	0.29	High
Unplugged coding can be applied at the elementary school level.	3.72	0.44	Moderately high
Unplugged coding supports active and collaborative learning.	3.67	0.46	Moderately high
Unplugged coding aligns with current curriculum goals.	3.28	0.51	Moderate

These findings indicate that teachers generally perceived unplugged coding as appropriate and beneficial, particularly in school contexts where access to computers is limited. Nevertheless, perceptions were less strong regarding alignment with formal curriculum requirements, suggesting uncertainty about how unplugged coding can be systematically embedded within existing instructional structures.

3. Teachers' Readiness to Implement Unplugged Coding

The readiness aspect assessed teachers' perceived ability to plan, implement, and evaluate unplugged coding activities in elementary science classrooms. As shown in Table 3, this aspect recorded the lowest overall mean score (3.02), indicating moderate to low readiness across participating teachers.

Table 3. Teachers' Readiness to Implement Unplugged Coding

Indicator Statement	Mean	SD	Interpretation
I feel confident explaining unplugged coding concepts to students.	2.94	0.55	Moderate to low
I am ready to design unplugged coding activities for science lessons.	2.89	0.58	Moderate to low
I know how to integrate unplugged coding into existing lesson plans.	2.94	0.52	Moderate to low
I am ready to implement unplugged coding in my science classroom.	3.06	0.49	Moderate
I know how to assess students' learning outcomes from unplugged coding.	2.83	0.60	Moderate to low
I feel supported by available instructional resources.	3.00	0.54	Moderate
I am willing to try unplugged coding despite limited experience.	3.39	0.46	Moderate
I need training before implementing unplugged coding.	3.78	0.42	Moderately high

The readiness data indicate that most teachers across the participating schools did not yet feel confident in planning and implementing unplugged coding in elementary science learning. Low scores on instructional design and assessment indicators suggest limited practical preparedness. At the same time, the relatively high score on the need for training reflects teachers' awareness of their current limitations and their openness to professional development.

Qualitative Results

Qualitative data were collected through semi-structured interviews with elementary school teachers and supported by field notes. The interviews aimed to explore teachers' understanding, perceptions, and preparedness regarding unplugged coding in elementary school science learning, particularly in contexts with limited computer access. The analysis yielded three main themes, each consisting of several subthemes reflecting teachers' lived experiences and practical considerations, as shown in Figure 1.

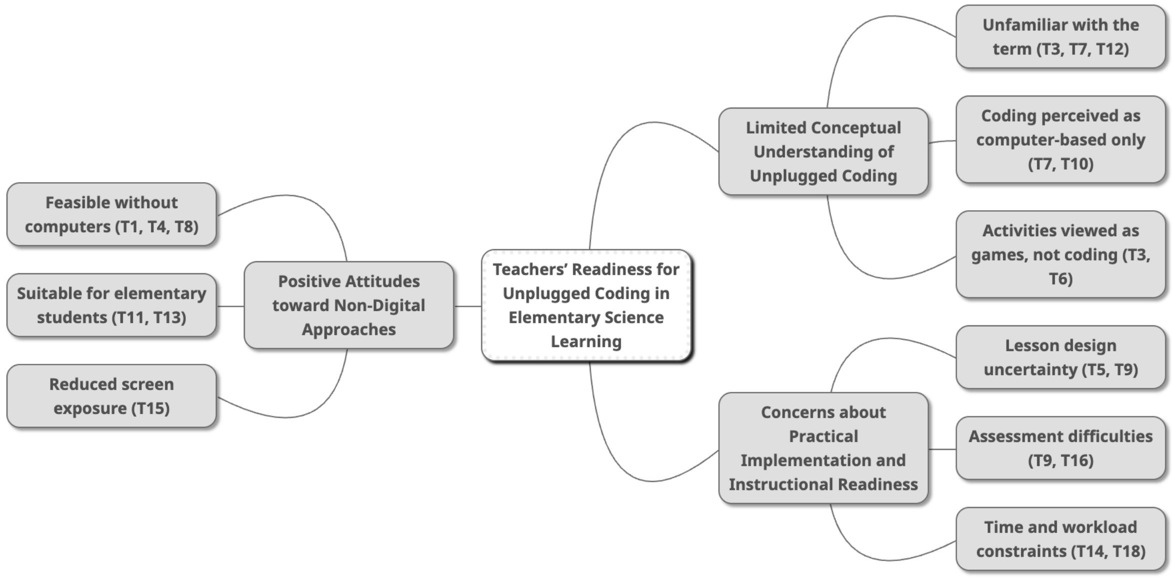

Figure 1. Themes of Teachers' Experiences with Unplugged Coding in Elementary Science Learning

1. Limited Conceptual Understanding of Unplugged Coding

Interview data indicated that most teachers had limited conceptual understanding of unplugged coding. Several teachers stated that they were unfamiliar with the term prior to participating in the study. Although they frequently used games, group activities, or hands-on experiments in science lessons, these practices were not recognized as part of coding or computational thinking.

One teacher explained:

"Honestly, I had never heard the term unplugged coding before. I often use games or experiments in science, but I did not realize that those activities could be related to coding or computational thinking" (T3).

Another teacher shared:

"I always thought coding had to use computers. When you mentioned unplugged coding, I was confused at first because I did not know coding could be done without technology" (T7).

These statements suggest that teachers tended to define coding narrowly as computer-based programming. Activities that did not involve digital devices were rarely conceptualized as coding instruction, even when they required logical sequencing or problem-solving. As a result, teachers' understanding remained intuitive and fragmented rather than grounded in formal conceptual frameworks.

2. Positive Attitudes toward Non-Digital Approaches

Despite limited conceptual knowledge, teachers expressed positive attitudes toward unplugged coding, particularly in relation to contextual constraints. Teachers repeatedly highlighted the limited availability of computers in their schools and viewed non-digital approaches as more feasible and inclusive.

One teacher commented:

"In our school, computers are very limited. If coding always needs computers, it will be difficult. But if it can be done without computers, then it feels more realistic for us" (T1).

Teachers also perceived unplugged coding as appropriate for elementary students because it relied on concrete activities and collaboration.

As another teacher noted:

"Elementary students like learning through activities and games. If coding can be taught like that, I think students will be more interested and understand better" (T11).

Some teachers also expressed concerns about excessive screen time and viewed unplugged coding as a way to balance digital competence with healthy learning practices.

"Children already spend a lot of time with screens. If we can teach logical thinking without screens, that would be better" (T15).

These responses indicate that teachers were open to unplugged coding as long as it aligned with classroom realities and students' developmental needs.

3. Concerns about Practical Implementation and Instructional Readiness

Although teachers viewed unplugged coding positively, many expressed concerns regarding practical implementation. Teachers frequently mentioned uncertainty about lesson design, instructional strategies, and assessment methods.

One teacher stated:

"I understand the idea, but I still do not know how to turn it into a lesson. What activities should I prepare, and how do I connect them to the science topic?" (T5).

Another teacher highlighted assessment-related difficulties:

"If we use unplugged coding, how do we assess students? I am not sure what indicators we should look at" (T9).

Teachers also pointed to structural constraints such as limited time and heavy workloads.

"We already have many learning targets. Trying a new method without clear guidance feels risky because we are responsible for completing the curriculum" (T14).

These concerns suggest that teachers' limited readiness was not due to resistance to innovation, but rather to a lack of pedagogical guidance, instructional examples, and professional development opportunities.

Discussion

This study explored elementary school teachers' knowledge, perceptions, and readiness regarding unplugged coding within the context of science learning, particularly in schools with limited access to computers. The findings provide insight into teachers' positioning at an early stage of instructional change related to computational thinking, coding, and artificial intelligence, as encouraged by recent curriculum policies.

The quantitative findings indicate that teachers' knowledge of unplugged coding was generally moderate, with notable gaps in core computational thinking components such as algorithmic thinking and abstraction. Many teachers tended to conceptualize unplugged coding primarily as learning activities conducted without digital devices, rather than as a structured cognitive approach that supports problem decomposition, sequencing, and procedural reasoning. This suggests that teachers' understanding remains largely operational rather than conceptual. While similar patterns have been reported in previous studies indicating that computational thinking is often perceived as a technical or computer-related skill (AYTEKİN & TOPÇU, 2024; Lin et al., 2024; Liu & Hu, 2025; Moreno-Palma et al., 2024; Zhang et al., 2024), the present findings extend the literature by demonstrating how this limited conceptualization constrains the meaningful integration of unplugged coding into science instruction, where systematic reasoning and evidence-based thinking are central learning objectives.

rom a theoretical perspective, these findings indicate that teacher readiness should be understood as a developmental construct rather than a static attribute. Teachers in this study appear to be situated at an early awareness and informational stage of instructional adoption. They recognize the relevance of unplugged coding and its potential alignment with curriculum demands, yet they have not developed the pedagogical schemas or instructional confidence necessary for classroom enactment. This helps explain the observed discrepancy between teachers' generally positive perceptions and their limited readiness to implement unplugged coding in practice.

Teachers' perceptions of unplugged coding were largely positive, particularly regarding its feasibility and developmental appropriateness for elementary students. Teachers viewed unplugged activities as compatible with active and collaborative learning and as responsive to infrastructural constraints commonly encountered in their schools. These findings are consistent with earlier research highlighting the accessibility and inclusiveness of unplugged approaches, especially in under-resourced educational contexts (Moreno-Palma et al., 2024, 2024; Walstra, 2024; Zhang et al., 2024). However, the present study highlights a critical limitation in relying on positive perceptions alone: feasibility does not automatically translate into instructional adoption when teachers lack concrete pedagogical pathways and curriculum-aligned guidance.

Despite favorable attitudes, teachers' readiness to implement unplugged coding was found to be moderate to low. Teachers expressed uncertainty related to lesson design, alignment with science learning objectives, and assessment strategies. Qualitative findings further revealed hesitancy to experiment with new instructional approaches without explicit models and institutional support, particularly given existing workload demands and accountability pressures. These results reinforce the view that readiness encompasses not only motivation and beliefs, but also pedagogical knowledge, curriculum coherence, and perceived manageability. Without these supporting conditions, instructional innovations risk remaining at the level of intention rather than sustained classroom practice.

The discrepancy between teachers' positive perceptions and limited readiness underscores an important challenge in policy-driven educational reform. While curriculum policies encourage the introduction of coding and artificial intelligence, the findings suggest that policy alignment alone is insufficient to ensure effective implementation. Without structured professional development, exemplar lesson designs, and assessment guidance, such initiatives may be adopted unevenly or remain symbolic rather than instructional. Strengthening teacher capacity is therefore essential not only for initial adoption but also for long-term sustainability, as routine instructional planning and assessment must be feasible within teachers' everyday practices.

From a science education perspective, the findings suggest that unplugged coding holds pedagogical promise for strengthening core scientific practices, including reasoning, sequencing, and problem solving. However, because teachers have limited prior experience with implementation, unplugged coding is currently perceived as an abstract or generic instructional idea rather than a science-specific pedagogical strategy. Addressing this gap requires targeted efforts to support teachers in explicitly connecting unplugged coding activities with concrete science content, inquiry processes, and learning outcomes.

From a practical instructional perspective, these findings have several implications for elementary science teaching. Professional development initiatives should emphasize unplugged coding as a thinking-oriented pedagogy rather than merely an alternative to digital technology. Teachers need structured support to understand how unplugged activities can foster scientific practices such as identifying patterns, designing procedures, and explaining phenomena. For example, sequencing-based unplugged activities can be aligned with science topics involving processes or cycles, such as plant growth, energy transformation, or changes in states of matter.

In addition, curriculum alignment should be made explicit through concrete instructional examples. Unplugged coding can be embedded within existing science lessons as problem-solving tasks that require students to plan step-by-step solutions, predict outcomes, and revise procedures based on evidence. Framing unplugged coding in this way allows teachers to perceive it not as an additional curricular burden, but as an instructional strategy that directly supports science learning objectives.

Assessment practices should also focus on indicators that capture both computational thinking and scientific reasoning. Rather than assessing coding performance per se, teachers can evaluate students' ability to sequence actions logically, justify procedural decisions, identify errors, and explain causal relationships. Such assessment indicators align naturally with science learning outcomes and help reduce the complexity of implementing new assessment systems.

Finally, the provision of practical support materials—such as lesson templates, activity examples, and assessment rubrics—is essential for reducing teacher uncertainty and workload concerns. Resource-efficient and context-sensitive instructional materials can support gradual adoption and increase teachers' confidence in integrating unplugged coding into everyday science instruction. By addressing these needs, unplugged coding has the potential to function as an inclusive and sustainable pedagogical approach for developing computational thinking through elementary science learning, particularly in contexts where access to digital technology remains limited.

CONCLUSION

This study examined elementary school teachers' knowledge, perceptions, and readiness regarding unplugged coding in the context of science learning, particularly in schools with limited access to computers. The findings show that while teachers generally held positive perceptions toward unplugged coding, their conceptual understanding and readiness for classroom implementation remained limited.

Quantitative results indicated that teachers' knowledge of unplugged coding was moderate, with clear gaps in key computational thinking components such as algorithmic thinking and abstraction. Teachers tended to interpret unplugged coding mainly as non-digital activity rather than as a structured pedagogical approach for developing problem-solving skills. In contrast, teachers' perceptions were largely positive, reflecting their recognition of unplugged coding as a feasible and inclusive approach for elementary science classrooms, especially in contexts with constrained technological resources.

Despite these positive perceptions, teachers' readiness to implement unplugged coding was found to be moderate to low. Qualitative findings highlighted persistent concerns related to lesson design, curriculum alignment, and assessment practices. Teachers expressed the need for clear instructional guidance and professional support before attempting to integrate unplugged coding into science lessons. These findings suggest that positive attitudes alone are insufficient to ensure successful implementation.

The implications of this study are twofold. From a practical perspective, the findings highlight the need for targeted professional development that focuses on strengthening teachers' conceptual understanding of computational thinking and providing concrete examples of unplugged coding activities aligned with elementary science content. From a policy perspective, the results suggest that initiatives related to coding and artificial intelligence in elementary education should consider teachers' readiness and contextual constraints, particularly in schools with limited access to technology. Emphasizing unplugged approaches may help ensure more equitable and sustainable implementation across diverse school settings.

Overall, unplugged coding represents a promising pathway for integrating computational thinking into elementary science learning without reliance on digital devices. However, meaningful integration depends on systematic efforts to support teachers through capacity building, instructional resources, and curriculum-aligned guidance.

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