CULTURALLY GROUNDED UNPLUGGED COMPUTER SCIENCE INSTRUCTION AND COMPUTATIONAL THINKING DEVELOPMENT: A QUASI-EXPERIMENTAL STUDY FROM UZBEKISTAN

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Abstract: *Informatics education in low-resource settings often struggles to develop computational thinking (CT) when computer laboratories, stable electricity, and trained teachers are scarce. Unplugged computer science, which teaches computing concepts through physical and narrative activities rather than digital devices, has been proposed as a resource-independent alternative, and culturally responsive pedagogy has separately been shown to strengthen engagement and retention. This study combined both approaches by designing and testing an unplugged instructional model grounded in Uzbek cultural artefacts (ornament and suzani patterns, folk riddles, traditional games, and procedural crafts) for lower-secondary informatics classrooms. A quasi-experimental pre-test/post-test design was used with two intact classes (N = 60; experimental n = 30, control n = 30) taught by the same teacher over a six-to-eight-week intervention. CT was measured across five dimensions—abstraction, decomposition, pattern recognition, sequencing, and algorithmic reasoning—using a 25-item instrument adapted from the Computational Thinking Test. The experimental group's mean score rose from 11.87 to 20.43 (gain = 8.56), compared with 11.53 to 15.97 (gain = 4.44) in the control group. An independent-samples t-test confirmed a statistically significant post-test difference (t = 7.98, p < .001), and normalized gain scores favoured the experimental group (0.65 versus 0.33). Student perception data and classroom observations corroborated the quantitative gains, showing high enjoyment and engagement, with algorithmic reasoning the most demanding dimension for both groups. The findings suggest that culturally grounded unplugged instruction is a practical, low-cost strategy for strengthening computational thinking in infrastructure-constrained contexts, with implications for teacher training and curriculum design in Uzbekistan and comparable settings.*

Keywords: *unplugged computer science; computational thinking; culturally responsive pedagogy; informatics education; quasi-experimental design; Uzbekistan; secondary education*

1. INTRODUCTION

Computational thinking (CT) — the capacity to formulate problems and solutions in ways executable by a computer or a human — is increasingly treated as a foundational competency alongside literacy and numeracy (Wing, 2006; Grover & Pea, 2018; UNESCO, 2023). Yet access to the instructional conditions that build CT remains highly unequal. Many national curricula, including Uzbekistan's, now mandate informatics from an early grade (Ministry of Public Education of Uzbekistan, 2020), but rural and semi-urban schools frequently lack functioning computer laboratories, reliable electricity, or teachers trained in digital pedagogy (UNICEF, 2022; Tashpulatov & Rakhimova, 2023; Khimmataliev, 2024). The result, documented across several recent studies of Uzbek classrooms, is informatics teaching that remains textbook-based and disconnected from authentic problem-solving (Sharipova, 2023; Mardonov, 2024).

Unplugged computer science offers one response to this constraint. Originating with Bell, Witten, and Fellows' Computer Science Unplugged initiative, the approach teaches concepts such as algorithms, binary representation, and finite-state logic through card games, puzzles, and physical simulation rather than programming environments (Bell et al., 2012; Bell & Newton, 2017). A substantial evidence base — including a 32-study meta-analysis reporting outcomes comparable to block-based coding instruction (Hsu & Hwang, 2023) and a systematic review identifying unplugged activities as a viable low-cost route to CT (Chen et al., 2023) — supports its effectiveness, particularly for introductory learners and infrastructure-poor settings (Taub et al., 2015; Brackmann, 2017; Saputro et al., 2020; García-Peñalvo et al., 2021).

A separate but converging line of research argues that learning is strengthened when it is anchored in students' own cultural knowledge. Culturally responsive teaching increases engagement, comprehension, and identity-based motivation (Gay, 2018; Ladson-Billings, 2014), and recent work has begun to apply this logic specifically to computing education: Iwatani et al. (2024) traced connections between Appalachian problem-solving traditions and CT, Hu et al. (2024) examined embodied cognition in young children's unplugged activities, and Prantsoudi et al. (2025) integrated culturally responsive unplugged CT into language and arts lessons in Greece [Suggested addition]. Uzbekistan's own cultural repertoire — geometric carpet and suzani ornamentation, folk riddles (topishmoqlar), procedural crafts, and oral storytelling — contains sequential, iterative, and pattern-based structures with clear conceptual parallels to CT (Almatov, 2021; Oripov & Karimova, 2023). Despite this apparent fit, no published framework had previously combined unplugged pedagogy with Uzbek cultural content, and empirical, experimentally controlled evidence on informatics teaching methods within Uzbekistan remains scarce (Khujakulov & Mukhitdinov, 2022).

This study addressed that gap by designing an unplugged instructional model grounded in Uzbek cultural artefacts and testing its effect on lower-secondary students' computational thinking relative to conventional instruction. The guiding research question was: how does Uzbekistan culture-based unplugged computer science instruction influence students' computational thinking development in informatics classrooms? Three sub-questions addressed student perceptions of the model, the academic difference between unplugged and traditional instruction, and the practical challenges of classroom implementation. Building on this question, the study tested the hypothesis that students receiving the culturally grounded unplugged intervention would show significantly greater CT gains than students receiving standard instruction.

2. Theoretical Background

2.1 Unplugged Computer Science and Computational Thinking Frameworks

Unplugged pedagogy rests on constructivist and embodied-cognition foundations: learners build understanding through direct manipulation and physical action rather than passive reception (Piaget, 1970; Papert, 1980; Kotsopoulos et al., 2017). Wing's (2006, 2008) formulation of CT — abstraction, decomposition, algorithmic thinking, and debugging, later formalized by ISTE and CSTA (2011) — provides the conceptual target that unplugged tasks are designed to reach. Subsequent frameworks extended this cognitive core with affective and sociocultural dimensions: Brennan and Resnick (2012) added concepts, practices, and perspectives; Shute et al. (2017) organized CT into dispositions, competencies, and outcomes. These extensions matter for the present study because they legitimize treating motivation and cultural relevance as integral to CT development rather than incidental to it.

2.2 Culturally Responsive Pedagogy and the Uzbek Context

Uzbekistan's pedagogical tradition — oral riddles, proverbs, storytelling, and craft-based apprenticeship — encodes rule-based and sequential reasoning that maps onto CT constructs (Kamoliddinov, 2022; Khan, 2020). Carpet and suzani ornamentation follow geometric symmetry and repetition; folk games such as dastlab kim and traditional dice strategies embed conditional logic; and procedural traditions such as preparing plov mirror algorithmic decomposition (Almatov, 2021). Comparable culturally grounded approaches in Kazakhstan and Kyrgyzstan report improved motivation and retention in mathematics and literacy instruction (Yusupova, 2023; Bektemirov, 2022), and Gün-Tosik and Güyer (2024) found that unplugged CS instruction produced measurable gains specifically in the abstraction sub-component of CT [Suggested addition]. Yet, prior to the present study, this alignment between Uzbek cultural knowledge and computational reasoning had not been operationalized into a tested classroom intervention — a gap consistent with broader observations that culturally grounded unplugged materials remain rare relative to internationally templated ones (Kale et al., 2021).

3. Materials and Methods

3.1 Design

A quasi-experimental, pre-test/post-test, non-equivalent control-group design was used, comparing an experimental group receiving unplugged, Uzbek culture-based instruction with a control group receiving conventional textbook-based instruction. Cluster-level (intact classroom) assignment was used rather than individual randomization, reflecting standard constraints in school-based research (Cohen et al., 2018). Both groups were taught by the same teacher, covered identical curriculum objectives, and received equal instructional time; only the pedagogical method varied. The independent variable was mode of instruction; the dependent variable was computational thinking performance, operationalized across five sub-constructs — abstraction, decomposition, pattern recognition, sequencing, and algorithmic reasoning.

3.2 Participants

Participants were 60 students (Mage range 11–13 years; grades 6–7) drawn from two intact classes at one lower-secondary school in Uzbekistan, with 30 students assigned to the experimental condition and 30 to the control condition. A single-school design was adopted to hold curriculum implementation, classroom culture, and teacher style constant across conditions.

Pre-test scores were compared to establish baseline equivalence before the intervention began (see Section 4.1).

3.3 Instructional Intervention

The experimental group received six to eight weeks of unplugged instruction structured around an inquiry cycle of demonstration, guided practice, group collaboration, independent problem-solving, and reflective discussion. Weekly activities targeted specific CT constructs through cultural materials: pattern recognition through analysis of Uzbek carpet and suzani designs; sequencing through ordering the procedural steps of preparing plov or weaving a pattern; decomposition through breaking folk riddles into logical statements; conditional and iterative reasoning through role-play built on traditional story decision points; and elementary data representation through bead and ornament-grid encoding. The control group covered the same informatics topics through textbook explanation and teacher-led demonstration, without unplugged or cultural materials. To avoid disadvantaging the control group, selected unplugged lessons were shared with it after data collection concluded.

3.4 Instruments

Computational thinking was measured with a 25-item test (five items per dimension, scored 0/1, maximum score 25), structurally adapted from the Computational Thinking Test of Román-González et al. (2018) and contextualized with familiar examples for Uzbek learners without altering item difficulty. The instrument was piloted with 10–15 students outside the study sample. Complementary instruments included a structured classroom-observation checklist (four-point scale, adapted from Curzon et al., 2019, and Sáez-López et al., 2016), a five-point Likert perception questionnaire administered to the experimental group after the intervention, teacher reflection notes, and collected student artefacts (worksheets, pattern diagrams, riddle-logic diagrams) used for triangulation.

3.5 Data Analysis

Pre-test and post-test scores were checked for normality (Shapiro-Wilk, appropriate for group sizes below 50) and homogeneity of variance (Levene's test) prior to inferential testing. Because both assumptions were satisfied, parametric tests were used: an independent-samples t-test compared post-test scores between groups, and paired-samples t-tests examined within-group pre-to-post change. Normalized gain (N-Gain) scores were calculated to express learning effectiveness independent of ceiling effects. Because pre-test means did not differ significantly between groups (Section 4.1), the analysis did not require covariate adjustment (e.g., ANCOVA); the independent-samples t-test on post-test scores was the appropriate and sufficient comparison.

3.6 Ethical Procedures

The study received institutional ethics approval and school administration permission. Because participants were minors, parental or guardian consent and student assent were obtained, participation was voluntary with the right to withdraw without penalty, and data were anonymized using coded identifiers. Cultural materials were reviewed to avoid misrepresentation of Uzbek symbols and narratives.

4. Results

4.1 Baseline Equivalence

Pre-test scores did not differ meaningfully between groups (experimental M = 11.87, SD = 2.14; control M = 11.53, SD = 2.22; difference = 0.34 points), indicating that the two classes began the study at a comparable level of computational thinking (Table 1).

Group	N	Min	Max	Mean	SD
Experimental	30	8	16	11.87	2.14
Control	30	7	16	11.53	2.22

Table 1. Pre-test scores of experimental and control groups.

4.2 Post-Test Outcomes

Following the intervention, the experimental group scored substantially higher than the control group (Table 2). The experimental group achieved a mean post-test score of 20.43 (SD = 2.01), compared with 15.97 (SD = 2.31) for the control group — a raw difference of 4.46 points.

Group	N	Min	Max	Mean	SD
Experimental	30	16	24	20.43	2.01
Control	30	11	20	15.97	2.31

Table 2. Post-test scores of experimental and control groups.

Mean gain scores confirmed the pattern: the experimental group improved by 8.56 points (72.11%), nearly double the control group's 4.44-point (38.51%) improvement (Table 3).

Group	Pre-Test Mean	Post-Test Mean	Mean Gain	Improvement %
Experimental	11.87	20.43	8.56	72.11%
Control	11.53	15.97	4.44	38.51%

Table 3. Comparison of pre-test and post-test mean scores.

4.3 Computational Thinking by Dimension

All five CT dimensions improved in both groups, but gains were consistently larger in the experimental group (Table 4). Pattern recognition showed the largest gain overall (experimental +1.87 vs. control +1.07), plausibly reflecting the visual symmetry and repetition inherent in the ornament- and suzani-based tasks. Abstraction and decomposition each improved by 1.80 points in the experimental group, compared with 1.00 point in the control group, consistent with the cognitive demands of riddle-based and storytelling tasks. Algorithmic reasoning showed the smallest gain in both groups (experimental +1.36; control +0.43), indicating that constructing complete step-by-step procedures remained the most demanding skill regardless of instructional method.

CT Dimension	Exp. Pre	Exp. Post	Exp. Gain	Ctrl Pre	Ctrl Post	Ctrl Gain
Abstraction	2.20	4.00	1.80	2.13	3.13	1.00
Decomposition	2.27	4.07	1.80	2.20	3.20	1.00
Pattern Recognition	2.53	4.40	1.87	2.40	3.47	1.07

CT Dimension	Exp. Pre	Exp. Post	Exp. Gain	Ctrl Pre	Ctrl Post	Ctrl Gain
Sequencing	2.47	4.20	1.73	2.33	3.27	0.94
Algorithmic Reasoning	2.40	3.76	1.36	2.47	2.90	0.43
Total	11.87	20.43	8.56	11.53	15.97	4.44

Table 4. Computational thinking scores by dimension, experimental and control groups.

4.4 Inferential Statistics

Normality (Shapiro-Wilk) and homogeneity of variance (Levene's test) assumptions were satisfied for all pre-test and post-test distributions (all $p > .05$), supporting the use of parametric tests. An independent-samples t-test on post-test scores showed a statistically significant difference between groups, $t = 7.98$, $p < .001$, favouring the experimental group. Paired-samples t-tests confirmed that both groups improved significantly from pre-test to post-test (both $p < .001$), but the mean gain was substantially larger in the experimental condition. Normalized gain (N-Gain) scores were 0.65 (medium-to-high category) for the experimental group and 0.33 (medium-low category) for the control group, reinforcing that the culturally grounded unplugged model produced a stronger effect than conventional instruction (Table 5).

Test	Experimental Group	Control Group
Independent-samples t (post-test)	$t = 7.98$, $p < .001$	—
Paired-samples t (pre–post)	$p < .001$ (significant)	$p < .001$ (significant)
N-Gain score	0.65 (medium–high)	0.33 (medium–low)

Table 5. Summary of inferential statistics.

4.5 Student Perceptions and Classroom Observation

On the post-intervention perception questionnaire (five-point Likert scale), students in the experimental group rated the statement "Uzbek cultural examples made the lesson more interesting" highest ($M = 4.67$), followed by enjoyment of learning informatics through cultural activities ($M = 4.53$) and preference for unplugged over textbook-only instruction ($M = 4.47$). Perceived understanding of computational thinking ($M = 4.40$) and increased motivation ($M = 4.43$) were also rated highly, while perceived improvement in group problem-solving was rated somewhat lower, though still high ($M = 4.36$).

Structured classroom observation corroborated these self-reports: student enthusiasm received the highest observed rating ($M = 3.80$, "very high"), followed by teacher guidance ($M = 3.70$), student participation ($M = 3.73$), and group collaboration ($M = 3.67$); understanding of instructions was rated somewhat lower ($M = 3.53$), consistent with teacher reflection notes describing some initial difficulty with algorithmic-reasoning tasks that resolved with additional scaffolding. Teacher reflections also identified practical implementation costs — greater lesson-preparation time and more demanding classroom management during group activities — alongside an overall assessment that the model was feasible for schools with limited computer access.

5. DISCUSSION

The central finding — that Uzbek culture-based unplugged instruction produced significantly greater computational thinking gains than conventional teaching — supports

Wing's (2006) contention that computational thinking is a general reasoning capacity separable from digital tool use, and extends the substantial international evidence base for unplugged pedagogy (Bell et al., 2012; Brackmann, 2017; Hsu & Hwang, 2023; Chen et al., 2023) into a setting, and with materials, not previously examined empirically. Where prior unplugged research has largely relied on internationally templated activities (Bell & Newton, 2017; Curzon et al., 2019), the present study suggests that grounding those activities in learners' own cultural repertoire may add an additional increment of effectiveness beyond what generic unplugged materials achieve alone — consistent with Gay's (2018) account of culturally responsive teaching and with recent culturally situated CT work in other contexts (Iwatani et al., 2024; Prantsoudi et al., 2025) [Suggested addition].

The dimension-level pattern is informative for instructional design. Pattern recognition and abstraction/decomposition responded most strongly to cultural materials, plausibly because Uzbek ornamentation and riddle traditions map with unusual directness onto these specific constructs: suzani and carpet motifs are, structurally, repeating and symmetric visual algorithms, while riddles require exactly the information-filtering that defines abstraction. Algorithmic reasoning — requiring students to generate a complete, independent procedure rather than recognize or extend one — showed the smallest gain in both conditions, echoing Román-González et al.'s (2018) observation that algorithmic construction is typically the most cognitively demanding CT sub-skill, and Gün-Tosik and Güyer's (2024) finding that unplugged instruction's clearest advantage lies in abstraction rather than full algorithm design [Suggested addition]. This suggests that culturally grounded unplugged activities may be most immediately effective as scaffolding toward algorithmic reasoning rather than as a complete substitute for explicit instruction in procedure construction.

The convergence of quantitative gains with strongly positive perception and observation data addresses a secondary but practically important question: whether a culturally grounded model is merely effective or also experienced as engaging by students who must sustain it over weeks of instruction. The particularly high rating for cultural relevance ($M = 4.67$) suggests that the mechanism is not simply "active learning" in a generic sense — control-group students also improved — but something more specific to cultural familiarity reducing the psychological distance between students and an otherwise abstract subject, a pattern consistent with Ladson-Billings' (2014) and Gay's (2018) accounts of identity-connected learning.

The implementation challenges reported by the teacher — preparation time, classroom management during group work, and the need for scaffolding on algorithmic tasks — are consistent with challenges reported elsewhere for unplugged pedagogy (Hazzan et al., 2020) and point to a concrete, actionable implication: culturally grounded unplugged instruction is unlikely to succeed as a purely self-directed teacher resource and instead requires structured lesson plans, pre-prepared materials, and orientation training, a point with direct relevance for Uzbekistan's teacher-preparation programs given documented gaps in digital pedagogy training (Tashpulatov & Rakhimova, 2023; Mardonov, 2024).

6. Conclusion

This study designed and empirically tested an unplugged computer science instructional model grounded in Uzbek cultural artefacts and found that it produced significantly greater computational thinking gains than conventional textbook-based instruction across all five measured CT dimensions, with the largest relative advantage in pattern recognition, abstraction, and decomposition. Students perceived the model as enjoyable, culturally relevant, and motivating, and classroom observation confirmed high engagement, though algorithmic reasoning remained comparatively difficult for both groups. Taken together, the findings indicate that culturally grounded unplugged instruction is a viable, low-cost pedagogical strategy for developing computational thinking in schools where computer access is limited, and that it should be understood as a foundation for — rather than a replacement for — later digital programming instruction. For Uzbekistan specifically, the results support incorporating culturally responsive unplugged activities into teacher training and informatics curriculum materials, particularly in rural and semi-urban schools where infrastructure constraints are most acute.

7. Limitations

Several limitations qualify these conclusions. The sample was drawn from a single school (N = 60), limiting generalizability across Uzbekistan's more heterogeneous school contexts. The six-to-eight-week intervention window captures immediate learning gains but not retention over time, and the study did not include a delayed post-test. Findings are specific to students aged 11–13 (grades 6–7) and may not generalize to other educational stages. The CT instrument measured five dimensions but did not assess debugging, creativity, or computational communication, and the study did not test whether unplugged gains transfer to performance in actual programming environments such as Scratch or Python. Finally, because the intervention was delivered by a single teacher, the results may partly reflect that teacher's facilitation skill, and the cultural materials used represent a selection from Uzbekistan's broader cultural heritage rather than an exhaustive one. Future research should address these constraints through larger, multi-site samples, longer intervention periods with delayed post-testing, and explicit measurement of transfer to digital programming performance.

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