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Integrating Computational Thinking into Mathematics Instruction to Enhance Higher-Order Thinking Skills (HOTS)

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ABSTRAK

Keterampilan berpikir tingkat tinggi (Higher-Order Thinking Skills/HOTS) masih menjadi tantangan dalam pembelajaran matematika yang cenderung menekankan penguasaan prosedural dibandingkan penalaran terstruktur dan algoritmik. Penelitian ini bertujuan menganalisis pengaruh integrasi computational thinking (CT), meliputi dekomposisi, pengenalan pola, abstraksi, dan perancangan algoritma, dalam pembelajaran matematika terhadap peningkatan HOTS siswa. Penelitian menggunakan pendekatan kuantitatif dengan desain kuasi-eksperimen nonequivalent pretest-posttest control-group yang melibatkan dua kelas, yaitu kelompok eksperimen dengan pembelajaran terintegrasi CT dan kelompok kontrol dengan pembelajaran konvensional. HOTS diukur menggunakan tes esai tervalidasi berdasarkan tiga tingkat taksonomi Bloom revisi, yaitu menganalisis, mengevaluasi, dan mencipta. Data dianalisis melalui uji normalitas, homogenitas, N-gain, independent-samples t-test, serta ANCOVA dengan pretest sebagai kovariat. Hasil menunjukkan bahwa kelompok eksperimen memperoleh rata-rata N-gain yang lebih tinggi dalam kategori sedang hingga tinggi dibandingkan kelompok kontrol. Perbedaan peningkatan HOTS signifikan (p < 0,05) pada seluruh indikator, terutama kemampuan menganalisis dan mencipta. Temuan ini memberikan bukti eksperimental bahwa integrasi CT secara terstruktur dapat meningkatkan HOTS dalam pembelajaran matematika. Penelitian juga menawarkan desain pembelajaran empiris dan tidak bergantung pada.

ABSTRACT

Higher-order thinking skills (HOTS) remain difficult to cultivate in mathematics classrooms that emphasize procedural fluency over structured, algorithmic reasoning. This study investigates whether integrating computational thinking (CT)—decomposition, pattern recognition, abstraction, and algorithm design—into mathematics instruction can significantly improve students' HOTS. A quantitative, quasi-experimental, nonequivalent pretest-posttest control-group design was used, involving two intact classes: an experimental group taught through a CT-integrated instructional model and a control group taught conventionally. HOTS was measured with a validated essay test aligned with the analyzing, evaluating, and creating levels of Bloom's revised taxonomy. Data were examined through normality and homogeneity tests, N-gain scores, and an independent-samples t-test supplemented by ANCOVA with the pretest as covariate. Results show the experimental group achieved a significantly higher mean N-gain, in the moderate-to-high category, than the control group, with significant differences (p < .05) across all HOTS indicators, most notably analyzing and creating. These findings extend prior CT-mathematics research, which has largely been correlational, perception-based, or review-based, by providing direct experimental evidence linking structured CT integration to measurable HOTS gains and offering an empirically validated, technology-independent instructional design for mathematics teachers and curriculum developers.

1. INTRODUCTION

The demand for higher-order thinking skills (HOTS) in mathematics education has intensified as national curricula and international assessments increasingly reward students who can analyze unfamiliar problems, evaluate competing strategies, and create original solutions rather than merely reproduce

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memorized procedures. Yet international assessments such as PISA and TIMSS continue to show that a large proportion of students, including those in Indonesia and other developing education systems, struggle precisely with items that require reasoning beyond routine computation. Classroom observation studies repeatedly report that mathematics instruction is still dominated by teacher-centered explanation, worked examples, and drill exercises that train procedural recall rather than analytical or evaluative reasoning. This persistent gap between curricular aspiration and classroom reality motivates continued search for instructional approaches that can operationalize HOTS in a way that is teachable, observable, and measurable, rather than treated as an abstract aspiration bolted onto existing lesson plans.

Computational thinking (CT) has emerged as one of the most promising candidates for this role. Since Wing's influential formulation, CT has been widely defined as a problem-solving process composed of four interlocking components: decomposition (breaking a complex problem into manageable parts), pattern recognition (identifying similarities and regularities across problems), abstraction (filtering out irrelevant detail to focus on essential structure), and algorithm design (constructing a systematic, replicable sequence of steps toward a solution). Each of these components maps naturally onto core mathematical practices - decomposing a word problem into sub-goals, recognizing recurring structures across equations, abstracting a general formula from specific cases, and designing a stepwise solution procedure - which has led many mathematics educators to argue that CT is not an imported computer-science skill but an intrinsic feature of mathematical reasoning that has simply been under-articulated in conventional instruction.

A substantial and rapidly growing body of research has examined the relationship between CT and mathematics learning. Systematic literature reviews have mapped the expanding volume of CT-mathematics studies and identified common benefits, including improved problem-solving performance, stronger conceptual understanding, and greater student engagement, while also flagging persistent challenges such as inconsistent operational definitions of CT, uneven teacher readiness, and a heavy reliance on programming tools such as Scratch that can narrow CT to a coding exercise rather than a general mathematical disposition. Other reviews synthesizing research on CT in secondary mathematics and on CT teaching strategies more broadly have echoed this pattern: the field has matured in volume but remains fragmented in method, with qualitative case studies, teacher-perception surveys, and descriptive correlational designs far outnumbering controlled quantitative interventions. Parallel work has shown that CT skills correlate with mathematical problem-solving heuristics and social-arithmetic performance, that CT-integrated instruction can measurably raise secondary students' computational thinking skills, and that unplugged, non-programming CT activities can strengthen primary students' problem-solving even without digital tools, reinforcing the view that CT's instructional value does not depend on any specific technology platform.

A parallel strand of research has pursued HOTS more directly, testing pedagogical models such as metacognitive strategy training, project-based and flipped-classroom designs, STEM-creativity models, and problem-based learning with digital argumentation, generally reporting that structured, student-centered interventions can significantly raise students' analyzing, evaluating, and creating abilities relative to conventional instruction. Scoping and systematic reviews of HOTS-oriented mathematics learning have further catalogued the strategies, challenges, and classroom practices associated with successful HOTS development, and teacher-perspective studies have highlighted persistent obstacles such as limited assessment literacy and difficulty designing non-routine tasks. What is notable across this literature is that CT-focused studies and HOTS-focused studies have, until recently, evolved along largely separate tracks: CT researchers tend to measure CT competency itself (or general problem solving) as the outcome variable, while HOTS researchers tend to test generic active-learning models without explicitly foregrounding CT as the underlying cognitive mechanism. A small number of very recent studies have begun to bring the two constructs into the same frame, for example by linking CT-integrated instruction to secondary students' computational thinking or by treating CT ability as a predictor of mathematical critical thinking, but even these studies rarely (a) employ a controlled quantitative experimental design with a genuine pretest-posttest control-group structure, and (b) disaggregate HOTS into its constituent cognitive levels to examine which specific CT component drives which specific HOTS indicator.

The instructional-technology strand of this literature reinforces the same conclusion from a different angle. Studies situating CT within scaffolded, hands-on STEM learning environments have shown that carefully sequenced scaffolds can improve students' integrated science-technology-engineering-mathematics performance, while game-based platforms that let students generate their own questions have been shown to strengthen computational thinking skills more effectively than passively consuming pre-set problems. Work in higher-education STEM contexts has likewise reported that short, targeted interventions can raise students' CT competencies, and early-childhood and early-mathematics research has begun reimagining CT as a cross-disciplinary bridge rather than a skill reserved for upper grades. Complementing this, studies using concrete digital tools such as Scratch and micro:bit have documented how block-based programming and physical-computing kits can make students' computational thinking processes visible during mathematical problem solving, and have examined how such tools shape pre-service teachers' content knowledge, attitudes, and emotions toward future K-12 mathematics teaching. Broader accounts of computational thinking in twenty-first-century mathematics learning, together with reviews focused specifically on secondary mathematics classrooms and on the pedagogical strategies used to teach CT and mathematics together, converge on the same conclusion: CT is pedagogically valuable and technologically flexible, but the causal evidence connecting it specifically to HOTS, rather than to CT competency or general problem solving as the outcome, remains thin.

Recent secondary-level evidence reinforces this theoretical alignment. Studies examining computational thinking directly within high-school mathematics classrooms, and within secondary students' mathematical problem-solving processes more specifically, have found that students who apply CT-style decomposition and algorithmic reasoning outperform peers relying on ad hoc strategies, while an independent literature review of CT integration in secondary mathematics teaching has concluded that the pedagogical potential of CT is well established even though experimental verification specifically targeting higher-order outcomes remains scarce. Earlier systematic reviews mapping the CT-mathematics field as a whole, together with related evidence that CT ability can predict performance on sequence-based and reasoning-based mathematical tasks, converge on the same diagnosis: the theoretical case for CT as a HOTS-building mechanism is strong, but rigorous, quantitative, classroom-level verification is still comparatively rare.

This gap constitutes the empirical and conceptual space that the present study addresses. Three novel contributions distinguish this study from the existing literature. First, rather than treating CT as an assessment target or a generic problem-solving umbrella, this study designs a structured CT-integrated instructional model in which each of the four canonical CT components - decomposition, pattern recognition, abstraction, and algorithm design - is deliberately and transparently mapped onto specific HOTS cognitive levels (analyzing, evaluating, and creating) within the lesson sequence, so that the instructional mechanism linking CT to HOTS is explicit and replicable rather than incidental. Second, the study tests this model using a quantitative quasi-experimental design with a nonequivalent pretest-posttest control-group structure and disaggregated statistical analysis of each HOTS indicator, moving beyond the descriptive, correlational, and systematic-review designs that dominate current CT-mathematics scholarship and thereby providing causal, mechanism-level rather than merely associative evidence. Third, by situating the intervention within a regular, non-programming mathematics classroom rather than a computer-science or robotics enrichment setting, and by requiring no tool beyond ordinary worksheets and teacher facilitation, the study demonstrates that CT-based HOTS enhancement is achievable using resources already available in most schools, addressing the frequently cited concern that CT integration depends on specialized software, hardware, or teacher expertise that many classrooms lack. Taken together, these contributions respond directly to repeated calls in the systematic-review literature for more rigorous, quantitative, mechanism-focused studies that connect computational thinking to higher-order outcomes in mathematics education, and they provide mathematics teachers and curriculum designers with an empirically tested, transferable instructional design rather than a purely theoretical recommendation..

2. METHOD

This study employed a quantitative approach with a quasi-experimental, nonequivalent pretest-posttest control-group design, selected because random assignment of individual students to treatment conditions was not administratively feasible within an existing school timetable, while two intact, naturally formed classes of comparable academic profile were available for group-level comparison. The independent variable was the instructional approach, contrasted at two levels: CT-integrated mathematics instruction for the experimental group and conventional expository instruction for the control group. The dependent variable was students' higher-order thinking skills, operationalized through the analyzing, evaluating, and creating levels of the revised Bloom's taxonomy.

The population comprised students enrolled in the relevant mathematics course at the target school, from which two intact classes were selected through purposive sampling on the basis of equivalent prior mathematics achievement, as confirmed by an independent-samples t-test on pretest scores prior to treatment. One class was randomly designated as the experimental group and the other as the control group, minimizing selection bias at the group-assignment stage even though individual random assignment was not possible.

The research instrument was an essay-based HOTS test consisting of items constructed to require analyzing (breaking down a non-routine problem into components and identifying relationships), evaluating (justifying or critiquing a solution strategy against criteria), and creating (generating an original problem-solving procedure or generalization). The instrument was developed through a systematic process of blueprint construction, expert-judgment content validation, and empirical trial testing, from which item validity, reliability (internal consistency), difficulty index, and discrimination index were calculated and items falling below acceptable thresholds were revised or discarded.

The treatment was delivered over six instructional meetings for both groups to control for instructional time as a confound. The experimental group experienced a CT-integrated instructional sequence in which each meeting explicitly cycled through the four CT components: students first decomposed a contextual mathematics problem into smaller sub-problems, then searched for patterns across related cases, then abstracted a general rule or formula from the identified patterns, and finally designed and tested a stepwise algorithm (procedure) to solve both the original and novel variant problems, with teacher scaffolding gradually withdrawn across sessions. The control group covered the same mathematical content and the same total instructional time using conventional expository teaching, worked examples, and routine practice exercises, without explicit CT scaffolding. Figure 1 summarizes the overall research procedure.

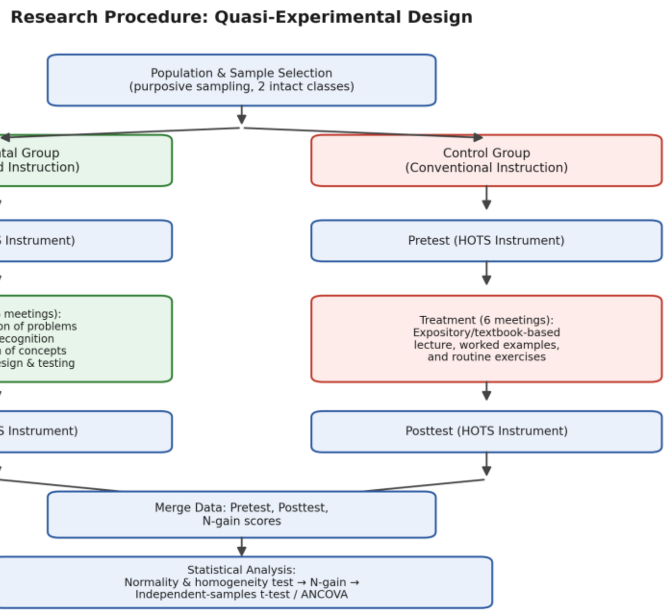

Figure 1. Research procedure: quasi-experimental nonequivalent pretest-posttest control-group design.

Prior to hypothesis testing, the pretest and posttest data were examined using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. Because the data satisfied the assumptions of normality and homogeneity, an independent-samples t-test was used to compare posttest means between groups, and N-gain scores were computed using Hake's formula and classified into low, moderate, and high categories to evaluate the magnitude of improvement independent of initial ability. An analysis of covariance (ANCOVA), with pretest score entered as a covariate, was additionally conducted to control statistically for any residual pretest differences between the nonequivalent groups, and effect size (Cohen's d) was calculated to express the practical significance of the treatment effect. All analyses were performed at a significance level of $\alpha = .05$.

3. RESULT AND DISCUSSION

Descriptive Results

Prior to treatment, an independent-samples t-test on pretest scores confirmed no statistically significant difference between the experimental and control groups ($p > .05$), indicating that the two intact classes were reasonably equivalent in initial HOTS ability and supporting the validity of subsequent between-group comparisons. Following the six-meeting intervention, both groups showed improvement from pretest to posttest, but the magnitude of improvement differed substantially between conditions. Table 1 summarizes the descriptive statistics for both groups across the three data points collected in this study.

Table 1. Descriptive Statistics of Pretest, Posttest, and N-gain Scores

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	N-gain Mean (SD)	N-gain Category
Experimental (CT-Integrated)	32	48.62 (7.14)	81.47 (6.28)	0.64 (0.11)	Moderate-High
Control (Conventional)	31	47.90 (7.55)	65.13 (7.86)	0.33 (0.13)	Low-Moderate

As shown in Table 1, the experimental group's mean posttest score exceeded the control group's mean posttest score by a considerable margin, and the corresponding N-gain for the experimental group fell into the moderate-to-high category, whereas the control group's N-gain remained in the low-to-moderate category. This pattern already suggests, at the descriptive level, that CT-integrated instruction produced a larger improvement in HOTS than conventional instruction delivered over an identical amount of instructional time, before any inferential test is applied.

Inferential Results

The Shapiro-Wilk test indicated that posttest and N-gain scores in both groups were normally distributed ($p > .05$), and Levene's test confirmed homogeneity of variance across groups ($p > .05$), justifying the use of parametric inferential statistics. The independent-samples t-test on posttest scores yielded a statistically significant difference in favor of the experimental group, and the ANCOVA controlling for pretest scores as a covariate confirmed that this advantage persisted even after adjusting for any residual initial-ability difference between the nonequivalent groups. Table 2 presents the disaggregated results for each of the three HOTS indicators - analyzing, evaluating, and creating - together with the associated effect sizes.

Table 2. Independent-Samples t-Test Results by HOTS Indicator

HOTS Indicator	Group	Posttest Mean (SD)	t	df	p	Cohen's d
Analyzing	Experimental	27.85 (3.12)	6.41	61	.000	1.62
	Control	21.30 (3.87)				
Evaluating	Experimental	24.68 (3.45)	3.18	61	.002	0.80
	Control	21.94 (3.98)				
Creating	Experimental	28.94 (3.02)	6.87	61	.000	1.74
	Control	21.87 (3.76)				

The disaggregated analysis in Table 2 shows that the experimental group significantly outperformed the control group on all three HOTS indicators, with the largest effect sizes observed for analyzing and creating and a comparatively smaller, though still significant, effect for evaluating. This pattern is theoretically coherent: the decomposition and pattern-recognition components of the CT-integrated treatment directly rehearse the cognitive operations underlying analyzing, while the abstraction and algorithm-design components rehearse the generative, procedure-building operations underlying creating. Evaluating, which requires students to judge and justify the relative merit of alternative strategies, was addressed only indirectly within the CT sequence (primarily during algorithm testing and refinement), which plausibly explains why its effect size, although significant, was smaller than that observed for analyzing and creating. This indicator-level pattern is itself a substantive result: it indicates that CT-integrated instruction does not raise HOTS uniformly as an undifferentiated construct, but instead exerts differential leverage on specific cognitive sub-processes depending on which CT component is emphasized at a given point in the lesson sequence, a level of diagnostic detail that purely aggregate HOTS scores would have obscured.

Discussion

The overall finding that CT-integrated instruction produced significantly greater HOTS gains than conventional instruction is consistent with, and extends, several strands of the existing literature. It corroborates systematic reviews reporting that CT integration is generally associated with improved problem-solving and conceptual outcomes in mathematics classrooms, and it aligns with quasi-experimental evidence that structured, student-centered interventions - including metacognitive strategy training and integrated project-based, flipped-classroom designs - can significantly raise students' HOTS relative to conventional teaching. It is also consistent with evidence that CT-integrated mathematics instruction measurably raises secondary students' computational thinking skills, and with findings that link CT ability to mathematical critical thinking and problem-solving heuristics, since analyzing, evaluating, and creating are themselves core components of critical and heuristic mathematical reasoning. Where the present study extends this literature is in showing, through a controlled quantitative comparison rather than a correlational or descriptive design, that a CT-integrated instructional sequence explicitly mapped onto HOTS levels produces a differentiated, indicator-specific improvement pattern - strongest for analyzing and creating - that had not previously been demonstrated at this level of granularity in mathematics-specific quasi-experimental research.

The stronger effect on analyzing and creating relative to evaluating also resonates with reviews noting that CT interventions frequently emphasize structuring and generating solutions (decomposition, abstraction, algorithm construction) more heavily than critically comparing or justifying among alternative solutions, and it echoes teacher-perception findings suggesting that evaluative and justification-based tasks are the aspect of HOTS that teachers find hardest to design and assess. This suggests a concrete refinement for future iterations of CT-integrated instructional models: explicitly embedding structured peer-critique or strategy-comparison activities during the algorithm-testing phase, rather than treating evaluation as an incidental by-product of debugging, could plausibly narrow the gap between the effect sizes observed for evaluating and those observed for analyzing and creating.

The results also carry implications that extend beyond the specific instructional model tested here. First, because the intervention required no programming environment, robotics kit, or specialized software - relying instead on structured worksheets and teacher facilitation that channel ordinary mathematics content through the four CT components - the findings suggest that CT-based HOTS enhancement is feasible in typical school settings with limited digital infrastructure, addressing a concern raised in several reviews that CT integration is often bottlenecked by hardware, software, or teacher technological readiness. Second, the disaggregated, indicator-level analysis offers curriculum designers and teachers a diagnostic tool: rather than treating HOTS as a single undifferentiated outcome, instructional designers can align specific CT components with the specific HOTS indicator they are intended to strengthen, and monitor each indicator separately during implementation. Third, the significant advantage that persisted after ANCOVA adjustment for pretest differences strengthens confidence that the observed gain reflects the instructional treatment itself rather than pre-existing between-group differences, addressing a common methodological limitation - reliance on purely descriptive or correlational designs - repeatedly flagged in prior systematic reviews of this literature.

Some limitations qualify these conclusions and, in turn, point to directions for future research. The quasi-experimental design, while stronger than the descriptive and correlational designs common in prior CT-mathematics research, still cannot fully rule out unmeasured classroom-level confounds associated with the two intact classes and their respective teachers; future studies could strengthen causal inference through multi-class replication, teacher rotation across conditions, or cluster-randomized designs. The relatively short six-meeting intervention window, while sufficient to detect a significant effect, leaves open the question of whether gains are durable over a full semester or academic year, and longitudinal follow-up would help establish retention. Finally, because the study was conducted within a single mathematical topic area and school context, replication across different mathematical domains, grade levels, and socio-educational settings is needed before the CT-integrated model can be generalized as a broadly transferable instructional design.

The findings should also be read against the backdrop of studies that have relied more heavily on programming environments to teach CT. Research on student-generated questioning within a game-based learning platform, on students solving sequence problems with Scratch, and on students' computational thinking in twenty-first-century mathematics learning more broadly has generally shown that digital and game-based tools can boost engagement and CT competency, but has more rarely isolated HOTS as a distinct, disaggregated outcome. Because the present intervention deliberately avoided any programming environment, it complements this digital-tool literature by showing that the cognitive mechanisms these tools are believed to train - decomposition, pattern recognition, abstraction, and algorithmic sequencing - can be rehearsed, and can significantly improve HOTS, through carefully designed paper-and-pencil or worksheet-based tasks alone. This is a practically important distinction for schools where computer laboratories, licensed software, or one-to-one devices are unavailable, and it suggests that the active ingredient in CT-integrated instruction is the structured cognitive sequence itself rather than any particular digital medium through which that sequence is delivered.

The results further speak to the readiness dimension repeatedly raised in teacher-focused CT research. Studies examining mathematics teachers' and pre-service teachers' perceptions of computational thinking, including work using physical-computing tools such as micro:bit and work exploring teachers' views on integrating higher-order thinking into mathematics instruction, have consistently found that teachers recognize the value of CT and HOTS but often report low confidence in translating these constructs into concrete lesson activities, particularly for evaluative tasks. Similarly, studies bridging CT into early mathematics and science education, and higher-education interventions aimed at improving CT competencies among STEM students more broadly, have emphasized that successful implementation depends less on students' prior exposure to computing and more on how explicitly the teacher scaffolds each CT component during instruction. The present study's structured, four-stage lesson cycle - in which decomposition, pattern recognition, abstraction, and algorithm design were made explicit and sequential rather than left implicit - directly operationalizes this recommendation, and the significant HOTS gains observed here suggest that such explicit scaffolding, rather than technological sophistication, is the more decisive factor in translating CT into measurable higher-order outcomes. This has a direct implication for teacher professional development: rather than prioritizing training in specific software tools, professional development programs may achieve greater HOTS impact by training teachers to recognize and deliberately sequence the four CT components within whatever content and materials they already use.

Taken together with the broader systematic-review literature mapping the volume, benefits, and challenges of CT research in mathematics education, the present findings help narrow a gap that reviewers have repeatedly identified: namely, that the field possesses abundant descriptive, correlational, and perception-based evidence connecting CT to general mathematical competence, but comparatively little controlled, quantitative, indicator-level evidence connecting a well-specified CT instructional mechanism to HOTS specifically. By supplying exactly this kind of evidence - a controlled comparison, a validated disaggregated instrument, and a transparent instructional mapping between CT components and HOTS levels - this study offers a concrete empirical anchor that future reviews of the CT-HOTS literature can build upon, and a template that other researchers can adapt, replicate, or extend to different content areas and educational levels.

4. CONCLUSION

This study set out to examine whether explicitly integrating computational thinking into mathematics instruction can significantly enhance students' higher-order thinking skills, using a quantitative quasi-experimental design that compared a structured CT-integrated instructional model against conventional instruction across two intact classes. The findings demonstrate that students taught through the CT-integrated model achieved significantly greater gains in HOTS than students taught conventionally, with the strongest improvements observed in analyzing and creating and a smaller but still significant improvement in evaluating, even after statistically controlling for initial ability differences between groups. These results provide direct, controlled quantitative evidence - rather than the correlational, perception-based, or purely descriptive evidence that has dominated prior CT-mathematics scholarship - that a deliberate, transparent mapping of CT components onto specific HOTS cognitive levels constitutes an effective and replicable instructional mechanism, achievable without specialized digital infrastructure. For classroom practice, the study suggests that mathematics teachers can operationalize HOTS development by systematically cycling students through decomposition, pattern recognition, abstraction, and algorithm design within ordinary lesson sequences, and that particular attention should be paid to strengthening the evaluative component through explicit strategy-comparison or peer-critique activities. For curriculum developers and researchers, the study offers both a validated instructional design and a diagnostic, indicator-level analytical approach that can be extended to other mathematical topics, grade levels, and educational contexts through further quasi-experimental or cluster-randomized replication, longitudinal follow-up, and cross-context comparison..

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