

Computational Thinking Across Disciplines

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Abstract: Computational thinking (CT) is no longer confined to computer science; it is now understood as a transferable way of framing problems and building solutions across diverse subjects, including mathematics, science, language arts, music, social justice, and teacher education. Evidence shows that this cross-disciplinary use is not just aspirational. For example, elementary interdisciplinary STEM classrooms saw CT scores rise by 17% overall, with similar gains for girls (18%) and boys (16%). Participation data also highlights growth at scale, with over 103,000 users and 1,268 teachers engaging with arts-integrated computing through platforms like EarSketch, which combines coding with music, entrepreneurship, and equity. Curriculum studies further demonstrate that core CT practices—such as decomposition, abstraction, data use, and algorithmic thinking—can emerge in non-computer science subjects when assignments are intentionally designed. However, significant structural challenges remain. Many teacher professional development efforts rely heavily on tests (60%) rather than classroom observations (0%) or culturally responsive methods (6%). Overall, while CT can successfully transfer across disciplines when tasks preserve subject authenticity, broader implementation is constrained by weak assessment practices, insufficient teacher training, and inequities in prior exposure.

Keywords: Computational Thinking, Interdisciplinary Education, STEM, Humanities, Music Education, Teacher Professional Development, Assessment, Equity, K–12 Education, Higher Education

Computational Thinking Across Disciplines

The concept of cross-disciplinary CT should not be treated as a slogan but rather as an educational design problem. The best modern research does not merely conceptualize CT in terms of decomposition, abstraction, pattern recognition, and algorithmic reasoning; it instantiates those practices within domain-bounded tasks. The shift is important since transfer is lost when CT is taught as decontextualized coding syntax, but gains traction when learners simulate biological systems, organize arguments in English, remix music with code, or analyze social patterns with data-informed representations. A recent cross-case study in language arts, biology, and physics discovered that instructional form modified student acceptance of CT-integrated lessons (Yeni et al., 2024). Such pre-programming experience influenced behavioral intention and secondary students were less initially enthusiastic than primary students. Success across disciplines, however, does not happen automatically or across the board, but rather, it is pegged on the ability of CT to integrate into the epistemology of the host discipline (see Diagram 1) (Tariq et al., 2025). Evidence since 2020 also weakens the claim that CT is valuable only where programming output is the obvious endpoint. In higher education, researchers examining 101 student-generated artifacts across mathematics, sociology, music, and English found demonstrable CT performance at levels ranging from “capstone” (score 4) to “no usage” (score 0), which indicates that disciplinary assignments can elicit computational reasoning without collapsing into computer science imitation (Zhang, Y et al., 2025). Such findings reposition CT as a representational and organizational logic that disciplines can appropriate differently rather than a fixed content package exported unchanged from CS.

Conceptual Grounding

A defensible definition of CT across disciplines must remain operational, not ceremonial. The literature converges on a multidimensional view: learners break complex tasks into manageable parts, detect structure, abstract relevant variables, and produce sequenced procedures or models. What varies across disciplines is the object being transformed. In mathematics, CT often structures problem decomposition and rule-based representation (see Figure 2) (Tariq et al., 2025); in biology, it supports modeling and systems reasoning; in language arts, it appears through storytelling logics

and procedural composition; in music, it emerges through iterative design, timing, pattern, and debugging. Such variation is not a weakness. It is the mechanism by which transfer becomes educationally meaningful.

Review records further show that CT research has reached sufficient scale to justify synthesis rather than isolated enthusiasm. One umbrella review screened 239 records and retained 33 studies - 18 systematic reviews and 15 meta-analyses - while another recent review in STEM education began with 12,146 articles and narrowed the pool to 23 relevant studies (see Figure 1) (Zhang, J. et al., 2025). Scale, however, has not produced methodological maturity at the same rate. Meta-analyses averaged an AMSTAR quality score of 10.9, while systematic reviews averaged 6.11, and the field remains concentrated geographically, with Chinese authors producing 63.6% of included meta-analyses in one umbrella review (Lunny et al., 2026). Cross-disciplinary CT research is therefore growing rapidly, but its evidence architecture is still uneven.

Empirical Evidence Across Disciplines

Brightest causal-looking gains are now found in interdisciplinary STEM interventions. An elementary project on coding and pre/post data in a zoo context involving psychology, evolutionary biology, and computer science involved 57 students who completed coding tasks and 38 of them who provided both pre- and post-data (Cantlon et al., 2024). The result was not a trifle: The scores in computational thinking of students during the post-test were higher than in the pre-test by 17 percent, mean scores rose by 45 percent to 62 percent, and the difference turned out to be statistically significant, $t(17) = 3.96$, $p=0.001$. Student persistence also improved, with attempts on post-test problems increasing by 10%, $t(17)=3.20$, $p=0.003$. These large gains are important since they indicate that genuine disciplinary setting can enhance instead of watering down CT training.

Teacher-mediated integration produces a different but equally important form of evidence. A six-month professional-development program designed to merge CT with literacy and mathematics enrolled five teachers, with three completing the full cycle of workshops, lesson design, implementation, and data collection (Nolte et al., 2024). Classroom enactments demonstrated that stronger CT integration corresponded with clearer lesson structuring and richer student interaction, while the study's contrasting cases showed that CT infusion depends less on tool availability than on pedagogical translation. The conclusion aligns with the larger professional development review: across studies, 52% targeted pedagogical content knowledge, 71% used block-based programming, 60% relied on quizzes or tests, and no studies examined classroom observations. A field that wants disciplinary transfer cannot keep assessing teacher learning as if implementation never happens in real classrooms (Espinal et al., 2024).

Arts-integrated computing offers unusually strong evidence against narrow STEM-only assumptions. The *Your Voice is Power* curriculum joined computing, music, entrepreneurship, and social justice into a K-12 format built around EarSketch platform. Its scale exceeded that of many CT interventions: the platform attracted over 200,000 new users in 2021, with 103,000 joining during the competition period, and 1,268 teachers registered on the competition website (Moore et al., 2022). Retention also outperformed expectations, as "14.5% submitted again in Round 2, exceeding our goal of 5% repeat entrants." Demographic participation further mattered: Round 2 respondents included 27.9% Black or African American and 19.0% Hispanic or Latino students, signaling that culturally resonant design can widen access without sacrificing rigor (Moore et al., 2022). Higher education confirms that disciplinary plurality is not limited to outreach programs. Analysis of undergraduate artifacts across mathematics, sociology, music, and English found that assignment prompts can elicit decomposition, data practices, abstraction, and algorithms even in non-CS courses, though not every discipline supports every CT component equally (Zhang, Y. et al., 2025). That asymmetry is pedagogically useful rather than problematic. It suggests that authentic transfer should be measured by fit-to-discipline rather than by the extent to which all courses imitate programming classes. CT in sociology may foreground data organization and abstraction; CT in English may privilege structured process and representational logic; CT in music may surface

through sequencing, iteration, and pattern. Educational design improves when those differences are treated as productive specialization rather than failure.

Disciplinary integration, however, does not guarantee universal academic payoff. In a cross-sectional study of 81 computer science undergraduates, researchers modeling the relationship between self-reported CT and academic performance found surprisingly few direct positive links (Lemay et al., 2021). Creativity showed a significant positive relationship with academic performance, whereas cooperativity showed a significant negative one. That result matters because it punctures the inflated claim that any CT intervention will necessarily raise grades. Cross-disciplinary CT should be justified by domain-relevant cognitive and representational gains, not by overpromised universal achievement effects. Equity remains the central stress test for the field. One IEEE study on incoming higher-education students reported “significant inequalities in computational thinking across gender, type of school, and prior programming experience,” which means that cross-disciplinary adoption occurs atop unequal entry conditions (González-Pizarro et al., 2024). Another IEEE paper described an “adaptive gamified e-learning platform” built to cultivate CT in undergraduates from multiple disciplines, indicating that researchers increasingly recognize motivational design and adaptive scaffolding as compensatory mechanisms rather than optional embellishments (Ng et al., 2023). Cross-disciplinary CT will remain rhetorically inclusive but materially selective unless prior exposure gaps are treated as a design variable.

Even K–12 tools now frame CT as a multidisciplinary bridge rather than a coding silo. The IEEE Sucre4Stem paper explicitly presents a tool for integrating “computational thinking and programming across multidisciplinary disciplines” (Trilles et al., 2024), while another IEEE study on future music educators states that a music programming course was designed to examine how it affects CT development in undergraduate music contexts (Gouzouasis & Bakan, 2011). These cases matter less for isolated effect sizes than for their disciplinary direction: one routes CT into broad school subjects; the other legitimizes CT inside professional music education. Together they show that recent IEEE-indexed work is moving beyond CS infusion toward curricular redesign.

Diagrams and Figures

Figure 1 visualizes the reduction from 12,146 identified records to 23 analyzed studies, making visible how broad the CT literature has become and how selective rigorous synthesis must be (Tariq et al., 2025).

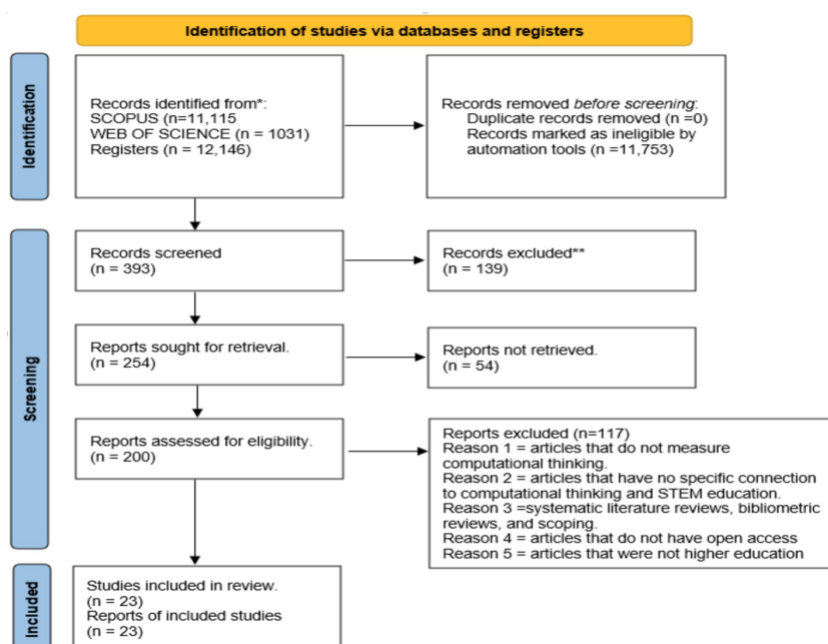


Figure 1. PRISMA screening diagram from a 2024 review of CT in STEM education

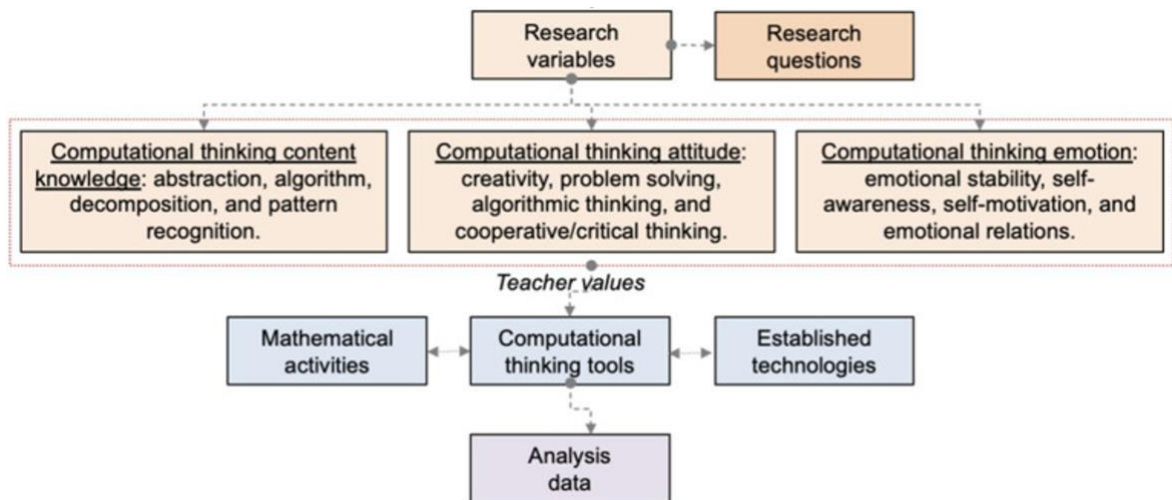


Figure 2. Conceptual framework for integrating CT into mathematics teacher preparation

The framework underscores a recurring finding in the literature: CT transfer strengthens when content knowledge, attitudes, and emotion are addressed together rather than as isolated outcomes (Jeong & González-Gómez, 2026).

1	Disciplinary Task Authenticity: (CT is embedded in biology, music, literacy, or mathematics tasks)
2	CT Practices Become Visible: In-Domain (decomposition, abstraction, pattern recognition, algorithmic logic, data use)
3	Student Acceptance Is Mediated by Prior Exposure + Teacher Scaffolding: (primary learners and those with coding experience show stronger behavioral intention)
4	Measured Outcomes Improve Only When Assessment Matches the Task (artifact-based scoring and classroom observation, not quizzes alone)
5	Sustainable Transfer Requires Equity-Oriented Professional Development and Curriculum Design: (culturally resonant tasks, subgroup reporting, sustained teacher preparation)

Diagram 1. Synthesis of cross-disciplinary CT transfer

This synthesis condenses the common logic running through K–12 integration studies, teacher-professional development research, and higher-education artifact analyses.

Discussion

The strongest empirical pattern is comparative: authentic integration outperforms symbolic integration. Students improved when CT served biology inquiry, music remixing, or literacy-linked lesson design; enthusiasm fell when interdisciplinary form felt unfamiliar or externally imposed (Yeni et al., 2024). That is why primary students with prior programming experience in the cross-case study showed greater behavioral intention, while some secondary learners responded less enthusiastically. Learner response tracks perceived coherence, not merely novelty. That coherence problem is compounded by how the field currently measures success.

Assessment practices currently lag behind curricular imagination. When a review shows 60% dependence on quizzes, 0% classroom observations, and only 6% culturally responsive pedagogy, the implication is unmistakable: the field often measures recall about CT more reliably than performance of CT inside real disciplines (Espinal et al., 2024). By contrast, artifact-based scoring, longitudinal classroom observation, and discipline-specific rubrics move closer to the phenomenon

itself. Cross-disciplinary CT will not mature through generic instruments alone. Even where assessment improves, a further caution applies to how CT outcomes are interpreted.

Methodological caution should refine the field, not weaken it. The 2021 academic-performance study showed that CT does not map mechanically onto higher grades, while review-level evidence confirms heterogeneity in effects across instructional modalities (Lemay et al., 2021). That combination yields a sharper claim: CT is most valuable when it augments disciplinary reasoning, representational fluency, and problem decomposition, not when it is sold as a universal academic booster (Zhang, J. et al., 2025). Taken together, these three patterns—the primacy of authentic tasks, the immaturity of assessment, and the limits of universal achievement claims—define the conditions under which cross-disciplinary CT is both defensible and improvable.

Future Directions

Future work should replace generic transfer claims with discipline-sensitive causal designs. Randomized or quasi-experimental studies ought to compare CT-infused and non-CT versions of the same disciplinary task, because that is the only way to test whether CT contributes beyond standard instruction. Longitudinal follow-up is equally necessary; short-term gains like the 17% improvement in elementary CT scores are promising, but persistence across grades and subjects remains under-measured (Cantlon et al., 2024).

Teacher preparation should become the field’s main infrastructure investment. Sustained professional development, not one-off workshops, appears decisive in helping teachers translate CT into literacy, mathematics, and integrated elementary curricula. Reviews also show that classroom observation is nearly absent, a gap that future designs should close through lesson artifacts, implementation logs, observation protocols, and student work samples (Nolte et al., 2024).

Equity-centered design should move from peripheral recommendation to default criterion. Large participation in culturally resonant programs such as *Your Voice is Power* suggests that CT adoption broadens when students see identity, music, community issues, and creative agency reflected in the task (Moore et al., 2022). Future research should therefore report subgroup outcomes by gender, race, language background, and prior exposure as standard practice rather than supplemental analysis.

Conclusion

The post-2020 scholarship helps reach a solid conclusion: computational thinking can be transportable across disciplines, yet it can be effectively transported only when the pedagogy is mindful of the logic of the field of destination. Biology-related coding, mathematics-inspired micro: bit work, music-based programming, literacy-related teacher professional development, and artifact-based higher-education tasks all demonstrate that CT can be learned as a domain-shaped means of organizing complexity. Simultaneously, the record reveals three nontrivial constraints of weak assessment design, teacher preparation that is uneven, and inequitable prior exposure. Cautious synthesis is thus the most responsible, not a celebratory one but conditional: CT across disciplines is real, measurable, and educationally useful but its benefits require authentic tasks, rigorous assessment, and equity-minded implementation.

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