

Baseline diagnosis of critical and computational thinking for implementing the integrative model of science, technology, and sustainability (micts) at Campo de la Cruz Educational Institution

Diagnóstico inicial del pensamiento crítico y computacional para la implementación del modelo integrador de ciencia, tecnología y sostenibilidad (MICTS) en la Institución Educativa Campo de la Cruz.

Diagnóstico inicial do pensamento crítico e computacional para a implementação do modelo integrativo de ciência, tecnologia e sustentabilidade (MICTS) na Instituição Educacional Campo de la Cruz

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Palavras-chave: pensamento crítico; pensamento computacional; depuração; métodos mistos; educação para a sustentabilidade; STEAM; diagnóstico inicial.

Abstract

This article reports a baseline diagnosis conducted at Campo de la Cruz Educational Institution before implementation of the Integrative Model of Science, Technology, and Sustainability (MICTS). Using a sequential explanatory mixed-methods design, we combined a rubric-based quantitative assessment of critical and computational thinking with qualitative classroom-embedded evidence to contextualize the baseline. In the quantitative component (N = 390; stratified random sampling across educational levels), performance was concentrated in the lower categories: performance was concentrated in the lower categories: 51.3% (n = 200) of students were classified at the Initial level and 41.0% (n = 160) at the Basic level (92.3% combined), while 6.4% (n = 25) reached Intermediate and 1.3% (n = 5) Advanced. On an ordinal 1–4 coding of the four levels, the overall mean was 1.58 (SD = 0.67), indicating a low central tendency with limited dispersion. Qualitative themes suggest that this bottom-heavy distribution is consistent with opportunity-to-learn constraints, including predominantly teacher-centered routines, limited opportunities for open-ended reasoning, novice debugging strategies in programming-adjacent activities, and sustainability framed more as a general concern than as inquiry- and design-driven practice. The baseline provides a reference point for MICTS implementation planning and for later pretest–posttest evaluation aligned with sustainability-oriented educational goals.

Resumen

Este artículo informa de un diagnóstico de referencia realizado en la Institución Educativa Campo de la Cruz antes de la implementación del Modelo Integrador de Ciencia, Tecnología y Sostenibilidad (MICTS). Utilizando un diseño secuencial explicativo de métodos mixtos, combinamos una evaluación cuantitativa basada en rúbricas del pensamiento crítico y computacional con evidencia cualitativa integrada en el aula para contextualizar la línea de base. En el componente cuantitativo (N = 390; muestreo aleatorio estratificado por niveles educativos), el desempeño se concentró en las categorías inferiores: el 51.3% (n = 200) de los estudiantes fueron clasificados en el nivel Inicial y el 41.0% (n = 160) en el nivel Básico (92.3% combinados), mientras que el 6.4% (n = 25) alcanzó el Intermedio y el 1.3% (n = 5) el Avanzado. En una codificación ordinal de 1 a 4 de los cuatro niveles, la media general fue de 1.58 (DE = 0.67), lo que indica una baja tendencia central con dispersión limitada. Los temas cualitativos sugieren que esta distribución con predominio de dificultades es coherente con las limitaciones en las oportunidades de aprendizaje, que incluyen rutinas predominantemente centradas en el profesor, oportunidades limitadas para el razonamiento abierto, estrategias de depuración para principiantes en actividades relacionadas con la programación y una concepción de la sostenibilidad más como una preocupación general que como una práctica basada en la indagación y el diseño. La línea base proporciona un punto de referencia para la planificación de la implementación de MICTS y para una posterior evaluación pretest-posttest alineada con los objetivos educativos orientados a la sostenibilidad.

Resumo

Este artigo apresenta um diagnóstico inicial realizado na Instituição Educacional Campo de la Cruz antes da implementação do Modelo Integrativo de Ciência, Tecnologia e Sustentabilidade (MICTS). Utilizando uma abordagem sequencial explicativa de métodos mistos, combinamos uma avaliação quantitativa baseada em rubricas do pensamento crítico e computacional com evidências qualitativas inseridas na sala de aula para contextualizar o diagnóstico inicial. No componente quantitativo (N = 390; amostragem aleatória estratificada por níveis de ensino), o desempenho concentrou-se nas categorias mais baixas: 51,3% (n = 200) dos alunos foram classificados no nível Inicial e 41,0% (n = 160) no nível Básico (92,3% no total), enquanto 6,4% (n = 25) atingiram o nível Intermediário e 1,3% (n = 5) o Avançado. Em uma codificação ordinal de 1 a 4 dos quatro níveis, a média geral foi de 1,58 (DP = 0,67), indicando uma baixa tendência central com dispersão limitada. Os temas qualitativos sugerem que essa distribuição com maior concentração de alunos na parte inferior da escala é consistente com as limitações de oportunidade de aprendizado, incluindo rotinas predominantemente centradas no professor, oportunidades limitadas para raciocínio aberto, estratégias de depuração para iniciantes em atividades relacionadas à programação e sustentabilidade abordada mais como uma preocupação geral do que como uma prática orientada por investigação e design. A linha de base fornece um ponto de referência para o planejamento da implementação do MICTS e para avaliações posteriores de pré e pós-teste alinhadas com objetivos educacionais voltados para a sustentabilidade.

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Introduction

Across educational systems, critical thinking, computational thinking, and sustainability-oriented competencies have become prominent goals for twenty-first-century schooling. Translating these ambitions into routine classroom practice, however, often proves difficult, especially where technology access is uneven, and teachers have limited preparation, time, and assessment support for sustained integration (Dos Santos, 2025; Liu, 2022; Mills et al., 2024; Ogegbo & Ramnarain, 2022). In such contexts, baseline diagnosis is not a formality: it is a practical prerequisite for planning instruction, targeting support, and evaluating whether an integrative model produces meaningful change over time.

Critical thinking is commonly described as a set of practices for interpreting information, evaluating evidence, constructing and critiquing arguments, and monitoring one's own reasoning. Empirical work in inquiry- and problem-based STEM instruction suggests that when classroom designs make reasoning visible, through explanation, justification, and reflective discussion, students' critical thinking dispositions and problem-solving outcomes can improve (Hebecci & Usta, 2022; Topsakal et al., 2022). These findings imply that critical thinking development depends on repeated opportunities to practice reasoning routines, not only on curricular statements.

Computational thinking has developed in parallel as a way to describe problem-solving practices such as decomposition, abstraction, algorithmic design, and debugging, and recent work has argued for broader, curriculum-relevant conceptualizations of the construct (Palop et al., 2025). Even short, authentic interdisciplinary STEM experiences can elicit elements of computational thinking when tasks are structured and meaningful to learners (Cantlon et al., 2024). Among its sub-skills, debugging is particularly important because it requires discrepancy noticing, causal reasoning, and metacognitive monitoring, moves that overlap with high-quality evidence evaluation and argumentation. Research on debugging instruction indicates that learners often begin with trial-and-error strategies but can shift toward more analytic approaches when debugging is explicitly framed as hypothesis generation, tracing, and systematic testing (DeLiema et al., 2024; Gao & Hew, 2023; Panorkou et al., 2023). Studies in robotics and block-based contexts similarly show that debugging behaviors respond to the structure of learning activities (Socratous & Ioannou, 2021; Sung et al., 2022).

Sustainability education adds a requirement: sustainability competencies are unlikely to develop deeply when environmental topics are treated only as generic awareness themes rather than as contexts for inquiry, evidence use, and design. Scoping work on sustainability competencies in secondary education underscores the importance of integrated learning designs that connect environmental themes to systems thinking and actionable problem solving (Sposab & Rieckmann, 2024). This emphasis aligns with applied studies combining inquiry-based learning with education for sustainable development to strengthen both critical thinking and sustainable awareness (Setiyaningsih et al., 2024) and with mapping work that explicitly links thinking skills to ESD targets (Misbah et al., 2024). From this perspective, sustainability can function as a context for making thinking visible: students can investigate local problems, justify decisions with evidence, test solutions, and reflect on trade-offs.

Taken together, these strands suggest that critical thinking, computational thinking, and sustainability are not independent "add-ons." They can be mutually reinforcing when learning designs connect reasoning, design, and reflection, particularly through routines such as explanation, justification, and systematic debugging.

Implementation research nevertheless highlights persistent obstacles, limited resources, time constraints, and uncertainty about assessment and classroom management of open-ended tasks, that can prevent these competencies from becoming routine school practices (Dos Santos, 2025; Liu, 2022; Ogegbo & Ramnarain, 2022). This makes feasible entry points especially important. Unplugged computational thinking approaches have therefore attracted attention as low-resource strategies for developing algorithmic reasoning without continuous device access, particularly when teachers make underlying concepts explicit and connect them to later digital work (Brackmann et al., 2017; Dagiené et al., 2024; Kite & Park, 2023; Malveira de Oliveira et al., 2025; Vázquez Uscanga et al., 2024; Yilmaz & Izmirlı, 2023).

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The present study is situated within this landscape. Campo de la Cruz Educational Institution is a public school serving students across primary, lower-secondary, and upper-secondary levels and includes communities where implementation constraints, such as uneven access to technology, can shape what is feasible to do routinely (Liu, 2022; Ogegbo & Ramnarain, 2022). In response, the institution identified adoption of the Integrative Model of Science, Technology, and Sustainability (MICTS) as a strategic priority for strengthening cognitive, technological, and environmental

dimensions of student learning. The MICTS model frames learning as an integrated endeavor that weaves scientific inquiry, educational technologies, and school practices oriented toward environmental care so that students can connect what they learn to local, territorial, and community contexts.

This article reports a baseline diagnostic study conducted before the implementation of the Integrative Model of Science, Technology, and Sustainability (MICTS) in a public educational institution characterized by uneven access to technological resources. Beyond its local relevance, this study contributes to the broader discourse on STEM integration in low-resource settings by providing empirical evidence on students' initial competencies in critical and computational thinking under real-world constraints.

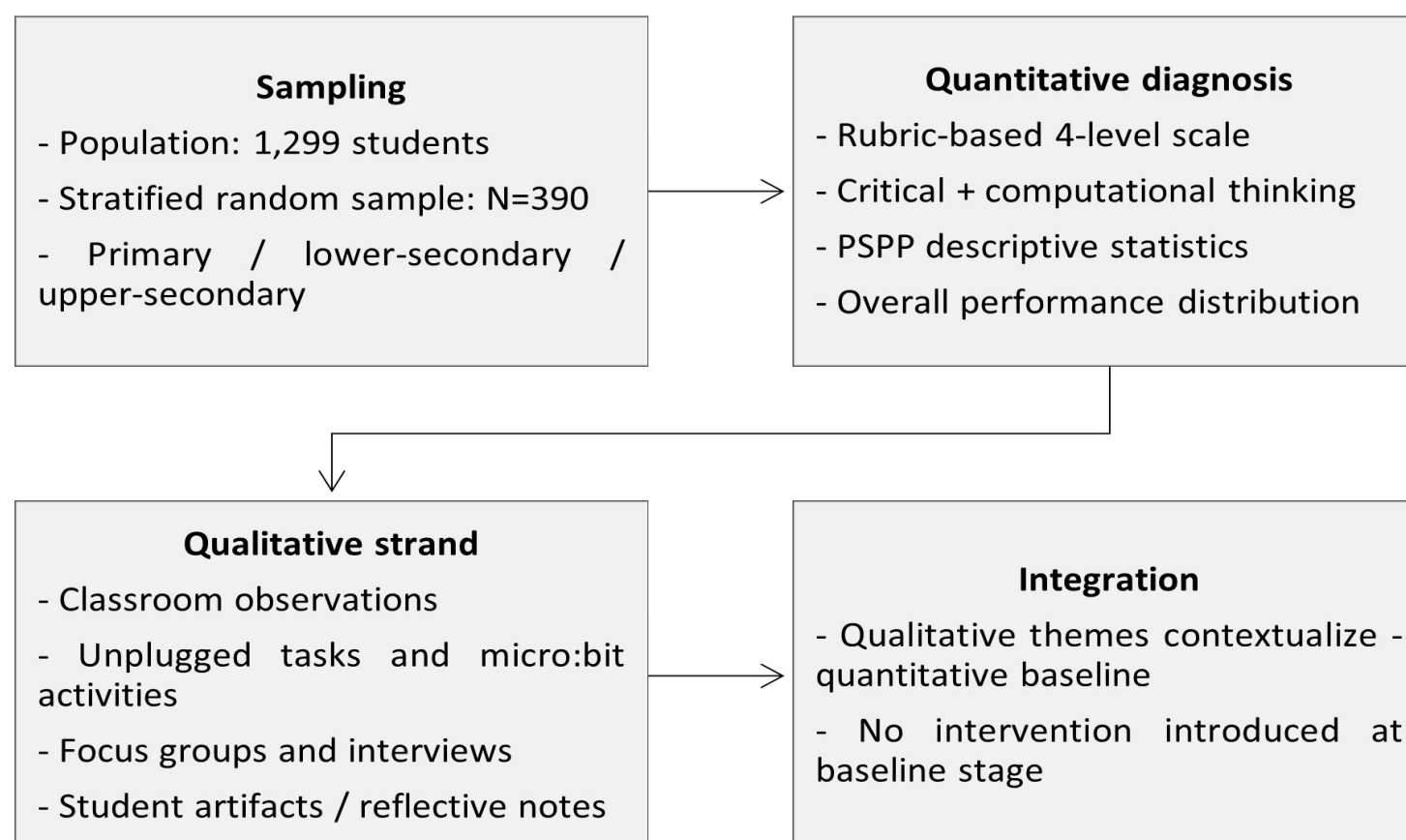
In particular, the study addresses a persistent gap in the literature: while many STEM and educational technology initiatives assume access to digital infrastructure, fewer studies document baseline conditions in contexts where such access is limited or inconsistent. By combining a rubric-based quantitative assessment with qualitative classroom evidence, this research offers a context-sensitive diagnostic framework that can inform the design of scalable and resource-aware STEM and sustainability-oriented interventions. Thus, the contribution of this study lies not only in documenting a local baseline but also in advancing understanding of how integrated STEM and sustainability education can be grounded in realistic institutional conditions, particularly in underserved or resource-constrained environments.

Methods

Design

This study used a sequential explanatory mixed-methods design as a baseline diagnosis before implementing the Integrative Model of Science, Technology, and Sustainability (MICTS). A rubric-based quantitative assessment established students' baseline performance, and qualitative evidence was collected to contextualize the pattern by documenting classroom routines, problem-solving behaviors, and relevant contextual constraints. No experimental or quasi-experimental manipulation was introduced at this stage.

The baseline diagnosis targeted two macro-dimensions aligned with MICTS: critical thinking and computational thinking. These constructs were operationalized through four rubric dimensions used for tasks and scoring: (1) Interpretation and Analysis, (2) Evaluation of Evidence, (3) Algorithms and Sequences, and (4) Debugging of Problems. The purpose of the baseline was descriptive, establishing where students were situated before any structured intervention, rather than causal attribution or program evaluation. The study design is summarized in [Figure 1](#).



[Figure 1](#). Study design (baseline, pre-intervention).

The study was conducted at Campo de la Cruz Educational Institution, a public school serving students across primary, lower-secondary, and upper-secondary levels. The target population comprised all 1,299 enrolled students. A stratified random sampling procedure by educational level was applied to preserve proportional representation while maintaining feasibility, resulting in a sample of 390 students (approximately 30% of the population). No additional exclusion criteria were applied beyond enrollment status at the time of data collection.

The baseline workflow followed the sequential logic of the mixed-methods design. The institutional diagnostic assessment was administered and scored using an analytic rubric. Results were compiled in a format compatible with GNU PSPP (an open-source statistical analysis software similar to SPSS) using aggregated frequency counts by rubric level (rather than student-level records) to ensure efficient reporting and confidentiality. A qualitative follow-up was conducted to interpret how performance levels manifested in classroom practice and to document contextual factors before MICTS implementation.

The quantitative instrument consisted of an institutional diagnostic assessment scored with an analytic rubric based on a four-level ordinal scale (Initial, Basic, Intermediate, Advanced). The rubric was aligned with the two macro-dimensions of the study, critical thinking and computational thinking, and operationalized through four dimensions: (i) Interpretation and Analysis, (ii) Evaluation of Evidence (critical thinking), (iii) Algorithms and Sequences, and (iv) Debugging of Problems (computational thinking). These dimensions were designed to capture key cognitive processes, including comprehension, analysis, evidence-based argumentation, inference, decomposition, abstraction, algorithmic reasoning, and error identification and correction.

To strengthen methodological rigor, the rubric underwent a structured validation process before implementation. Content validity was established through expert judgment by a panel of experienced teachers and school leaders in STEM education, who evaluated each criterion for relevance, clarity, and alignment with the targeted constructs. A Content Validity Index (CVI) was calculated based on expert ratings, yielding values above 0.80 for all dimensions, indicating adequate agreement and content representativeness.

Inter-rater reliability was addressed through evaluator calibration procedures. Before scoring, raters participated in structured calibration sessions in which sample student responses were jointly analyzed to ensure consistent interpretation of rubric levels. Subsequently, a subset of assessments was independently scored by multiple evaluators, and agreement was estimated using Cohen's Kappa coefficient, indicating substantial inter-rater reliability. For reporting purposes, quantitative results are presented as an overall performance distribution across the four-level scale. Although this representation is intentionally compact, the underlying rubric structure reflects a more detailed operationalization of the constructs assessed.

Quantitative Analysis

Descriptive statistics were generated using GNU PSPP, including frequency tables and percentages by performance level. To ensure confidentiality and reporting efficiency, analyses were conducted using aggregated frequency counts with case weighting, rather than individually identifiable records.

For a concise summary of baseline performance, rubric levels were coded as an ordinal 1–4 scale (Initial = 1, Basic = 2, Intermediate = 3, Advanced = 4), allowing the calculation of mean and standard deviation as descriptive indicators of the ordered distribution.

Due to institutional data management procedures, only aggregated quantitative data were preserved. Consequently, disaggregated frequency tables at the dimension level (e.g., critical thinking versus computational thinking) were not retained, which limits the ability to perform domain-specific quantitative comparisons.

Quantitative Strand and Integration

The qualitative strand was designed to clarify how students approached tasks and how instructional routines shaped opportunities to practice critical and computational thinking. Evidence was collected through:

Classroom observations guided by a structured matrix, focusing on interaction patterns, visible reasoning strategies, problem-solving behaviors, and the pedagogical use of technology.

Unplugged performance tasks, including paper-and-pencil algorithm activities, logical mazes, pattern-completion tasks, and decomposition exercises. These tasks allowed the observation of computational thinking behaviors without requiring digital devices.

Programming-adjacent microcontroller activities (micro:bit), in which students addressed simple environmental and technological problems using sensors, conditional logic, data reading/representation, and iterative debugging.

Six student focus groups across grade levels were used to elicit perceptions of learning, perceived difficulties, attitudes toward technology, and sustainability-related behaviors in daily life.

Semi-structured interviews with teachers and students to document prevailing teaching practices in science and technology, institutional constraints, and perceived barriers to developing the target competencies.

Brief reflective diaries in which students described their reasoning process during computational and environmental activities.

Artifact review when available (e.g., notebooks, written algorithms, solution sketches, and micro: bit products).

Sustainable consciousness was examined qualitatively (rather than as a separate quantitative rubric score) to document how students connected environmental concerns to scientific concepts, evidence use, and technological practices at baseline.

Materials were organized in a structured matrix and analyzed thematically using a combination of deductive codes aligned with the focal constructs (critical thinking, computational thinking, and sustainable consciousness) and inductive codes capturing context-specific patterns. The coding process was conducted manually to maintain flexibility in handling diverse qualitative data sources (observations, interviews, focus groups, and student artifacts).

Two researchers participated in the coding process. An initial coding framework was developed based on the theoretical constructs and applied independently to a subset of the data. The researchers then compared coding outputs, discussed discrepancies, and refined the coding scheme iteratively. Inter-coder agreement was assessed through consensus procedures, and disagreements were resolved through discussion until agreement was reached.

This iterative coding process enhanced the credibility and consistency of the qualitative analysis. Integration occurred at the interpretation stage, where qualitative themes were used to contextualize the quantitative baseline distribution and to clarify how performance categories manifested in practice. Methodological triangulation across quantitative summaries, classroom observations, and participant narratives further strengthened interpretive validity. Although formal statistical measures of inter-coder reliability were not calculated, the use of iterative consensus and triangulation across data sources contributed to the robustness of the qualitative findings.

Ethics and Confidentiality

The diagnostic formed part of the institution's pedagogical processes and involved no experimental manipulation. Quantitative reporting relied on aggregated counts by performance category and avoided personally identifying information. Qualitative materials were handled using non-identifying codes. Teachers and students were informed that the purpose of the diagnosis was to support educational improvement and to prepare for implementation of the MICTS model, and participation in interviews or focus groups was voluntary within school activities.

Results

Quantitative Baseline (Overall Performance)

The baseline diagnostic shows a negatively skewed distribution of performance levels. Of the 390 students assessed, 200 (51.3%) were classified at the Initial level and 160 (41.0%) at the Basic level, meaning 92.3% of the sample clustered in the two lowest categories. Only 25 students (6.4%) reached the Intermediate level, and 5 (1.3%) were rated as Advanced. [Figure 2](#) reports the distribution and corresponding percentages.

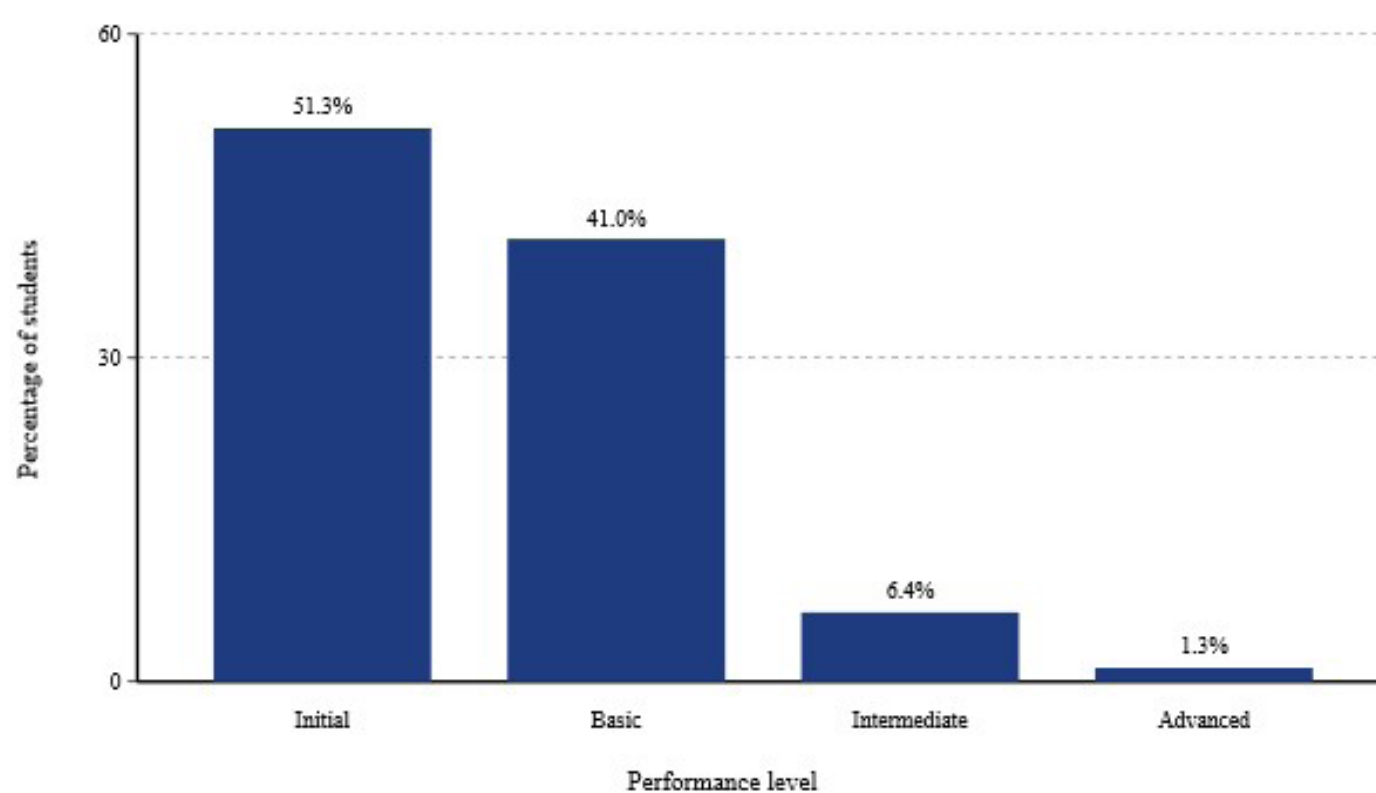


Figure 2. Overall distribution of performance levels (percent of students). n = 390.

Considering that the sampling strategy was stratified by educational level, a complementary examination of performance trends across levels was conducted based on available institutional records and qualitative triangulation.

Although disaggregated quantitative frequency tables were not preserved for formal statistical reporting, consistent patterns emerged.

In general, students in upper-secondary education tended to show relatively higher proportions of Intermediate performance and greater engagement with tasks requiring explanation, argumentation, and structured problem solving. In contrast, primary and lower-secondary students were more frequently concentrated in the Initial and Basic levels, particularly in tasks involving evidence evaluation and independent algorithmic reasoning. These trends are consistent with expected developmental progression in both critical and computational thinking skills. However, it is important to note that, across all educational levels, the majority of students remained within the two lowest performance categories, reinforcing the overall interpretation of a system-wide baseline requiring instructional strengthening.

Additionally, although the sampling was stratified by educational level, the absence of preserved disaggregated quantitative data limits the ability to conduct formal statistical comparisons across levels. The observed differences are therefore interpreted as indicative trends supported by qualitative evidence rather than as statistically validated contrasts.

Using an ordinal 1–4 coding of the four performance levels (Initial=1, Basic=2, Intermediate=3, Advanced=4), the overall baseline mean was 1.58 with a standard deviation of 0.67, indicating limited dispersion around a low central tendency. [Table 1](#) summarizes these descriptive statistics.

Table 1. Summary statistics for the overall performance index (1–4 ordinal coding).

Indicator	Value
Sample size (N)	390
Mean (1–4 performance scale)	1.58
Standard deviation	0.67
Minimum	Initial
Maximum	Advanced

In substantive terms, the distribution indicates that, before implementation of MICTS, most students predominantly demonstrated Initial or Basic performance on tasks requiring interpretation, evidence evaluation, algorithmic planning, and debugging. In the original institutional analysis, bar charts were produced in PSPP from the same frequency tables; because only aggregated counts were preserved for this manuscript, [Figure 2](#) reproduces the overall pattern.

Domain-Level Interpretation (Critical Thinking and Computational Thinking)

The overall baseline aggregates performance across the rubric dimensions representing critical thinking (Interpretation and Analysis; Evaluation of Evidence) and computational thinking (Algorithms and Sequences; Debugging of Problems). Although disaggregated quantitative frequency tables by rubric dimension were not retained as standalone datasets, domain-level interpretation was supported through qualitative triangulation. Classroom observations, task-based evidence, and participant narratives provided consistent patterns that allowed differentiation between critical thinking and computational thinking behaviors in practice.

This integrative approach enabled a construct-level interpretation of baseline performance, where qualitative evidence was used to identify how students engaged with interpretation, evidence evaluation, algorithmic reasoning, and debugging processes. While not equivalent to disaggregated statistical analysis, this triangulation strengthens interpretive validity by linking observed classroom practices to the aggregated quantitative distribution.

It is important to note that these domain-level interpretations are derived from qualitative triangulation rather than disaggregated quantitative comparisons. While consistent patterns were observed across data sources, the absence of dimension-specific quantitative summaries prevents confirming whether one domain systematically underperformed relative to the other. This reinforces the need for future analyses that retain domain-level metrics to support more differentiated instructional planning.

Critical Thinking (Interpretation and Analysis; Evaluation of Evidence)

For critical thinking, baseline observation and interview materials commonly reflected difficulty moving from recognition or recall toward explanation and justification. Students often produced short answers with limited supporting reasons, and classroom talk tended to emphasize procedural completion rather than argumentation. When tasks invited interpretation, students more often restated information than compared alternatives or identified relationships; when

tasks invited evaluation of evidence, students were less likely to explain why a specific piece of information supported a claim. This pattern is consistent with evidence that instructional routines and teacher preparedness can constrain students' opportunities to practice higher-order reasoning in everyday lessons (Ogegbo & Ramnarain, 2022).

Computational Thinking (Algorithms and Sequences; Debugging of Problems)

For computational thinking, unplugged and microcontroller-based activities suggested that many students could follow a demonstrated sequence but struggled to independently decompose tasks, anticipate errors, or articulate why a change should work. In unplugged tasks (e.g., paper-and-pencil algorithms, mazes, pattern tasks, and decomposition exercises), students often completed steps when the procedure was explicit but had difficulty generalizing a strategy or representing their own algorithm clearly. In micro:bit activities, students could engage with sensors and conditional logic at a basic level, but debugging behaviors frequently relied on repeated trial-and-error modifications rather than systematic tracing, testing, and revision.

These baseline behaviors align with research describing how novice debugging often begins with unsystematic strategies before instruction supports more causal, reflective approaches (Gao & Hew, 2023; DeLiema et al., 2024) and with evidence that unplugged tasks can surface computational thinking processes when teachers make underlying algorithms explicit (Brackmann et al., 2017; Vázquez Uscanga et al., 2024).

Sustainable Consciousness (Qualitative Baseline)

Sustainable consciousness was not assessed as a separate quantitative score in the initial diagnostic table; instead, baseline evidence was drawn from observations, focus groups, and interviews. Across these sources, sustainability was frequently framed as a general concern (e.g., "caring for the planet") with weak connections to scientific concepts, evidence, or specific technological practices. This matters for MICTS implementation because sustainability competencies tend to develop more consistently when environmental topics are integrated with inquiry, evidence use, and design decisions rather than addressed as isolated awareness messages (Sposab & Rieckmann, 2024).

Qualitative Themes (Contextualizing the Baseline)

Across instruments, baseline qualitative evidence converged on a small number of recurrent themes that help interpret the overall quantitative pattern, most notably teacher-centered routines, limited opportunities for student explanation, and novice debugging behaviors in programming-adjacent tasks. These themes provide a practical interpretation of what low baseline performance looked like in daily classroom activity and student work products. Table 2 summarizes the qualitative themes used to contextualize the baseline.

Table 2. Qualitative themes observed at baseline and their interpretive relevance.

Theme	What was observed at baseline	How it help interpret the baseline
Predominance of teachercentered routines	Classroom activity often emphasized recall and procedural reproduction, with limited time for student explanation or argumentation.	Limits opportunities to practice the reasoning processes targeted by critical thinking and to externalize strategies needed for computational thinking.
Novice debugging strategies	In programmingadjacent tasks, students frequently attempted changes by trial and error rather than articulating hypotheses and testing systematically.	Helps explain low performance where tasks require planning, monitoring, and error diagnosis rather than only executing known procedures.
Uneven integration of technology	Technologymediated inquiry and iterative design work appeared sporadic rather than routine across lessons.	Constrains repeated practice of algorithmic reasoning and structured problem solving under authentic conditions.
Sustainability is framed as a generic concern	Environmental issues were often described in broad terms (e.g., "care for the planet") with weak links to specific scientific concepts or technological tools.	Suggests a need for integrated tasks that connect sustainability topics to evidence use, modeling, and design decisions.

Discussion

The baseline diagnostic indicates that most students are performing at the lower end of the four-level rubric scale (Table 1). Rather than treating this as an individual “deficit,” we interpret the pattern as an institutional and instructional signal: a strongly bottom-heavy distribution is consistent with learning environments where students have had limited routine exposure to tasks that require sustained explanation, evidence evaluation, algorithmic planning, and reflective error analysis.

Interpreting the Baseline considering Prior Work

International literature on STEAM and computational thinking repeatedly highlights that ambitious competency goals often outpace schools’ capacity to enact them, especially when teachers have limited preparation, time, or instructional materials for routine integration (Dos Santos et al., 2025; Ogegbo & Ramnarain, 2022). The Campo de la Cruz baseline is compatible with this broader pattern: without frequent opportunities to practice reasoning-visible routines in class, students are less likely to demonstrate higher performance levels when evaluated with rubrics that target those competencies.

The qualitative themes summarized in Table 2 further support this interpretation. Teacher-centered classroom routines, sporadic technology-mediated inquiry, and limited open-ended reasoning opportunities can plausibly suppress both critical thinking (through reduced argumentation and evidence use) and computational thinking (through reduced opportunities to design, test, and revise procedures). This is consistent with studies reporting that instructional design features, such as inquiry-based or problem-based STEM structures, are associated with improvements in critical thinking dispositions and problem-solving outcomes (Topsakal et al., 2022; Hebebcı & Usta, 2022) and that even short interdisciplinary STEM experiences can elicit computational thinking when tasks are authentic and structured (Cantlon et al., 2024).

More broadly, reviews emphasize that computational thinking outcomes are sensitive to curriculum integration choices and to the extent to which instruction foregrounds reasoning rather than tool operation (Mills et al., 2024; Palop et al., 2025). This reinforces reading the baseline as a signal about routine learning opportunities, not only as an indicator of individual capability.

Debugging and Metacognition as a Bridge Construct

A particularly actionable interpretation concerns debugging. Debugging is not only a programming skill; it is a structured form of discrepancy noticing, causal reasoning, and metacognitive monitoring. Research on systematic debugging emphasizes that learners often begin with trial-and-error strategies, but can shift toward more analytic approaches when instruction explicitly frames debugging as hypothesis generation, tracing, and testing (Gao & Hew, 2023; DeLiema et al., 2024). For an integrative model such as MICTS, this distinction is critical because the same cognitive processes underpin both computational debugging and evidence-based reasoning in critical thinking tasks. In practical terms, classroom routines that normalize “explaining the bug,” predicting outcomes, and justifying fixes may strengthen both computational and critical thinking through shared mechanisms.

Evidence from block-based programming and educational robotics contexts similarly suggests that the structure of learning activities influences debugging strategy use and learning outcomes (Socratous & Ioannou, 2021; Sung et al., 2022). Debugging has also been positioned as a productive platform for transdisciplinary learning because it makes reasoning, representation, and revision explicit (Panorkou et al., 2023).

Feasible Entry Points Under Resource Constraints

The baseline also highlights the need for interventions that are feasible under uneven technology access. Evidence from unplugged computational thinking approaches suggests that algorithmic reasoning and related skills can be developed through carefully structured non-digital activities, especially when teachers make the underlying concepts explicit and connect them to later work with digital tools (Brackmann et al., 2017). This aligns with the MICTS orientation: unplugged tasks can provide a low-cost entry point for building shared language about procedures, decomposition, and debugging before more complex microcontroller-based projects are introduced.

Recent work on unplugged integration in secondary science and across curricula further emphasizes the importance of aligning unplugged tasks with subject goals and making process-based reasoning visible to students (Kite & Park, 2023; Vázquez Uscanga et al., 2024). From a system perspective, multi-country accounts of computational thinking adoption in compulsory education similarly indicate that implementation pathways vary and that teacher support and curriculum alignment are recurring bottlenecks (Dagiené et al., 2024).

Building on these findings, several actionable guidelines can be derived for institutions operating under similar resource constraints. Integrating structured reasoning routines into everyday classroom practice, such as requiring

students to justify answers, explain procedures, and reflect on errors, can strengthen both critical and computational thinking without requiring additional technological resources. These routines can be embedded into existing curricula and adapted across subjects.

Unplugged computational thinking activities represent a practical and scalable entry point. Activities such as algorithm design using paper-based tasks, logical sequencing exercises, and guided debugging scenarios can support the development of core computational practices while reducing dependency on continuous device access.

Gradual integration of low-cost technological tools (e.g., microcontrollers such as micro: bit or similar platforms) can facilitate transition toward more complex STEM activities. When combined with explicit instruction in debugging and iterative design, these tools can enhance students' engagement with problem-solving processes.

Sustainability contexts can be used as an organizing framework for learning. Framing tasks around local environmental challenges allows students to connect abstract concepts to real-world problems, promoting inquiry, evidence use, and decision-making. This approach supports the integration of STEM and Education for Sustainable Development (ESD) in a way that is both contextually relevant and pedagogically meaningful.

Teacher professional development emerges as a critical enabling factor. Supporting teachers in designing and facilitating reasoning-centered and inquiry-based activities, particularly in low-resource environments, can significantly influence the effectiveness of implementation efforts. Together, these entry points provide a flexible and context-sensitive pathway for institutions seeking to implement integrated STEM and sustainability models under real-world constraints, thereby enhancing the transferability and practical relevance of the present findings.

Sustainability: From Awareness to Competency

The qualitative baseline suggests that sustainability may be present as a general value but not yet as an inquiry- and design-driven competency in everyday learning experiences. This aligns with broader sustainability education work emphasizing that sustainability competencies develop more consistently when learning designs integrate environmental themes with inquiry, evidence use, and systems thinking rather than relying primarily on awareness-raising activities (Sposab & Rieckmann, 2024). In the MICTS framework, sustainability therefore becomes a productive context for making thinking visible: students can be asked not only to “care for the environment,” but to model local problems, justify decisions with evidence, test solutions, and reflect on trade-offs.

In applied contexts, inquiry-based learning combined with ESD has been used to target both critical thinking and sustainable awareness (Setiyaningsih et al., 2024), while broader mapping and synthesis work highlights how thinking skills can be explicitly connected to ESD targets (Misbah et al., 2024). In parallel, bibliometric evidence suggests rising attention to computational thinking in children's education for a sustainable future, reinforcing the relevance of integrating cognitive and sustainability goals (Wong Mee Mee et al., 2025).

Methodological and Practical Implications

Methodologically, the mixed-methods structure strengthens the baseline by pairing a clear quantitative distribution with a qualitative context (Table 2). At the same time, this report is intentionally conservative in its quantitative scope: because only the overall distribution is presented here, the discussion emphasizes system-level implications rather than fine-grained comparisons across rubric domains. Practically, the baseline still supports decision-making: a distribution with most students clustered in Initial/Basic levels points to school-wide instructional routines, rather than isolated remediation, as a central lever for change.

Limitations and Future Directions

This study presents a single-institution baseline, and its quantitative reporting is intentionally aggregated. While this approach supports data confidentiality and reporting efficiency, it constrains the analytical granularity of the findings. In particular, the absence of disaggregated results at the macro-dimension level (i.e., critical thinking versus computational thinking) prevents the identification of domain-specific performance differences and limits the ability to determine whether students exhibit differential competencies across these constructs.

Although qualitative evidence provides consistent indications of distinct patterns, such as greater difficulty in evidence-based reasoning and reliance on trial-and-error strategies in debugging, these interpretations cannot be statistically validated within the current dataset. Accordingly, future research phases should prioritize the preservation of disaggregated quantitative data to enable domain-level analyses, more precise identification of competency gaps, and longitudinal pretest–posttest comparisons aligned with the MICTS implementation timeline.

From a measurement perspective, although initial validation procedures were conducted (including content validity through expert judgment and inter-rater agreement via calibration), further psychometric strengthening of the rubric is

warranted. Future studies should incorporate larger-scale reliability testing and dimensional analyses to enhance the robustness of the instrument.

In addition, qualitative data derived from focus groups may be subject to social desirability bias, as participants could have adjusted their responses to align with perceived expectations of teachers or researchers. This potential bias should be considered when interpreting self-reported perceptions and attitudes.

Despite these limitations, the study provides a context-sensitive baseline that informs actionable pathways for intervention. The literature suggests several feasible directions for future implementation, including strengthening teacher preparedness for integrating computational thinking (Ogegbo & Ramnarain, 2022), framing debugging as an explicit reasoning routine (Gao & Hew, 2023; DeLiema et al., 2024), and leveraging unplugged activities as equitable entry points to technology-enhanced inquiry (Brackmann et al., 2017). Complementary approaches such as design-based learning (Wang et al., 2022) and targeted STEAM professional development (Mehddi et al., 2025) further support the scalability of these strategies. When embedded within sustainability-oriented projects, these approaches offer a coherent and pedagogically viable pathway for advancing integrated STEM competencies in resource-constrained contexts.

Conclusion

This article reported a baseline diagnosis conducted at Campo de la Cruz Educational Institution before implementation of the Integrative Model of Science, Technology, and Sustainability (MICTS). The purpose of the baseline was not to evaluate an intervention, but to make the school's starting point visible in a way that can guide instructional planning and support later pretest–posttest evaluation.

Quantitatively, the baseline distribution is strongly concentrated in the lower performance categories (Table 1; Figure 2). Across the four-level scale, 92.3% of students were classified at Initial or Basic levels, and only a small minority reached Intermediate or Advanced. When the ordered levels are summarized as an ordinal 1–4 index, the mean of 1.58 with a standard deviation of 0.67 (Table 2) indicates a low central tendency with limited dispersion. Taken together, these results suggest that the competencies targeted by the diagnostic are not yet established as routine, school-wide practices for most learners.

The qualitative themes summarized in Table 2 help interpret why a bottom-heavy distribution is plausible in this context. Baseline observations and participant accounts indicate (i) predominantly teacher-centered routines with limited space for explanation and argumentation, (ii) novice approaches to debugging and error analysis in programming-adjacent activities, (iii) sporadic technology-mediated inquiry rather than repeated cycles of design–test–revise, and (iv) sustainability themes present as general concerns but weakly connected to evidence-based inquiry and technological problem solving. In this sense, the baseline is best interpreted as a school-wide opportunity-to-learn pattern rather than as a narrow issue confined to a small subgroup of students.

For MICTS implementation, the baseline points to a coherent set of instructional priorities that can guide future action. Strengthening teacher professional learning emerges as a central element, particularly in promoting classroom routines that make student thinking visible through explanation, justification, and reflection on errors. Within this framework, debugging can be reframed as a cross-cutting reasoning practice that supports both computational and critical thinking by encouraging hypothesis-driven analysis and systematic problem solving. In parallel, unplugged activities offer an equitable entry point for developing algorithmic reasoning in contexts with limited technological access, especially when explicitly connected to underlying concepts and progressively linked to digital tools. Finally, sustainability can be operationalized not only as a thematic focus but as a context for inquiry and design, where students engage with local problems, use evidence to justify decisions, and reflect on trade-offs. Together, these priorities provide an integrated and context-sensitive pathway for advancing the objectives of the MICTS model.

This baseline report also has clear limitations. It describes a single institution and presents quantitative findings in an intentionally aggregated form. Future phases of the project should preserve more fine-grained quantitative outputs where available, document rubric scoring procedures (including consistency across scorers), and implement follow-up measurement after MICTS implementation to enable interpretable pretest–posttest comparisons. Strengthening the assessment strategy for sustainable consciousness, while preserving contextual relevance, would also improve the ability to track change over time in that domain.

In sum, the baseline diagnosis provides both a “mirror” and a reference point: it documents a distribution in which most students are clustered in the lower performance levels and offers an instructional interpretation grounded in observed classroom conditions. As Campo de la Cruz implements MICTS, this baseline can support targeted planning and provide the empirical starting point needed for later evaluation of change aligned with sustainability-oriented educational goals.

References

- Brackmann, C. P., Román-González, M., Robles, G., Moreno-León, J., Casali, A., & Barone, D. A. C. (2017). Development of computational thinking skills through unplugged activities in primary school. In *Proceedings of the Workshop in Primary and Secondary Computing Education* (pp. 65–72). <https://doi.org/10.1145/3137065.3137069>
- Cantlon, J. F., Becker, K. T., & DeLong, C. M. (2024). Computational thinking during a short, authentic, interdisciplinary STEM experience for elementary students. *Journal for STEM Education Research*. <https://doi.org/10.1007/s41979-024-00117-0>
- Dagienė, V., Kamyli, P., Giannoutsou, N., Engelhardt, K., Malagoli, C., & Bocconi, S. (2024). Fostering computational thinking in compulsory education in Europe: A multiple case study. *Baltic Journal of Modern Computing*, 12(2). <https://doi.org/10.22364/bjmc.2024.12.2.05>
- DeLiema, D., Bye, J. K., & Marupudi, V. (2024). Debugging pathways: Open-ended discrepancy noticing, causal reasoning, and intervening. *ACM Transactions on Computing Education*. <https://doi.org/10.1145/3650115>
- Dos Santos, D. S. J. M., Silveira, A. P. R., Breda, A., & Lavicza, Z. (2025). Challenges in science, technology, engineering, arts, and mathematics education in Cape Verde: A study of a mathematics teacher training project. *Education Sciences*, 15(1), 81. <https://doi.org/10.3390/educsci15010081>
- Gao, X., & Hew, K. F. (2023). A flipped systematic debugging approach to enhance elementary students' program debugging performance and optimize cognitive load. *Journal of Educational Computing Research*. <https://doi.org/10.1177/07356331221133560>
- Hebeci, M. T., & Usta, E. (2022). The effects of integrated STEM education practices on problem solving skills, scientific creativity, and critical thinking dispositions. *Participatory Educational Research*, 9(6), 358–379. <https://doi.org/10.17275/per.22.143.9.6>
- Kite, V., & Park, S.-Y. (2023). Context matters: Secondary science teachers' integration of process-based, unplugged computational thinking into science curriculum. *Journal of Research in Science Teaching*. <https://doi.org/10.1002/tea.21883>
- Liu, J. (2022). Research on challenges and solutions in elementary schools' STEAM education promotion in rural China. *BCP Social Sciences & Humanities*, 19, 401–407. <https://doi.org/10.54691/bcpssh.v19i.1637>
- Malveira de Oliveira, A., Vaz-Rebello, P., & Bidarra, G. (2025). Unplugged activities in the development of computational thinking with Poly-Universe. *Multimodal Technologies and Interaction*, 9(9), 95. <https://doi.org/10.3390/mti9090095>
- Mehddi, F., Kazi, A. S., & Butt, A. I. (2025). From theory to practice: How STEAM professional development shapes teacher beliefs and perceptions about design thinking activities. *SAGE Open*, 15(3). <https://doi.org/10.1177/21582440251355779>
- Mills, K. A., Cope, J., Lamoureux Scholes, L., & Rowe, L. (2024). Coding and computational thinking across the curriculum: A review of educational outcomes. *Review of Educational Research*. <https://doi.org/10.3102/00346543241241327>
- Misbah, M., Hamidah, I., Sriyati, S., Samsudin, A., Prahani, B. K., & Abdul Rahman, N. F. (2024). Visualization and analysis of mapping thinking skills to encourage education for sustainable development (ESD). *E3S Web of Conferences*, 568, 04001. <https://doi.org/10.1051/e3sconf/202456804001>
- Ogebo, A. A., & Ramnarain, U. (2022). Teachers' perceptions of and concerns about integrating computational thinking into science teaching after a professional development activity. *African Journal of Research in Mathematics, Science and Technology Education*, 26(3), 181–191. <https://doi.org/10.1080/18117295.2022.2133739>
- Palop, B., Díaz, I., Rodríguez-Muñiz, L. J., & Santaengracia, J. J. (2025). Redefining computational thinking: A holistic framework and its implications for K–12 education. *Education and Information Technologies*. <https://doi.org/10.1007/s10639-024-13297-4>
- Panorkou, N., York, T., & Germia, E. (2023). Using debugging as a platform for transdisciplinary learning. *Cognition and Instruction*. <https://doi.org/10.1080/07370008.2023.2270094>
- Setiyaningsih, L. B., Riandi, R., Amprasto, A., & Mardiyah, M. (2024). Application of the inquiry-based learning model with education for sustainable development to enhance critical thinking skills and sustainable awareness. *Journal Penelitian Pendidikan IPA (JPPIPA)*, 10(10), 7790–7802. <https://doi.org/10.29303/jppipa.v10i10.8943>

- Socratous, C., & Ioannou, A. (2021). Structured or unstructured educational robotics curriculum? A study of debugging in block-based programming. *Educational Technology Research and Development*, 69(6), 3081–3100. <https://doi.org/10.1007/S11423-021-10056-X>
- Sposab, K., & Rieckmann, M. (2024). Development of sustainability competencies in secondary school education: A scoping literature review. *Sustainability*, 16(23), 10228. <https://doi.org/10.3390/su162310228>
- Sung, W. H., Ahn, J.-H., & Black, J. B. (2022). Elementary students' performance and perceptions of robot coding and debugging: Embodied approach in practice. *Journal of Research in Childhood Education*, 36(4), 681–696. <https://doi.org/10.1080/02568543.2022.2045399>
- Topsakal, İ., Altun Yalçın, S., & Cakir, Z. (2022). The effect of problem-based STEM education on the students' critical thinking tendencies and their perceptions for problem solving skills. *Science Education International*, 33(2), 136–145. <https://doi.org/10.33828/sei.v33.i2.1>
- Vázquez Uscanga, E. A., Nussbaum, M., & Naranjo, I. (2024). Integrating unplugged computational thinking across curricula: A qualitative study of students' and teachers' perspectives. *International Journal of Instruction*, 18(1), 357–378. <https://doi.org/10.29333/iji.2025.18120a>
- Wang, D., Luo, L., Luo, J., Lin, S., & Ren, G. (2022). Developing computational thinking: Design-based learning and interdisciplinary activity design. *Applied Sciences*, 12(21), 11033. <https://doi.org/10.3390/app122111033>
- Wong Mee Mee, R., Che Yob, F. S., Pek, L. S., Abd Rauf, M. F., Ming-mei, Y., & Derahvasht, A. (2025). Building digital thinkers: A bibliometric analysis of computational thinking in children's education for a sustainable future. *Contemporary Educational Technology*, 17(3), ep581. <https://doi.org/10.30935/cedtech/16309>
- Yilmaz, T., & Izmirli, S. (2023). Effect of unplugged and plugged coding activities on secondary school students' computational thinking skills. *Journal of Educational Technology and Online Learning*. <https://doi.org/10.31681/jetol.1375335>