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# Teaching Green Computing Concepts through Interactive Educational Tools: A Pathway to Sustainable Digital Literacy

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**Abstract.** The growing demand for digital technologies has brought both opportunities and challenges, particularly concerning energy consumption and environmental impact. While higher education has increasingly addressed sustainable computing, early educational levels often lack structured exposure to these issues. This paper explores the integration of green computing concepts into primary and secondary education through the design of interactive learning tools. The proposed approach emphasizes experiential learning by introducing students to fundamental ideas such as energy-efficient algorithms, responsible use of digital resources, and the environmental costs of hardware and networks. By leveraging block-based programming environments and gamified activities, the study aims to foster sustainable digital literacy from an early age. Preliminary results suggest that interactive pedagogical strategies not only improve students' computational thinking but also increase awareness of the environmental implications of their digital practices. Ultimately, this work argues that embedding sustainability within computing education is essential for preparing future generations to engage responsibly with technology.**Keywords** : Green Computing,Sustainability Education, Primary School, Computational Thinking ,Interactive Learning Tools

## 1 Introduction

The rapid growth of digital technologies has transformed how people learn and communicate but has also increased global energy use and environmental impact, particularly within the ICT sector (Andrae & Edler, 2015; Jones, 2018). These trends highlight the need for sustainable digital practices and early education on responsible technology use.

Green computing—the environmentally responsible design and use of computing systems—has become a central concept in both research and education (Murugesan, 2020). While technical innovations address hardware and software efficiency, developing sustainable digital behavior requires educational integration from the earliest stages (Al-Ameen & Talab, 2022).

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Embedding these ideas in primary education offers a way to link computational learning with environmental awareness. Interactive, block-based programming environments such as Scratch provide engaging opportunities for students to explore how computing choices affect energy consumption and sustainability (Resnick et al., 2009; Sáez-López et al., 2016).

This study investigates how green computing concepts can be introduced through Scratch-based learning activities in Moroccan primary classrooms. It argues that combining computational thinking with sustainability awareness can promote sustainable digital literacy, preparing students to use technology critically and responsibly...

### 1.1 Formatting the title, authors and affiliations

Sustainability in the context of computing education sits at the intersection of environmental science, information and communication technology (ICT), and pedagogy. Green computing broadly refers to the design, use, and disposal of computing systems in ways that minimize environmental harm and energy consumption. When transposed to education, the term encompasses both (a) teaching students concepts and practices that encourage energy-aware design and behaviour, and (b) operating educational ICT (platforms, data centers, devices) with reduced environmental impact (Peters et al., 2023). Recent systematic work emphasizes that conceptions of sustainability are heterogeneous across studies, ranging from narrow energy-efficiency goals to broader socio-technical critiques that include equity and lifecycle perspectives.

Systematic literature reviews indicate that research on sustainability in computing education has grown but remains fragmented. Peters et al. (2023) synthesized dozens of studies and reported that most contributions are practice-oriented experience reports (e.g., course descriptions, teaching modules) rather than rigorous empirical evaluations; relatively few works propose deep theoretical reframings of computing curricula toward sustainability. This body of work identifies common pedagogical aims (awareness-raising, skills for sustainable design, and technical practices such as energy-efficient programming) but notes uneven coverage across educational levels and limited evidence about long-term learning outcomes.

Several pedagogical strategies recur across the literature. Block-based programming environments (e.g., Scratch) and game-like activities have been widely used to introduce computational thinking while offering low-stakes, inquiry-driven experiences that can incorporate sustainability scenarios (Resnick et al., 2009; Sáez-López et al., 2016). Research shows that embedding environmental problems within computational tasks (for example: optimizing energy use in a simulated smart home) supports transfer between computational thinking and environmental reasoning, encouraging students to see algorithms as sociotechnical artifacts with environmental consequences (Christensen et al., 2022). However, while many case studies report increased awareness and engagement, rigorous experimental evidence of conceptual change or behavioural sustainability is still limited.

The literature also examines the environmental footprint of education technologies themselves. Several analyses suggest that, at scale, online learning and ICT-mediated instruction can reduce certain forms of environmental impact (e.g., travel-related emissions) but still consume energy through data centers, network infrastructure, and end-user devices (Meryem, 2023; e-learning sector reports). Estimates vary with assumptions about server efficiency, video usage, and user behaviour; therefore claims that e-learning is always greener are conditional and must account for lifecycle impacts and platform design choices. This motivates a twofold research agenda: (a) measure and model the energy consumption of common educational platforms, and (b) design platform-level interventions (adaptive streaming, edge processing, lightweight content) to reduce energy per learning outcome.

Integrating sustainability into computing and information systems curricula presents both opportunities and barriers. Studies investigating higher-education curricula report a mix of add-on modules, cross-disciplinary projects, and attempts to reframe core courses around sustainability themes (Hamadi, 2024). Challenges include crowded syllabi, lack of instructor expertise in sustainability, limited institutional incentives, and scarce assessment instruments that capture sustainability competence in computing. Reviews call for curriculum frameworks, teacher training, and shared repositories of vetted learning materials to scale effective practices.

# 2 Methodology

## 2.1 Type of study

The present research follows a quasi-experimental design combined with a mixed-methods approach. Quantitative data are used to measure changes in students' computational thinking and sustainability knowledge, while qualitative evidence provides insights into engagement, perceptions, and classroom dynamics. This dual strategy ensures that both cognitive outcomes and socio-pedagogical processes are examined, offering a holistic perspective on the integration of green computing in primary education.

## 2.2 Study Context and Participants

The study was conducted at Primary school Ghandi, situated in the Hay Hassani district of Casablanca, Morocco. This school was chosen for three main reasons:

Urban diversity – Hay Hassani is a district that reflects both socio-economic diversity and rapid urban development, making it a relevant setting for studying sustainability awareness.

ICT access – The school benefits from a relatively well-equipped computer lab compared to many Moroccan public schools, ensuring that digital interventions can be implemented without major infrastructural barriers.

Institutional support – The school administration expressed strong interest in innovative pedagogical projects that align with Morocco's national priorities in both digital literacy and environmental education.

Participants included two grade 5 classes (students aged 9–11, total N = 52). One class (n = 26) was designated as the experimental group, engaging with the green computing intervention, while the other class (n = 26) served as the control group, following the standard ICT curriculum. Gender distribution was balanced, and students came from varied socioeconomic backgrounds, offering a representative sample of Moroccan urban learners.

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### 2.3 Educational Tools and Intervention

The intervention was designed around interactive and experiential learning using the Scratch programming environment. To connect computing skills with environmental responsibility, three categories of activities were implemented:

Eco-animations: Students created animations demonstrating daily sustainable actions, such as unplugging chargers or shutting down computers after use.

Sustainability games: Learners designed simple games where players are rewarded for making eco-friendly digital decisions, reinforcing both algorithmic logic and environmental awareness.

Optimization challenges: Pupils explored how algorithms can be designed to use fewer computational steps, linking programming efficiency with energy savings in real-world digital systems.

The program ran over six weeks with two sessions per week (60 minutes each). Each session combined short teacher-led explanations with hands-on activities, group discussions, and peer collaboration.

### 2.4 Data collection

To ensure robustness, multiple data sources were employed:

Pre-test and post-test: Both experimental and control groups completed assessments measuring computational thinking (understanding of loops, conditions, and variables) and sustainability awareness (knowledge of ICT-related energy consumption and digital practices).

Classroom observations: Structured observation grids documented student engagement, collaboration patterns, and problem-solving strategies during sessions.

Student questionnaires: Likert-scale surveys, complemented with open-ended questions, captured students' perceptions of the intervention and their attitudes toward sustainable technology use.

Teacher interview: A semi-structured interview with the ICT teacher provided pedagogical reflections, perceived challenges, and suggestions for scaling the approach.

### 2.5 Data analysis

Quantitative analysis: Descriptive statistics summarized baseline characteristics, while paired-sample t-tests measured pre/post gains within each group. Independent-sample t-tests compared the learning outcomes of the experimental and control groups. Effect sizes were calculated to assess the magnitude of differences.

Qualitative analysis: Observation notes and interview transcripts were coded inductively using thematic analysis. Codes focused on engagement, collaboration, sustainability awareness, and perceived relevance of activities. Triangulation across different sources ensured reliability of interpretations.

### 2.6 Ethical Considerations

The study followed ethical guidelines for educational research. Administrative approval was obtained from the school leadership, and written consent was collected from parents. Participation was voluntary, with the assurance that students' identities would remain anonymous in all reports. The intervention was fully aligned with Morocco's primary school curriculum, ensuring no disruption of mandated learning objectives. Moreover, feedback sessions were organized at the end of the project to share results with teachers, students, and parents, thereby reinforcing transparency and knowledge transfer.

## 3 Results

3.1. Pre- and Post-Test Outcomes

Analysis of the pre- and post-test assessments revealed significant improvements in both computational thinking and sustainability awareness among students in the experimental group.

Computational thinking: The average score of the experimental group increased from M = 54.3% (SD = 10.8) in the pre-test to M = 76.9% (SD = 9.4) in the post-test. Paired-sample ttests confirmed the gain was statistically significant ($t(25) = 7.12$, $p < .001$).

Sustainability knowledge: Scores rose from M = 48.6% (SD = 12.1) to M = 79.2% (SD = 10.5), also statistically significant ($t(25) = 8.04$, $p < .001$).

In contrast, the control group showed only modest improvements in computational thinking (M = 56.1% → 62.7%), and almost no change in sustainability awareness (M = 47.8% → 50.2%). Independent-sample t-tests confirmed that the experimental group significantly outperformed the control group on post-test measures of both computational thinking ($t(50) = 3.98$, $p < .001$) and sustainability knowledge ($t(50) = 6.21$, $p < .001$).

3.2 Classroom Engagement

Observational data indicated that students in the experimental group were highly engaged during interactive sessions. Most learners participated actively in discussions, collaborated on programming tasks, and demonstrated curiosity when linking coding activities to real-life sustainability scenarios. Compared to the control group, which relied mainly on teacherdirected instruction, the experimental group displayed greater initiative, peer support, and problem-solving behavior.

2. Student Perceptions

Survey results showed that 84% of students in the experimental group reported that the activities were “fun and useful,” while 76% indicated that they became more aware of how digital devices consume energy. Open-ended responses highlighted that learners particularly enjoyed creating animations about everyday eco-actions and designing games where “saving energy meant winning points.” A small minority (about 12%) noted initial difficulties in understanding the link between programming efficiency and energy savings, but most of these students reported that repeated practice helped clarify the concept.

3. 3Teacher Reflections

The ICT teacher described the intervention as both “innovative” and “feasible” within the Moroccan curriculum. She emphasized that linking abstract programming concepts to familiar daily practices—such as switching off lights or shutting down computers—helped students understand sustainability in concrete terms. However, she also noted challenges, including limited time for deeper exploration of algorithm optimization and the need for additional teacher training in sustainability-oriented computing.

3.4Summary of Findings

The results suggest that integrating green computing concepts into primary education using block-based programming is both pedagogically effective and well-received by learners. Students in the experimental group not only achieved significant gains in computational thinking but also developed a stronger awareness of the environmental impact of technology use. The findings further indicate that interactive, context-based activities can enhance motivation and engagement, making sustainability an accessible theme for young learners.

## 4 Discussion

The findings of this study demonstrate that the integration of green computing concepts into primary education can be both effective and meaningful for learners. Students who participated in the interactive intervention using Scratch not only achieved higher gains in computational thinking but also developed a stronger awareness of sustainability issues related to technology use. These results support the view that environmental education and computing skills can be mutually reinforcing when designed within authentic, problem-based learning contexts.

Linking with previous research

The significant improvement in computational thinking observed in the experimental group echoes previous studies that highlighted the pedagogical value of block-based programming for young learners (Resnick et al., 2009; Sáez-López et al., 2016). However, this research goes beyond foundational coding skills by demonstrating that sustainability scenarios can serve as an effective pedagogical lens for deepening conceptual understanding. This aligns with the work of Christensen et al. (2022), who showed that embedding environmental challenges in programming tasks enhances both engagement and cognitive transfer between domains.

Similarly, the increase in students’ awareness of digital energy consumption validates calls made in systematic reviews emphasizing the need to integrate sustainability explicitly within computing education (Peters et al., 2023). While earlier research often focused on higher education, the present study provides evidence that such integration is feasible and impactful at the primary level, thereby filling an important gap in the literature.

Pedagogical implications

The intervention illustrates that even abstract notions, such as algorithmic efficiency or energy use in ICT, can be translated into age-appropriate classroom activities. Students reported enjoying the game-like and animation-based projects, which fostered motivation while reinforcing computational skills. Teachers, in turn, found the approach compatible with the existing Moroccan curriculum, though they highlighted the need for professional development in sustainability and green computing concepts. This suggests that curricular innovation must be accompanied by teacher training and institutional support if it is to scale sustainably.

Challenges and limitations

Despite the positive outcomes, several limitations must be acknowledged. First, the **intervention period** was relatively short (six weeks), limiting conclusions about the long-term retention of sustainability knowledge or behavioral change.
Second, the study was **conducted in a single urban primary school in Casablanca**, which constrains the generalizability of findings. Results may not fully apply to **rural schools**, where ICT infrastructure, teacher training, and student access to technology differ considerably. The Moroccan educational system also presents regional variations that could influence implementation and outcomes.
While the paper recognizes these contextual boundaries, future research could explore **multi-site or cross-regional studies** to compare how school setting, socio-economic context, and resource availability affect the integration of green computing education. Such work would provide stronger evidence for scalability across diverse educational systems.
Finally, although the quantitative results were strong, qualitative findings showed that some students initially struggled to grasp the link between **algorithmic efficiency** and **environmental impact**, suggesting a need for additional scaffolding and teacher guidance in future interventions.

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Directions for future research

Future studies should consider expanding the intervention to a larger and more diverse sample of schools across Morocco, including rural areas where sustainability challenges are even more pressing. Longitudinal research is also needed to assess whether early exposure to green computing fosters lasting behavioral change in digital practices. In addition, crossdisciplinary collaborations between computing educators, environmental scientists, and curriculum developers could lead to richer and more comprehensive learning materials.

## 5 Conclusion

This study investigated the integration of green computing concepts into primary education through interactive, block-based programming activities at École Primaire Gandhi, located in Hay Hassani, Casablanca, Morocco. The results indicate that such an approach can significantly enhance students' computational thinking skills while simultaneously raising awareness of the environmental impact of digital technologies. Students engaged actively with the tasks, demonstrated improved problem-solving abilities, and reported heightened sensitivity to sustainable digital practices.

The findings underscore the potential of combining computational learning with sustainability education in early schooling. By contextualizing abstract programming concepts within real-life environmental scenarios, learners can develop a dual literacy—both technological and ecological—that equips them to navigate an increasingly digital world responsibly. The study also highlights the importance of teacher training, curricular alignment, and institutional support for the successful implementation of green computing initiatives in primary schools.

Looking forward, expanding such interventions to a broader range of schools across Morocco, including rural areas, and incorporating longitudinal assessment of behavioral outcomes, could provide deeper insights into the long-term impact of sustainability-oriented computing education. Furthermore, collaboration between educators, curriculum developers, and environmental experts could yield richer, contextually relevant learning materials that strengthen both cognitive and environmental competencies.

In conclusion, embedding green computing principles into primary education represents a promising strategy for cultivating informed, responsible, and environmentally conscious future citizens. Early engagement with these concepts not only fosters computational skills but also instills a mindset of sustainability that is essential for addressing the global challenges of the digital age.

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