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Transforming primary education through aidriven steam: empowering the next generation of innovators in Atlántico, Colombia

Transformando la educación primaria a través del vapor impulsado por la inteligencia artificial: empoderando a la próxima generación de innovadores en Atlántico, Colombia

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Abstract

This study explores innovative strategies for enhancing STEAM competencies among primary school students in the Department of Atlántico, Colombia. Grounded in a qualitative, interpretive paradigm and guided by hermeneutic phenomenology, the research involved classroom observations and semi-structured interviews with four primary teachers recognized for their implementation of interdisciplinary, technology-supported practices. The analysis—through coding, categorization, and triangulation—yielded theoretical constructs concerning conceptual frameworks, STEAM competency descriptors, and pedagogical strategies. Results indicate that the integration of STEAM approaches fosters critical thinking, creativity, and problem-solving skills in young learners. The study emphasizes the importance of ongoing teacher professional development to ensure educational practices align with emerging technological and pedagogical trends.

Keywords: Innovative strategies, Primary education, Qualitative research, STEAM competencies.

Resumen

Este estudio pretende generar un constructo teórico sobre estrategias innovadoras para el desarrollo de competencias STEAM en estudiantes de primaria del Departamento del Atlántico (Colombia). A través de la observación y de entrevistas semiestructuradas con cuatro profesores clave, los datos recogidos fueron codificados, categorizados y triangulados. El estudio identificó constructos teóricos emergentes relacionados con referencias conceptuales, descriptores de competencias STEAM y tipos de estrategias innovadoras. Los resultados sugieren que la aplicación de las competencias STEAM fomenta el pensamiento crítico y la resolución de problemas en los alumnos de primaria. Se recomienda la formación continua del profesorado para garantizar que las prácticas pedagógicas se mantienen alineadas con los avances tecnológicos y las tendencias educativas actuales.

Palabras Clave: *Estrategias innovadoras, Educación primaria, Investigación cualitativa, Competencias STEAM*

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Introducción

The rapid evolution of global challenges calls for a trans- formation of traditional educational approaches. Integrating STEAM competencies—Science, Technology, Engineering, Arts, and Mathematics—into primary education provides a holistic pathway to foster critical thinking, creativity, and collaborative problem-solving. In the Atlántico Department of Colombia, educational institutions increasingly acknowledge the relevance of pedagogical innovation to prepare students for a dynamic and competitive future.

The current educational landscape requires going beyond conventional disciplinary boundaries by adopting interdisciplinary and experiential learning frameworks. By promoting inquiry-based learning and real-world application of knowledge, STEAM education equips students with the cognitive and social tools needed to navigate uncertainty and complexity. Furthermore, it cultivates a mindset oriented toward innovation, adaptability, and continuous learning—essential qualities for their future personal and professional development. This study addresses the need to update teaching practices by exploring innovative strategies that enhance STEAM competencies in primary education. Grounded in a qualitative, interpretive methodology, it contributes to the theoretical development of educational practices aligned with 21st-century competencies. Emphasis is placed on understanding how pedagogical innovation can be contextually adapted to the sociocultural realities of Atlántico, considering equity, inclusion, and the democratization of access to technology and scientific knowledge.

By examining the implementation of STEAM-based initiatives in selected institutions, the study highlights both the strengths and limitations of current approaches while proposing feasible recommendations. Ultimately, its purpose is to foster a more resilient, reflective, and inclusive educational ecosystem capable of responding to contemporary societal needs through the empowerment of young learners. The transformation of primary education through AI-driven STEAM approaches in Atlántico (Colombia) is grounded in the convergence of a range of theoretical and pedagogical elements addressing the challenges of the 21st century. On one hand, educational innovation encompasses the design of strategies and learning environments that shift the focus from rote memorization to hands-on, collaborative, and explorative methodologies, as described by [1]. This shift relies heavily on digital tools and data analytics, which enable teachers to personalize instruction, adapt to individual learning paces, and foster higher student engagement. On the other hand, the STEAM framework seeks not only to integrate multiple disciplines but also to cultivate creative thinking, problem-solving skills, and a sense of curiosity about the world—key competencies that lay the foundation for more advanced scientific and technological learning, as noted by [2].

Central to this vision is the inclusion of the arts within the STEM model, which broadens how students engage with ideas and encourages the use of storytelling, visual communication, and design as catalysts for innovation. By exploring how design principles intersect with scientific concepts, learners better understand the creative aspects of problem-solving, become more comfortable with iterative processes, and gain the confidence to propose innovative solutions. This creative dimension is especially meaningful in the early primary stages, where holistic development and the nurturing of imagination play a crucial role in shaping future academic and professional pathways.

The use of artificial intelligence (AI) in the classroom significantly enhances the capacity of educators to tailor learning experiences, monitor student progress, and make data-driven decisions. In line with the connectivism approach proposed by [3], AI augments how students build and navigate their own networks of knowledge. They can access global resources—from specialized online platforms to virtual communities of practice—and integrate what they learn into the local context of Atlántico. By combining AI-powered analytics with teacher expertise, classrooms transform into adaptive learning ecosystems where immediate feedback, individualized attention, and targeted remediation are possible. This dynamic approach addresses learning gaps more efficiently and fosters an inclusive environment in which all students, regardless of their starting points, can advance. Nonetheless, the success of AI-driven STEAM methodologies hinges on the cultivation of socio-emotional competencies, which anchor cognitive processes to empathy, perseverance, and collaboration [4], [5]. As students move through increasingly complex problem-solving tasks—such as building prototypes, coding simple robotics, or conducting scientific experiments—they encounter challenges, failures, and the need to communicate effectively with their peers. These experiences highlight the importance of empathy and assertiveness to maintain trust, manage conflicts, and embrace an iterative mindset that views each obstacle as an opportunity for improvement. Self-regulation and resilience become vital in an educational model that values curiosity and experimentation over the one-time right answer.

Design thinking, as outlined by [6], complements this process by providing a structured methodology for tack- ling open-ended problems, starting with empathy-driven re- search, moving to ideation, and then into rapid prototyping and testing. Within a STEAM context, design thinking gives learners a tangible framework for understanding how knowledge from diverse fields (e.g., engineering principles, visual arts, mathematics, and technology) converges to generate solutions relevant to local and global challenges. This synergy is evident when students in Atlántico collaborate on projects that address community needs, such as water purification or agricultural sustainability, integrating creative concepts with scientific and technical know-how, as suggested by [7], [8], [9]. In the specific context of Atlántico, Colombia, AI-enabled STEAM education has the potential to bridge gaps in access and quality, particularly in rural or under-resourced regions. Initiatives that incorporate mobile devices, open educational resources, and community-based maker spaces can mitigate infrastructure limitations while providing learners with global opportunities for exploration and collaboration. This aligns with [10-12], who underscore the importance of including families and local communities as active stakeholders in educational innovation. By leveraging AI, schools in Atlántico can also identify precise learning needs, facilitate teacher professional development, and design more adaptive curricula that reflect both national educational standards and the diversity of student interests. Ultimately, the convergence of educational innovation, STEAM methodologies, artificial intelligence, and socio-emotional skill-building lays the groundwork for a paradigm shift in primary education. These elements collectively empower

teachers and students to engage meaningfully with the technological and social complexities of the modern world. In doing so, the children of Atlántico, Colombia, can emerge as a generation of versatile, empathetic, and resourceful innovators—capable of contributing decisively to local development and global progress.

II. METHODOLOGY

This study adopts an interpretive paradigm with a qualitative approach, aiming to explore and understand the subjective meanings and lived experiences of primary school teachers who implement STEAM strategies in their classrooms. The interpretive paradigm posits that reality is socially constructed and context-dependent, and that knowledge is co-created through the interaction of researchers and participants, as explained by [13]. This approach is particularly suited to investigating educational innovation and human behavior in dynamic teaching environments.

Hermeneutic phenomenology, rooted in the works of Heidegger and Gadamer, was selected as the guiding methodology. This approach seeks to reveal the essence of participants' experiences by interpreting their narratives in relation to their sociocultural and institutional contexts. Unlike purely descriptive phenomenology, the hermeneutic tradition recognizes that the researcher's pre-understanding and interpretive lens con- tribute to constructing meaning. This methodology effectively captures the complex, emotional, and reflective dimensions of teachers' engagement with STEAM, offering deep insight into how they perceive their roles, challenges, and pedagogical transformations. Consistent with qualitative philosophy, data analysis followed iterative cycles of coding and interpretation based on Van Manen's phenomenological approach [14-15]. Particular attention was given to identifying themes related to pedagogical innovation, affective responses, classroom interactions, and institutional support mechanisms.

III. EXPERIMENTAL DESIGN

A. Research Design

A qualitative multiple-case study design, framed within hermeneutic phenomenology, was employed. The purpose was to explore, interpret, and describe the lived experiences of primary school teachers who implement STEAM strategies supported by Information and Communication Technologies (ICT), focusing on their impact on school coexistence. This interpretive design emphasizes understanding meaning from participants' perspectives and contextual realities.

Following Van Manen's phenomenological approach [16-19], the selection of cases—teachers from diverse primary school settings—enabled in-depth, comparative analysis of practices across institutional and geographical contexts (urban and semi-rural). Methodological triangulation (interviews, observations, and pedagogical artifacts) reinforced the study's internal validity and produced a richer, multifaceted understanding of the phenomena under investigation.

B. Objectives and Research Questions

General Objective: To analyze how ICT-mediated STEAM strategies influence school coexistence practices in primary education classrooms in the Atlántico Department of Colombia.

Research Questions:

- How do primary school teachers integrate ICT-mediated STEAM strategies into their classroom practices?

- What meanings do teachers assign to these strategies in terms of their impact on school coexistence?

- How do students respond—socially and emotionally—to these pedagogical interventions?

C. Participants and Sampling

Four in-service primary school teachers participated, selected through purposive sampling based on the following criteria:

- At least three years of experience teaching primary school.

- Documented participation in professional development related to STEAM or educational technology.

- Evidence of interdisciplinary, ICT-supported classroom strategies.

Sampling was non-probabilistic and criterion-based, aiming to gather rich, experiential narratives from teachers recognized as pedagogical innovators in their institutions. Two worked in urban settings and two in semi-rural contexts, thus ensuring contextual diversity in the analysis.

D. Intervention Context and Duration

Although not traditional experimental manipulation, the study involved observing and interpreting naturally occurring pedagogical practices: the implementation of STEAM projects incorporating ICT tools over a three-month period. Each teacher carried out 3–5 STEAM-based projects addressing both disciplinary content and socio-emotional competencies linked to school coexistence. These projects included digital storytelling, collaborative platforms, creative design apps, and coding environments adapted to actual classroom needs.

E. Data Collection Techniques

Data collection followed a triangulated strategy:

- Semi-structured Interviews: Conducted in two phases with each teacher, exploring pedagogical decision-making, reflections on student behavior, perceived changes in classroom dynamics, and professional development processes.

- Classroom Observations: Non-participant observations of STEAM sessions were conducted using field notes and a structured observation guide to document instances of collaboration, emotional expression, conflict resolution, and technology integration.

- Pedagogical Artifacts: Student-created products (digital stories, design outputs, coding projects) and teachers' lesson plans were collected to contextualize observed practices and enrich interpretive analysis.

F. Data Analysis Strategy

Data analysis involved iterative thematic coding using NVivo:

1) Transcription and organization of interviews and observation notes.

2) Initial coding to identify recurring concepts (e.g., empathy, collaboration, digital ethics).

3) Axial coding to group these concepts into broader categories (e.g., socio-emotional mediation, digital citizen- ship).

4) Interpretive synthesis, linking codes with narrative excerpts and visual evidence to reconstruct the pedagogical meaning of STEAM-ICT strategies.

Coding reliability was enhanced through researcher triangulation and member checking with participants. Data saturation occurred after the second interview round, when no new conceptual categories emerged.

G. Ethical Considerations

The study followed ethical protocols in line with national guidelines for educational research:

- Informed consent was obtained from all participants.
- Anonymity was preserved by using coded identifiers.
- Participants could withdraw from the study at any time without penalty.
- Audio recordings and documentation were securely stored for academic purposes only.

IV. RESULTS

Based on semi-structured interviews and classroom observations, the hermeneutic phenomenological analysis under- scored the critical role of multimedia tools in enhancing teachers' digital competencies, as well as the significant benefits of STEAM-based pedagogical practices for students' socio-emotional development and improved classroom coexistence. Various interrelated categories emerged, ranging from the adoption of multimedia applications and conceptual references for digital competence formation to contributions to pedagogical practice and teacher empowerment, along with emerging themes around digital citizenship and infrastructure needs. The integration of ICT within STEAM strategies further catalyzed positive transformations in school coexistence and classroom climate. Key findings are presented below.

A. Multimedia Tools Used by Teachers

Teachers reported using a variety of multimedia applications to strengthen their digital competencies and enrich student learning. Commonly mentioned platforms included Google Suite (Drive, Classroom, Meet), specialized software for presentations or design (Canva, PowerPoint), and interactive apps (Kahoot, ClassDojo). These tools facilitated lesson planning, grading, content creation, and classroom management. However, frequent connectivity issues and limited device availability often hindered the effective potential of multimedia integration, especially in semi-rural schools.

B. ICT Usage in STEAM Contexts

In the context of STEAM projects, teachers deliberately harnessed ICT to advance disciplinary learning and encourage reflection on values and coexistence. Activities such as coding cooperative games, designing digital prototypes to solve community problems, or creating interactive stories about classroom conflicts boosted student engagement and collaboration. Observational data showed reduced verbal aggression and stronger group cohesion among students working on digitally mediated tasks. Participants attributed these changes to the structured interactions provided by multimedia and coding environments, which reinforced both content mastery and communication skills, including empathy.

C. Conceptual References for Multimedia Use in Digital Competence Formation

Participants frequently cited UNESCO guidelines for ICT integration in teacher training [20], as well as the Colombian Ministry of Education standards [21-23] on digital competencies. These frameworks emphasize the need for continuous professional development covering both technical know-how and pedagogical design. Nevertheless, teachers indicated that official training programs

and resources remain scarce, relying instead on peer collaboration or self-guided tutorials. This situation highlights a gap in institutional support and under- scores the need for stronger policies to foster teachers' digital competence.

D. Technological Tools for Socio-emotional Learning

Teachers also underscored the relevance of multimedia in cultivating socio-emotional competencies. Platforms such as Book Creator, Canva, and coding environments (e.g., Scratch) provided meaningful opportunities to practice empathy, perspective-taking, and collaborative decision-making. One notable project engaged learners in producing short, animated films about real-life classroom conflicts, encouraging them to propose non-violent solutions and reflect on the emotional nuances of each scenario. This creative, simulation-based approach fostered emotional literacy, allowing students to address coexistence challenges in a safe environment.

E. Contributions of Multimedia Tools to Pedagogical Practice

All participants recognized substantial benefits from using multimedia tools:

- Higher Student Engagement: Visually appealing materials, interactive simulations, and dynamic media captured students' curiosity and promoted active participation.
- Personalized Instruction: Multimedia resources such as videos, animated tutorials, and gamified quizzes supported self-paced learning tailored to individual learning styles.
- Collaborative Learning: Shared documents and group projects enabled by digital applications bolstered team- work, creativity, and collective problem-solving.

Nevertheless, teachers noted the need for infrastructure improvements—reliable internet and sufficient devices—and consistent institutional support to ensure equitable access to multimedia tools.

F. Teacher Empowerment and Pedagogical Transformation

A notable finding concerned the professional empowerment of teachers trained in STEAM and ICT. Those who had participated in workshops displayed greater confidence and autonomy in designing technology-mediated instruction. Their lesson plans intentionally linked STEAM competencies with socio-emotional goals, adapting activities based on classroom dynamics. One teacher remarked, "Technology allowed me to turn conflicts into learning opportunities," shifting from a reactive, disciplinary approach to a proactive stance that builds coexistence. This underscores that, when backed by institutional support and continuous training, teachers can transform digital resources into meaningful pedagogical action.

G. Emerging Theme: Digital Citizenship and Coexistence

The concept of digital citizenship emerged strongly in shaping positive classroom coexistence. Students used ex- pressions like "respecting opinions," "listening to others," and "collaborating online," revealing their internalization of coexistence principles through digitally mediated STEAM tasks. Teachers played a significant role by emphasizing digital ethics, equitable participation, and respectful emotional expression. Consequently, digital coexistence evolved from a peripheral concern to a central axis in instructional design, highlighting the transformative potential of aligned, value-based technology use.

H. Observational Evidence

1) Changes in Classroom Coexistence Indicators: To supplement qualitative insights, the study measured three student-behavior constructs (Collaboration, Peaceful Conflict Resolution, and Classroom Climate). An upward trend in median values and reduced variability was observed following the introduction of ICT in STEAM projects, reflecting enhanced peer interactions and improved cooperative skills (Figure 1).

Qualitative coding of STEAM-Based Coexistence Indicators.

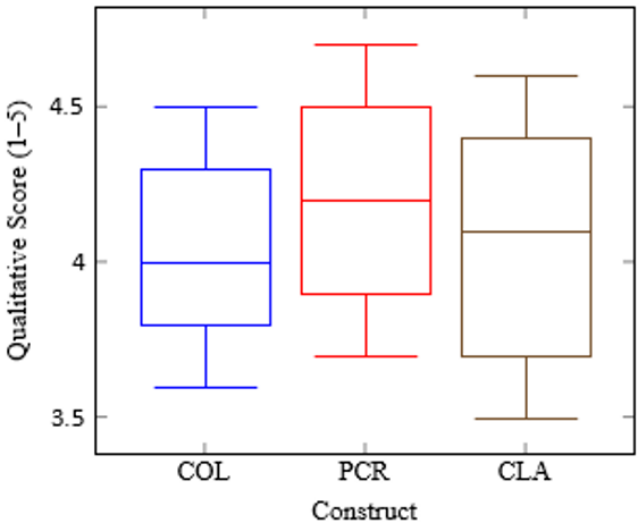

Figure 1. Boxplots of Teacher-Coded Coexistence Indicators (COL, PCR, CLA)

2) Teacher Confidence in Coexistence Management: In addition, teachers reported a marked increase in their perceived ability to manage classroom coexistence via STEAM-ICT initiatives. Figure 2 presents a comparative bar chart of four teachers' self-assessed confidence levels (scale 1–5) before and after the intervention. All four teachers showed noteworthy gains, underscoring the positive influence of focused ICT training and reflective practice on teacher self-efficacy and harmonious classrooms (Figure 2). V.

Teacher-reported confidence before and after STEAM Intervention

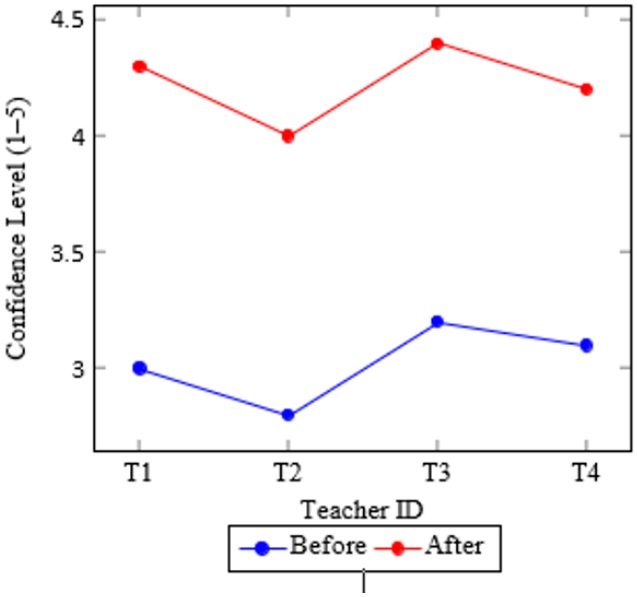

Figure 2. Teacher-Reported Confidence in Managing Coexistence through STEAM (Line Plot)

DISCUSSION

Findings from this study reinforce the notion that STEAM- based educational strategies—particularly those mediated by Information and Communication Technologies (ICT)—can significantly enhance school coexistence at the primary level. Teachers reported that STEAM's interdisciplinary and student- centered nature promotes active engagement, emotional regulation, and collaborative behavior among learners. Beyond facilitating academic and technological skills, these methods nurture socio-emotional competencies, such as empathy, conflict resolution, and digital citizenship.

When framed within meaningful learning experiences, integrating ICT enabled teachers to design pedagogical situations that tackled real social dilemmas, encouraging prosocial decision-making and providing safe spaces for reflective dialogue. Students responded positively to activities that allowed emotional expression and collective problem-solving, especially when employing creative

platforms like digital storytelling and collaborative design. Nonetheless, multiple challenges persist—particularly regarding limited access to technology resources in rural schools, where insufficient equipment and connectivity constrain widespread implementation. While participating teachers had prior experience in educational innovation, many highlighted Institutional supports emerged as a key enabler of success. Schools that promoted teacher autonomy, interdisciplinary planning, and curricular flexibility achieved more effective implementation of these strategies. Conversely, rigid schedules and inadequate administrative coordination hindered sustained development. Therefore, educational policy and leadership should prioritize structural and cultural changes that support pedagogical innovation and foster the development of 21st- century competencies, with an emphasis on peaceful coexistence.

VI. CONCLUSIONS

Interpretive and visual evidence from this study indicates that integrating STEAM and ICT into primary school education can serve as a powerful lever for enhancing school coexistence and socio-emotional development. Specifically:

- STEAM-based methodologies encourage empathy, collaboration, and responsible participation, reinforcing peaceful conflict resolution and improving the classroom climate.
- ICT tools, when used intentionally and ethically, promote inclusive, emotionally supportive learning environments and serve as mediators for democratic dialogue and digital citizenship.
- Teacher training and empowerment are crucial for the successful design and facilitation of these strategies. Empowered educators can translate technological innovation into deeply meaningful pedagogical actions.
- Institutional commitment and investment in infrastructure are essential to ensure equitable access to educational technologies and the sustainability of innovative practices in both urban and rural settings.

VII. FUTURE WORK

Based on these findings, future research should consider:

- Conducting longitudinal studies to assess the long-term impact of STEAM strategies on student behavior, emotional development, and social dynamics.
- Employing mixed-methods designs that combine qualitative insights with robust quantitative data on academic achievement, coexistence indicators, and socio-emotional competencies.
- Designing context-sensitive technological resources suitable for rural or under-resourced schools in the Atlántico region, ensuring cultural relevance and offline functionality.
- Exploring professional learning communities centered on STEAM and digital coexistence, fostering collective reflection, co-design of strategies, and the dissemination of best practices across institutions.

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