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RESEARCH ARTICLE

Collaborative Environments with Simulators: A Didactic Strategy to Strengthen Scientific Thinking in Schools.

Entornos colaborativos con simuladores: una estrategia didáctica para fortalecer el pensamiento científico en la escuela.

Ambientes colaborativos com simuladores: uma estratégia didática para fortalecer o pensamento científico na escola.

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Abstract

Introduction: Standardized test results show that Colombian secondary school students have difficulties in scientific literacy, especially in inquiry skills. **Objective:** To determine the impact of implementing a strategy based on collaborative learning complemented by simulators to strengthen scientific thinking skills. **Methodology:** The research was qualitative in nature, using an action research approach with a descriptive-interpretive scope. Forty students (aged 15-17) from a school in Barranquilla participated. Participant observation, a 10-item survey, and semi-structured interviews were used; the instruments were validated by expert judgment, and the information collected was analyzed using open-axial-selective coding and methodological triangulation. **Results:** Notable progress was recorded in question formulation, experimental design, evidence-based argumentation, and conclusion drawing. Students' perceptions indicate that there was an increase in motivation, peer support, and conceptual understanding thanks to interactive simulators and Padlet. **Conclusions:** Integrating virtual simulators into collaborative environments is an effective and scalable strategy for enhancing scientific thinking in science classrooms with limited resources.

Keywords: Collaborative learning; Educationals simulators; Science teaching; Scientific thinking; Secondary education

Resumen

Introducción: los resultados de pruebas estandarizadas muestran que los estudiantes colombianos de secundaria presentan dificultades en la alfabetización científica, sobre todo en habilidades de indagación. **Objetivo:** determinar el impacto de la implementación de una estrategia basada en el aprendizaje colaborativo complementada con simuladores para fortalecer habilidades de pensamiento científico. **Metodología:** La investigación fue de enfoque cualitativo de tipo investigación-acción, con un alcance descriptivo-interpretativo. Participaron 40 estudiantes (15-17 años) de un colegio de Barranquilla. Se aplicaron la observación participante, una encuesta de 10 ítems y entrevistas semiestructuradas; los instrumentos fueron validados por juicio de expertos y la información recolectada fue analizada mediante codificación abierta-axial-selectiva y triangulación metodológica. **Resultados:** se registraron avances notables en la formulación de preguntas, el diseño experimental, la argumentación con evidencias y la elaboración de conclusiones; las percepciones de los estudiantes indican que hubo un incremento en la motivación, apoyo entre pares y comprensión conceptual gracias a los simuladores interactivos y Padlet. **Conclusiones:** integrar simuladores virtuales en ambientes colaborativos constituye una estrategia eficaz y escalable para potenciar el pensamiento científico en aulas de ciencias con recursos limitados.

Palabras clave: Aprendizaje colaborativo; simuladores educativos; enseñanza de las ciencias; pensamiento científico; educación secundaria.

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Resumo

Introdução: Os resultados de testes padronizados mostram que os alunos colombianos do ensino médio apresentam dificuldades em alfabetização científica, sobretudo em habilidades de investigação. **Objetivo:** determinar o impacto da implementação de uma estratégia baseada na aprendizagem colaborativa complementada com simuladores para fortalecer habilidades de pensamento científico. **Metodologia:** A pesquisa foi de abordagem qualitativa do tipo pesquisa-ação, com alcance descritivo-interpretativo. Participaram 40 alunos (15-17 anos) de uma escola de Barranquilla. Foram aplicadas observação participante, uma pesquisa com 10 itens e entrevistas semiestruturadas; os instrumentos foram validados por julgamento de especialistas e as informações coletadas foram analisadas por meio de codificação aberta-axial-seletiva e triangulação metodológica. **Resultados:** foram registrados avanços notáveis na formulação de perguntas, no desenho experimental, na argumentação com evidências e na elaboração de conclusões; as percepções dos alunos indicam que houve um aumento na motivação, no apoio entre pares e na compreensão conceitual graças aos simuladores interativos e ao Padlet. **Conclusões:** integrar simuladores virtuais em ambientes colaborativos constitui uma estratégia eficaz e escalável para potenciar o pensamento científico em salas de aula de ciências com recursos limitados.

Palavras-chave: Aprendizagem colaborativa; simuladores educativos; ensino das ciências; pensamento científico; ensino médio.

1. INTRODUCTION

Education in the twenty-first century urgently requires transformation processes that enable students to develop the skills needed to face contemporary challenges (Srivastava, 2023). Bernate (2021) argues that such skills include leadership, emotional well-being, commitment to continuous learning, mastery of digital technologies, and participation in collaborative spaces. Accordingly, educational institutions must design academic programs that ensure comprehensive training, promote technological development, and respond to the demands of an ever-evolving society (Ávalos Dávila et al., 2021).

Today's society is deeply influenced by science and technology, whose rapid advancement significantly impacts people's quality of life (Lipizzi, 2024). In this context, authors such as Figueroa Céspedes et al. (2020) emphasize the importance of developing scientific thinking not only as an academic component but also as a practical tool for everyday life, enabling more active social participation. For this reason, science teaching and the promotion of scientific thinking constitute priority tasks for schools, requiring a critical revision of teaching methods to align them with the needs of the modern world (Ávalos Dávila et al., 2021; Khan & Sharma, 2023).

The results of the Programme for International Student Assessment (PISA), applied since 2000 to countries belonging to the Organisation for Economic Co-operation and Development (OECD), serve as an initial benchmark for analyzing the development of scientific competencies among Colombian students. Although the 2022 results in the science domain showed a decline compared to 2018, they also revealed a cumulative increase of 23 points between 2006 and 2022 (Fundación Empresarios por la Educación [ExE], 2024). Nevertheless, more than 50% of students did not reach the basic proficiency level (Level 2), highlighting the need for structural changes within the educational system (Ministerio de Educación Nacional [MEN], 2023).

In response to this situation, educational institutions have sought strategies to improve scientific literacy levels. This study emerges as an alternative to strengthen the performance of students at an educational institution in Barranquilla (Colombia) on the Saber 11 examination, whose results revealed significant difficulties in the specific competencies of the Natural Sciences domain, particularly in the inquiry competency. According to Demir (2024), this competency involves students' ability to formulate questions, design appropriate procedures, and analyze and interpret information to derive answers.

This article presents the results of a study aimed at implementing a didactic strategy based on collaborative learning in virtual environments, complemented by the use of educational simulators, to strengthen scientific-thinking skills. In line with this purpose, the study established four specific objectives oriented toward developing key dimensions of the inquiry competency: (1) strengthening the formulation and resolution of scientific questions, (2) developing the ability to design experimental procedures using simulators, (3) promoting evidence-based argumentation through collaborative work, and (4) establishing conclusions grounded in the evidence obtained during simulator-based experimental activities.

The novelty of this proposal lies in the simultaneous integration of virtual collaborative environments and educational simulators as the core of a didactic strategy implemented in a school context with limited resources. Although previous studies have examined collaborative learning and the use of simulators independently, few have articulated both components within a single didactic design to enhance inquiry-related scientific skills in Colombian secondary education. This integrated approach provides an innovative perspective by demonstrating that the combination of interactive digital tools and collaborative dynamics can generate significant improvements in the development of scientific thinking, thereby extending the approaches previously documented in the literature.

2. THEORETICAL FRAMEWORK

Scientific Thinking

Today's world, shaped by technological influence and scientific advances, requires deep reflection on the teaching and learning processes that take place in schools (Lengua et al., 2020). This context demands that Natural Sciences teachers guide their pedagogical practice toward designing learning environments that foster critical thinking and informed decision-making for personal and societal well-being (Díaz Arriagada, 2021).

Promoting the development of scientific thinking requires schools to establish a clear action plan that includes adequate resources, relevant activities, and continuous teacher training (Mardones & Pino, 2022; Martelo Caballero, 2023). It is essential that students participate from an early age in meaningful learning experiences that enhance their scientific skills. This idea aligns with Mendoza-Mendoza & Loor-Colamarco (2022) and Pérez (2025), who argue that scientific thinking develops gradually and requires the implementation of pedagogical strategies tailored to students' needs and interests, supported by collaboration among teachers, families, and other educational stakeholders.

Several core skills contribute to the development of scientific thinking, including question formulation, experimentation, argumentation, and drawing evidence-based conclusions (Díaz Arriagada, 2021; Figueroa Céspedes et al., 2020; Mardones & Pino, 2022; Montaño Hilario & Padilla Martinez, 2020; Sepúlveda Obreque et al., 2023).

Formulating scientific questions is a key skill for understanding natural phenomena. Berson & DeCoito (2021) state that scientific questioning fosters deeper learning by enabling students to better interpret such phenomena. Similarly, Younis (2022) argues that learning to pose questions strengthens critical-thinking skills and facilitates engagement with scientific inquiry. Consequently, learning environments should encourage this skill from early ages (Paños et al., 2022).

The teacher plays a crucial role in this process. According to Conejera et al. (2021) and Rodríguez-Navarrete et al. (2022), teachers must be able to formulate high-quality questions that promote scientific-thinking competencies, as such questions nurture creativity, higher-order thinking, and stronger argumentative responses (Secrieru & Calalb, 2025) indicate that questions aimed at developing scientific thinking should:

- Challenge students' prior knowledge.Encourage analysis from multiple perspectives.
- Support active knowledge construction through exploration.
- Require intellectual activities such as reading, writing, observing, and analyzing information.
- Foster collaborative learning and peer interaction.

Experimentation is another key didactic strategy. Studies show that when used as a pedagogical approach, experimentation strengthens curiosity, flexibility, teamwork, and analytical thinking, skills essential for meaningful science learning (Cabezas Caicedo, 2024). When combined with collaborative work, experimentation also promotes exploration, object manipulation, and perseverance (Sopla Tafur et al., 2024; Ortiz & Tigrero, 2023). Providing students with opportunities to explore a physical phenomenon, formulate questions, and analyze variable behavior constitutes a fundamental component of scientific-skill development.

Argumentation is equally central to scientific thinking (Miranda Irawan & Suyono, 2024). Montaño Hilario and Padilla Martinez (2020) maintain that argumentation not only supports scientific knowledge construction but also cultivates critical and reflective thinking. Sánchez Ruiz-Tagle (2021) and Fielding-Wells (2024) emphasize that promoting argumentation enhances students' investigative abilities by enabling them to formulate, analyze, and evaluate their arguments. Furthermore, developing argumentative skills prepares students to debate and propose solutions to scientific problems in their communities, fostering social awareness (Díaz Salcedo & Ramírez- Lavao, 2024)

Collaborative Learning Supported by Virtual Environments

The demands of the twenty-first century require students to develop skills such as teamwork, critical thinking, problem solving, creativity, autonomy, and social competencies (Novia et al., 2024; Singh et al., 2022). Collaborative learning emerges as a key strategy for fostering these competencies. Ghavifekr (2020) defines collaborative learning as an environment in which students not only acquire knowledge but also develop communication, autonomy, perspective-taking, and decision-making through interaction. Integrating research activities and critical thinking into collaborative environments further promotes deep and meaningful learning (Moustafa & Al-Rashaida, 2024).

Technological advancements have significantly enhanced collaborative learning environments. Research indicates that digital tolos, including web-based platforms and educational applications, strengthen teamwork, participation, and problem-solving skills, thereby increasing peer interaction and critical engagement among secondary students (Oskarita & Arasy, 2024). Tools such as Zoom, Google Meet, and Microsoft Teams became especially relevant during the COVID-19 pandemic (Flores-Hernández et al., 2021), as they facilitated communication and collaborative work from home, helping students learn to listen, dialogue, and value their peers' contributions (Espinosa Cevallos & Saltos Zambrano, 2024)

Educational Simulators and Their Application in the Teaching of Experimental Sciences

Technological innovation has introduced valuable tools for education, among them educational simulators. Kralikova & Lumnitzer (2022) describe simulators as technological resources that use graphics and animations to allow students to observe and manipulate real-world phenomena virtually. These tools enable the recreation of situations that may be difficult to explore in traditional classroom settings due to limited resources or logistical constraints (Orrego-Riofrio et al., 2024).

The integration of simulators into pedagogical practice has broadened instructional possibilities. Contreras & Hernández (2023) argue that simulators facilitate the modeling of real situations, promote personalized interaction, and support the validation of student actions within virtual environments, processes that foster inference, deduction, and meaningful learning. Moreover, these tools can stimulate the development of strategies and skills that strengthen autonomous learning.

Orrego-Riofrio et al. (2024) and Diab et al. (2024) highlight several advantages of educational simulators:

- They reduce risks inherent in real-life experimental activities.
- They provide immediate feedback when students manipulate variables.
- They adapt to each student's learning pace.
- They increase motivation and participation by creating dynamic and interactive learning environments.

In experimental science education, simulators have proven to be valuable instructional resources (Nandani & Raturi, 2024). Research in physics education, such as that of Rosales-Guaman et al. (2023), demonstrates that simulators enable students to formulate and test hypotheses, manipulate variables, and draw evidence-based conclusions, thereby promoting greater autonomy. Additionally, simulators reduce the need for complex numerical calculations, allowing students to focus on essential scientific concepts (Lonsky et al., 2023).

3. METHODOLOGY

Study Approach and Scope

This research follows a qualitative action-research approach, which is appropriate because it enables both understanding and transforming educational practice through stages of planning, implementation, observation, and reflection (Abdullaeva, 2024). The scope of the study is descriptive–interpretative, as it seeks to describe students' experiences with the implementation of collaborative learning and educational simulators, as well as to interpret the meanings they attribute to these experiences (Syam et al., 2023).

The study was conducted in a private educational institution located in the city of Barranquilla, Colombia. Participants were 40 tenth-grade students between 15 and 17 years of age. Inclusion criteria required students to be enrolled in tenth grade during the study and to provide parental or guardian informed consent. Exclusion criteria included completing less than 50% of the experimental activities or voluntarily withdrawing from the study.

Data Collection Techniques and Instruments

The data collection techniques used were participant observation, a survey, and a semi-structured interview. Table 1 presents the instruments employed, their purposes, and the moment of application.

The techniques and instruments used to collect data were participant observation, a survey, and a semi-structured interview. Table 1 presents detailed information on these aspects.

Table 1
Techniques and Data Collection Instruments

Technique	Instrument	Purpose	Time of Application
Participant observation	Teacher logbook and group performance rubric	To record interactions, attitudes, simulator use, and collaborative dynamics	During each project session
Survey	10-item questionnaire (closed and open items)	To gather perceptions, learning outcomes, and opinions on the simulator experience	Final session of the process
Semi-structured interview	Guide with open-ended questions directed at a focal sample	To explore students' experiences, perceptions, and suggestions in depth	One week after the intervention

Instrument validation was conducted through expert judgment. Three education-research specialists reviewed each instrument and provided recommendations regarding wording, pertinence, and alignment with the study objectives. Based on these recommendations, several items were adjusted to improve clarity and methodological coherence, ensuring that the instruments were appropriate for collecting relevant and meaningful information.

Data Analysis

Data were analyzed using qualitative content analysis structured in three stages:

1. **Open coding:** segmentation of responses and identification of meaningful units of analysis.

2. **Axial coding:** grouping of data into categories and subcategories emerging from the study objectives.

3. **Selective coding:** integration of thematic patterns and development of overarching interpretations.

The analysis was conducted manually using spreadsheets (Excel), and findings were later triangulated across the different data sources. To strengthen methodological rigor, the following quality criteria were applied:

- **Credibility:** verification of findings by an external researcher.

- **Methodological triangulation:** cross-analysis of observations, surveys, and interviews.

- **Member validation:** sharing preliminary results with a representative group of participants for feedback.

Procedure

The procedure was carried out in six phases:

Phase 1. Initial diagnosis: exploration of the context and students' prior knowledge.
Phase 2. Planning and intervention: design and implementation of sessions based on collaborative

learning and simulator use.

Phase 3. Systematic observation: continuous recording of interactions and performance through field notes and rubrics.

Phase 4. Final survey: collection of student perceptions regarding the learning experience.

Phase 5. Semi-structured interviews with a focal sample: in-depth exploration of student experiences.

Phase 6. Data analysis and triangulation: coding, categorization, and cross-validation of findings.

These phases were articulated iteratively, allowing for ongoing refinement of the intervention in accordance with the principles of action research.

Ethical Considerations

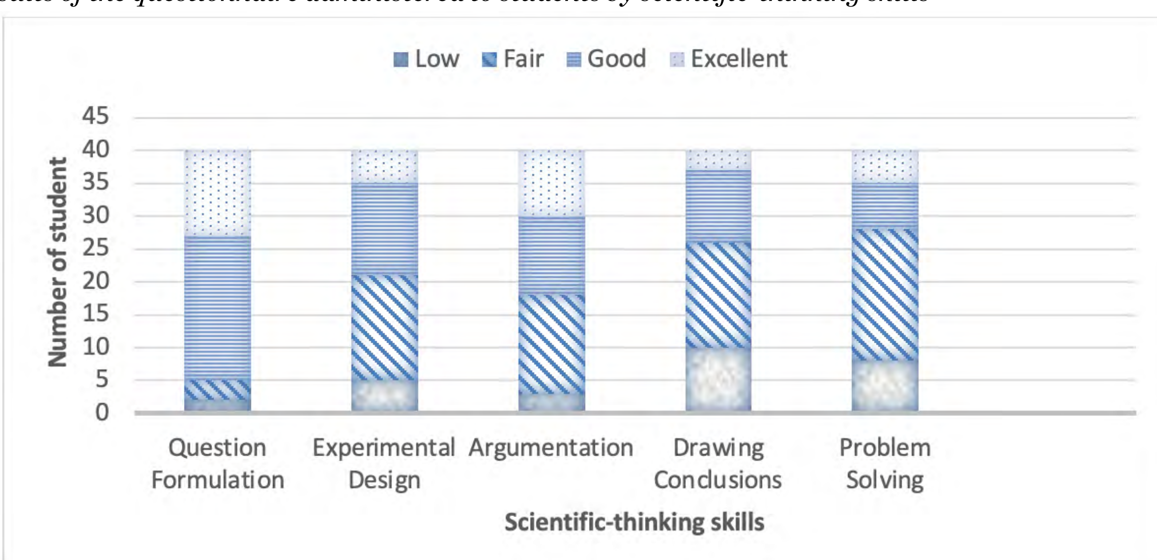
The study adhered to ethical principles aimed at safeguarding participants' rights and well-being. Parental or guardian informed consent was obtained, and student participation was entirely voluntary. Confidentiality was ensured through data anonymization and the exclusive use of findings for academic and research purposes. No physical or emotional risks were identified for participants, and the intervention was conducted in compliance with institutional and educational ethical guidelines.

4. RESULTS

The findings of the study provide consistent evidence of the positive impact of the collaborative-learning strategy supported by educational simulators on the development of scientific-thinking skills in tenth-grade students. During the initial sessions, observations revealed significant difficulties in formulating pertinent scientific questions, designing appropriate experimental procedures, constructing arguments based on empirical data, and drawing evidence-based conclusions. These difficulties were confirmed by the diagnostic questionnaire, in which more than 70% of the students obtained low performance levels in at least three of the four assessed skills (Figure 1).

Figure 1

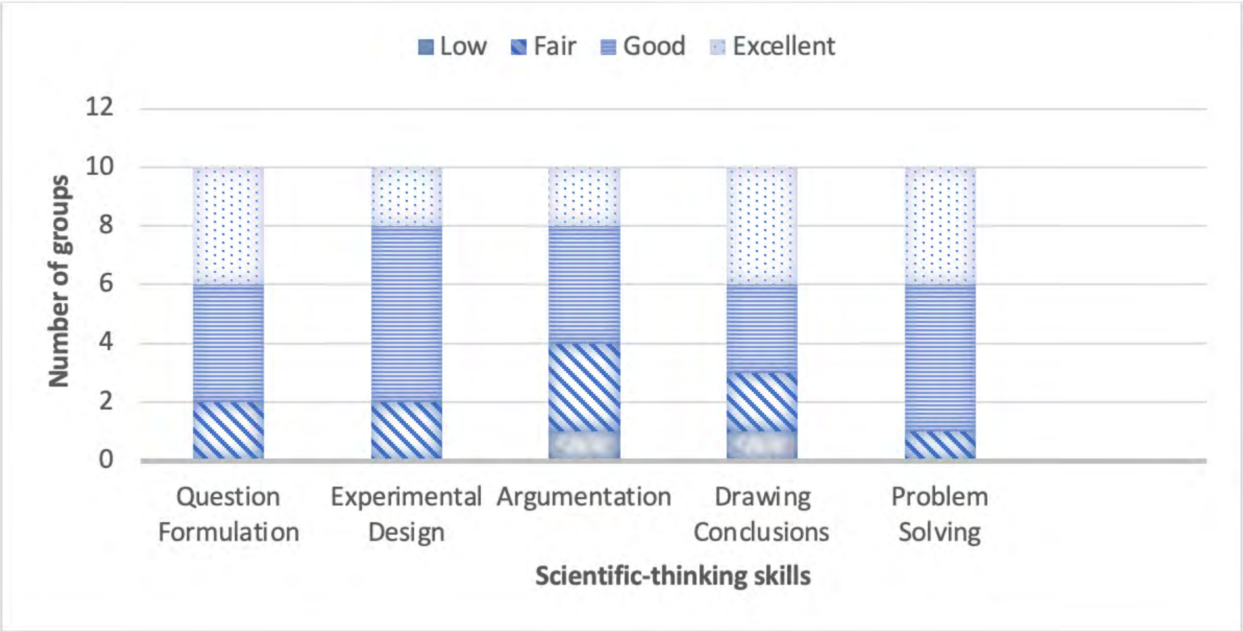
Results of the questionnaire administered to students by scientific-thinking skills



Following the implementation of the strategy, notable improvements were observed in students' performance. By the end of the third workshop, more than 80% of the student groups were able to formulate questions with clearly defined variables and design valid experimental procedures using simulation tools, as shown in Figure 2. These improvements were supported by observation logs and student interviews, in which participants reported feeling more confident when interpreting scientific phenomena and defending their ideas among peers.

Figure 2

Results Obtained by Student Groups at the Conclusion of Workshop 3



The results also indicate that virtual simulators facilitated students' understanding of concepts and the verification of variable behavior, allowing them to experiment in a flexible and safe environment. Padlet served as an effective collaborative platform through which students shared their findings, commented on their classmates' work, and received timely feedback from both the teacher and their peers. This dynamic enhanced motivation and strengthened students' sense of ownership in the learning process.

From a qualitative perspective, the content analysis of interviews and observations revealed improvement patterns related to scientific argumentation. Students demonstrated more accurate use of scientific terminology and showed a greater willingness to justify their ideas using data. They also acknowledged that the strategy encouraged active participation in workshop activities, fostering teamwork, idea exchange, and shared decision-making.

In summary, the results show that the implemented strategy not only strengthened specific scientific-thinking skills but also promoted a collaborative, active, and technologically enriched learning environment aligned with the demands of twenty-first-century education.

Table 2.
Results presented by category.

Category	Subcategory	Instrument	Result
Development of scientific thinking	*Formulation and resolution of scientific questions *Experimental design *Argumentation*-Drawing conclusions from evidence	Questionnaire Field journal Interview	The information provided by the administered questionnaires evidenced improvement in students' performance levels regarding scientific-thinking skills. Observations made by the researchers during each workshop showed significant gains in every scientific-thinking skill. Students reported that the activities enabled them to improve each of these skills.
Collaborative learning in virtual learning environments	*Motivation *Teamwork and peer support *Feedback *Opinion consensus	Field journal Interview Survey	Researchers found that teamwork enabled students to exchange opinions and viewpoints. Students reported that this alternative approach, different from traditional instruction, increased their motivation and interest in the tasks. Teacher feedback at various stages of the workshops served as an important reflective element, allowing each group to strengthen or redirect their work. The Padlet tool enabled groups to share their work with classmates and receive peer feedback on their contributions.
Simulators	*Motivation *Feedback *Experimentation *Verification	Field journal Interview Survey	The manipulation of the simulators served as a motivating element for students by allowing them to discover new aspects of the phenomena under study. The simulators provided a testing environment that helped each group refine their experimental design. The simulation tool's features enabled verification of each variable's behavior.

Note. The table presents results by category, subcategory, and the instruments used for data collection.

4. DISCUSSION

The findings of this study confirm the assertions of Mendoza-Mendoza & Loor-Camargo (2022), who highlight the importance of promoting learning environments that integrate creativity, interaction, and educational technologies to enhance scientific thinking. Consistent with Quic and Cardona (2020), the implemented strategy, based on collaborative learning and educational simulators, fostered collective knowledge construction and peer argumentation, both of which are essential for the development of scientific competencies.

Regarding the use of technologies, the results support the observations of Gómez-Duarte (2022), showing that ICT-mediated environments create opportunities to deepen conceptual understanding, identify problems, and explore solutions through experimental activities. Improvements in the design of procedures and in the verification of variable behavior align with the findings of Bizzio et al. (2024), who emphasize that simulators facilitate conceptual understanding and the safe manipulation of complex phenomena. Likewise, the opportunities for repeated experimentation and immediate feedback offered by these tools correspond with the contributions of Rosales-Guamán et al. (2023), who highlight their value in strengthening students' autonomy and data interpretation.

The incorporation of Padlet as a collaborative space reinforced the insights of Pinto (2023) and Petro de Hoyos & Monsalve Lesmes (2022), as it enabled the exchange of ideas and continuous peer feedback.

This environment contributed to elevated levels of motivation, as also noted by Abdullah et al. (2024) and Cuenca Benavides et al. (2023), who demonstrate that alternative methodologies combining collaboration and digital tools foster greater engagement and a stronger sense of ownership in the learning process.

From a qualitative perspective, the improvements observed in scientific argumentation are consistent with the work of Martelo Caballero (2023), who stresses that argumentation is a central component of scientific thinking and requires spaces that promote reflection, dialogue, and evidence-based validation of ideas. In this study, students demonstrated greater precision in the use of scientific terminology and a stronger inclination to justify their conclusions, reinforcing the effectiveness of the implemented strategy.

The original contribution of this study lies in the simultaneous integration of virtual collaborative environments and educational simulators within a unified didactic design applied in a Colombian school context with limited resources. Although existing research examines collaborative learning and simulators separately, few studies combine both elements to strengthen scientific inquiry skills in secondary education. This integrated approach demonstrates that the combination of collaborative dynamics and simulation tools not only enhances the understanding of scientific phenomena but also strengthens, in a comprehensive manner, question formulation, experimental design, argumentation, and evidence-based conclusion-making.

It is also important to consider certain tensions that contextualize the interpretation of the findings. The study was conducted in a single institution and did not include a control group, which limits the generalizability of the results. The relatively short duration of the intervention and the interpretive nature of the qualitative approach also imply that the conclusions emerge from a contextualized and situated analysis. Nonetheless, these limitations are inherent to action-research designs and do not diminish the relevance of the findings; rather, they delimit the scope of their application.

Overall, the evidence demonstrates that the implemented strategy significantly contributed to the strengthening of scientific-thinking skills and to the creation of a collaborative and technologically enriched learning environment. The integration of simulators with collaborative dynamics emerges as an innovative and viable didactic alternative for institutions with limited resources, expanding both theoretical and practical approaches in science education.

5. CONCLUSIONS

The findings of this study indicate that the strategy based on collaborative learning in virtual environments, complemented by the use of educational simulators, created a favorable setting for the exchange of ideas, reasoned debate, and joint knowledge construction. Collaborative work enabled students to formulate more pertinent scientific questions, design stronger experimental procedures, and enhance their ability to argue and draw evidence-based conclusions, advances that were reflected in the results obtained through the assessment instruments.

The use of Padlet as a collaborative tool extended interaction beyond the physical classroom, fostering continuous feedback processes among peers and between students and the teacher. Likewise, the features of the simulators enriched the learning environment by providing a virtual space for experimentation that allowed for the safe manipulation of variables and the exploration of phenomena not easily replicable in a school laboratory. This technological component contributed to increased student motivation and strengthened their active participation throughout the workshops.

One of the key lessons derived from this study is that technological resources alone do not guarantee the achievement of learning objectives. Their effectiveness depends on a carefully structured didactic design in which the teacher coherently integrates collaborative activities, simulators, and processes of reflection and scientific argumentation. In this sense, the proposed strategy becomes a valuable reference for promoting innovative pedagogical practices aimed at developing scientific competencies in educational institutions with limited resources.

Finally, this study opens new avenues for research. Future studies could examine how scientific-thinking skills evolve in longer-term or longitudinal processes, explore the integration of other types of simulators or collaborative platforms, or compare the effects of this strategy with those of a control group. Based on the findings, relevant questions emerge, such as: Which elements of collaborative work most strongly influence the formulation of scientific questions? How does the level of argumentation vary when different types of simulators are incorporated? What adjustments should be made to the didactic sequence to optimize its impact in diverse educational contexts? These lines of inquiry may guide future innovations in science education and strengthen our understanding of the dynamics that foster scientific thinking in the classroom.

Conflicts of interest

The authors declare that there are no conflicts of interest that may arise in relation to the article submitted for publication and that may involve third parties.

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