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Self-Perception of Critical Thinking in High School Students Through Scientific Inquiry on DNA Extraction

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Abstract

Background/purpose. Practical work is a key component of science education that can contribute to comprehensive learning and scientific literacy. This study presents the results of an Inquiry-Based Learning (IBL) approach using a DNA extraction practice with 4th-year secondary education Spanish students. The findings highlight significant improvements in knowledge acquisition and self-perception of critical thinking. Students reported high satisfaction and increased interest in science. This study addresses the issue of declining interest and curiosity towards science among students. The purpose is to evaluate the impact of an Inquiry-Based Learning strategy, centered on DNA extraction, on the development of self-perception of critical thinking and scientific knowledge among high school students.

Materials/methods. The study utilized a pre-experimental design with pre-test and post-test measures. It included 25 students who designed and conducted their own experiments on DNA extraction, followed by writing a scientific article. Instruments included questionnaires assessing knowledge, self-perception of critical thinking, and student satisfaction.

Results. The intervention led to significant improvements in knowledge scores (mean increase from 6.0 to 7.1) and self-perception of critical thinking, particularly in evaluating specific situations with objective and subjective data. Satisfaction levels were high, with students appreciating the hands-on and innovative approach.

Conclusion. The implementation of an Inquiry-Based Learning approach using DNA extraction improved students' knowledge and self-perception of critical thinking, particularly in evaluating situations with data. The high level of satisfaction indicates the potential of such strategies to enhance interest in science and promote scientific literacy.

1. Introduction

Science education significantly influences students' attitudes and perceptions of the subject, making it essential to present science as a human-centered and socially relevant discipline. This study focuses on understanding how scientific inquiry-based approaches, specifically DNA extraction activities, impact the self-perception of critical thinking among high school students. This area of research addresses the broader challenge of declining interest and curiosity in science as students advance in their education (Valero-Matas et al., 2017; Petrucci, 2017).

National and international assessments, such as PISA and TIMSS, have highlighted a persistent lag in scientific competence development within educational systems, particularly in Spain (PISA 2018, 2022; TIMSS, 2019). Addressing this gap is crucial, as it reflects a broader lack of readiness to meet the demands of a science- and technology-driven society (So et al., 2018). Enhancing science education not only aids cognitive development but also fosters essential skills for the 21st century, including problem-solving, rational thinking, and informed decision-making (Gopnik, 2012; Hidalgo Navarrete et al., 2023).

This study adopts a didactic intervention rooted in inquiry-based learning (IBL). The general objective is to analyze the effect of this approach on students' knowledge acquisition and their development of self-perception of critical thinking. Specifically, the study aims to:

1. Implement the inquiry-based intervention in a secondary education classroom.
2. Evaluate its impact on students' understanding of cellular biology.
3. Analyze changes in students' self-perception of critical thinking through pre- and post-intervention questionnaires.
4. Assess student satisfaction with the methodology employed.

By focusing on an innovative teaching approach, this study aims to contribute to the growing body of research emphasizing the importance of active, inquiry-driven education in fostering scientific literacy and critical thinking skills.

This research aligns with findings that scientific literacy and critical thinking are critical 21st-century skills that need to be cultivated through active and inquiry-based learning methods. Studies have shown that fostering scientific literacy enhances critical thinking, problem-solving, and communication skills, which are vital for navigating modern challenges (Seema, 2024; Vieira & Tenreiro-Vieira, 2016). Moreover, integrating real-world applications, such as DNA extraction activities, engages students and increases their scientific curiosity and competence (Forawi, 2016; Crowell & Schunn, 2016). By focusing on self-perception of critical thinking, this study emphasizes the importance of connecting educational strategies with personal and societal relevance.

The findings of this study reveal significant improvements in students' knowledge and their ability to critically evaluate and interpret scientific data. By demonstrating the effectiveness of inquiry-based learning, this research contributes to the growing need for innovative pedagogical strategies that prepare reflective and engaged citizens for the demands of the 21st century.

2. Literature Review

In secondary science education, methodologies that promote not only the acquisition of theoretical knowledge but also the development of practical and cognitive skills have become increasingly important. These approaches allow students to explore scientific concepts and foster self-perception of critical thinking, an essential competency for holistic student development. Practical work in the classroom, inquiry-based learning (IBL), and the integration of the scientific method are key strategies in science education. This review addresses the foundations and contributions of these methodologies to understand their impact on the development of self-perception of critical thinking and science learning in secondary education.

Practical work is a cornerstone of science education, enabling students to interact directly with scientific phenomena, apply theories in real-world contexts, and develop essential hands-on skills. Historically, laboratory work in science education has focused on verifying theoretical concepts, acquiring instrumental skills, and conducting measurements or observations. This empiricist-inductive approach, characterized by pre-designed, recipe-like instructions, limited the depth of learning and reduced science to a mechanistic activity (Castillo, 2021). Studies such as Vieira and Tenreiro-Vieira (2016) highlight how more dynamic and inquiry-oriented practices enhance students' engagement and critical thinking by promoting active experimentation rather than passive verification.

Contemporary education requires rethinking this methodology. Traditional, purely experimental approaches often fail to address critical aspects of scientific thinking, such as creativity, hypothesis formulation, and autonomous exploration (Carrascosa et al., 2006). Shifting to a guided inquiry-based methodology transforms laboratories into spaces where students critically investigate their environment, design experiments, and analyze results (Irwanto et al., 2019). This aligns with findings that practical work fosters deeper understanding and skills like problem-solving, hypothesis testing, and collaboration (Crowell & Schunn, 2016). Furthermore, early-stage approaches, such as the exploratory frameworks described by Gerde et al. (2013), emphasize questioning, predicting, and summarizing, laying the foundation for scientific literacy while also supporting interdisciplinary readiness in areas like language and math. Building on these foundational skills, inquiry-based approaches in secondary education further enhance students' ability to critically analyze and apply scientific concepts.

Recent advances in educational technologies, such as virtual labs and simulation software, further highlight the importance of integrating digital tools into IBL (Handelsman et al., 2004; Peralta-Roncal et al., 2022). Active, participatory methodologies, including small-scale investigations integrated into the teaching-learning process, have proven highly effective in engaging students. IBL links research and teaching, enabling students to use the scientific method under teacher guidance to construct knowledge through practical experience, collaboration, and discovery. This approach fosters scientific competencies and enhances self-perception of critical thinking (Greca et al., 2017; Irwanto et al., 2019). By integrating digital resources, students develop both digital and informational literacy, enhancing their ability to critically evaluate information (Zárate Moedano et al., 2022). This methodology improves critical thinking and logical reasoning while preparing students for lifelong learning (Moya et al., 2011; Bramastia & Rahayu, 2023).

The scientific method remains integral to developing scientific competencies, providing a structured framework for inquiry and problem-solving. Moreover, it fosters skills such as systematic analysis, logical reasoning, and critical evaluation, which are applicable in both scientific contexts and everyday situations (Diego-Rasilla, 2004; Hidalgo Navarrete et al., 2023). Key stages of the scientific process include problem definition, information gathering, hypothesis formulation, experimentation, result analysis, and communication (Arana-Cuenca et al., 2023). This structured approach not only deepens scientific understanding but also aligns with educational goals to encourage active learning and critical reflection (Seema, 2024; Crowell & Schunn, 2016).

While recent literature highlights limitations in the rigid, step-based structure of the traditional scientific method, it remains a valuable framework, particularly as a scaffold for introducing students to the fundamentals of scientific inquiry. Alternatives like Model-Based Inquiry (MBI) and IBL emphasize the iterative, exploratory, and collaborative nature of real-world science (Windschitl et al., 2008; Vázquez-Villegas et al., 2023). However, the traditional method provides a structured entry

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point for students to develop foundational skills, such as hypothesis formulation, experimentation, and data analysis, before transitioning to more open-ended, inquiry-driven approaches. This foundational use of the scientific method as a scaffold aligns with its role in structuring more complex inquiry-driven activities, such as the DNA extraction task in this study.

In this study, the classic scientific method was employed as a scaffold, guiding students through DNA extraction activities while allowing for creative adaptations and experimental design. This hybrid approach aligns with findings suggesting that combining structured frameworks with inquiry-based methods fosters both critical thinking and practical skills (McPherson, 2001; Gerde et al., 2013). By grounding the intervention in a familiar methodology, students were equipped with the tools to engage more confidently in scientific reasoning and collaborative problem-solving. This highlights the enduring relevance of the traditional method when integrated thoughtfully into innovative pedagogical strategies.

3. Methodology

The innovative proposal for teaching biology in secondary education focused on inquiry-based learning (IBL) through DNA extraction activities. This approach aimed to enhance students' scientific competence and foster essential skills such as question formulation, hypothesis development, experimental design, information retrieval, collaboration, synthesis, and scientific reporting. These competencies contribute to students' scientific literacy and the development of their self-perception of critical thinking (Arana-Cuenca et al., 2024).

3.1. Study Design

A quantitative methodology was employed with a pre-experimental design, utilizing pre-test and post-test evaluations. The pre-test included:

- An ad-hoc questionnaire assessing students' knowledge of genetics and DNA.
- A self-perception questionnaire evaluating critical thinking, based on the Generic Individual Competencies Questionnaire by Olivares y López (2017), as used by Lara Quintero et al. (2017).

The post-test repeated the same assessments to evaluate improvements in knowledge and changes in self-perception of critical thinking. Additionally, a satisfaction questionnaire was administered to assess students' acceptance and interest in the methodology.

3.2. Sample

The educational intervention was conducted in a private school in Granada province, equipped with advanced laboratory facilities. The school applies active methodologies, including project-based learning and laboratory practices, familiarizing students with similar proposals. The sample consisted of 25 fourth-year secondary students (11 female, 14 male) during the 2023/2024 academic year. The group included nine students identified as gifted and three students with learning difficulties (dyslexia and ADHD). The inquiry-based approach provided an engaging and motivating learning environment for all participants.

3.3. Intervention

The didactic intervention was designed and positively evaluated by a panel of experts. Starting with the initial question, "Can DNA be extracted?" a brainstorming session led to the inquiry question: "What is the effect of each reagent used in DNA extraction?" Students worked in teams to design experiments using the scientific method to explore this question. Each team also produced a scientific article detailing their findings.

3.4. Implementation Sequence

1. After completing the pre-test, students received a basic protocol for DNA extraction.

2. In groups, they modified the protocol to test the role of specific reagents, hypothesizing their effects and conducting controlled experiments.

3. Students performed the experiments, documented results, and captured observations through photographs.

4. Each student focused on one reagent or step, collaborating with peers to analyze results collectively.

5. Students wrote a scientific article following APA guidelines, including sections such as abstract, theoretical framework, methodology, results, discussion, and conclusions.

6. Results were discussed in class, with peer and self-assessment conducted using Likert scales, checklists, and rubrics.

3.5. Data Collection Tools

1. Knowledge Test: A 14-question multiple-choice test assessed understanding of DNA and prokaryotic/eukaryotic cell structure, with a maximum score of 10 points.

2. Critical Thinking Self-Perception Questionnaire: Adapted from Olivares y López (2017), this Likert-scale tool evaluated dimensions such as information analysis, judgment based on data, and self-regulated inference. Its reliability (Cronbach's alpha = 0.641) was deemed acceptable given the limited sample size.

3. Satisfaction Questionnaire: A validated tool from Romero-García et al. (2020), comprising 26 Likert-scale items, assessed dimensions like content delivery, planning, learning, and group interaction. Its reliability (Cronbach's alpha = 0.914) confirmed suitability.

Pre-test questionnaires were administered via Google Forms. Post-test questionnaires included satisfaction items. A follow-up assessment on critical thinking was conducted two months later to evaluate retention.

3.6. Data Analysis

Statistical analyses were conducted using SPSS 25.0 at a significance level of $\alpha = 0.05$. Non-parametric tests were applied due to the small sample size, as verified by the Shapiro-Wilk normality test ($N<50$, $p<0.05$).

1. Wilcoxon Signed-Rank Test: Used to compare pre-test and post-test results for both knowledge and critical thinking.

2. Effect Size: Calculated using Cohen's d, where values of 0.1-0.3 indicate small effects, 0.3-0.5 medium effects, and >0.5 large effects (Fritz et al., 2012).

4. Results

4.1. Knowledge Acquisition

Knowledge acquisition was assessed through a questionnaire administered before (pre-test), with an average score of 6.0±2.3, which increased to 7.1±2.3 in the post-test after implementing the intervention proposal. The sample size was 19 students (N=19), as only 19 out of the 25 initial students completed both questionnaires. The Wilcoxon signed-rank test was performed, comparing the scores of each student, and a significant difference was found (Z=-2.363 and Sig=0.018). Table 1 shows that 50% of the students improved their scores after the instructional intervention, with a large effect (calculated using Cohen's d, r=0.783).

Table 1. Average Ranks for Pretest-Posttest in Knowledge Acquisition. Wilcoxon Signed-Rank Test.

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		N	Average Ranks	Sum of ranks	Z	Sig	r
Global	Negatives Ranks	4	3.75	15.00	-2.363	0.018	0.830
	Positive Ranks	10	9.00	90.00			
	Tie	5					

4.2. Critical Thinking Self-Perception

In order to study the effect of the instructional intervention on the development of students' critical thinking self-perception, the critical thinking section of the Individual Generic Competencies Questionnaire designed by Olivares and López (2017) was used. The results are presented in Table 2, where it can be seen that, at the end of the experience, students' self-perception of their critical thinking increased.

Table 2. Self-Perception of Critical Thinking of Students Before and After the Instructional Intervention

	Pre-test		**Postest**	
	Mean	SD	Mean	SD
Global	3.44	0.37	3.65	0.42
Interpretation and analysis of information	3.21	0.53	3.32	0.54
Judgment of a specific situation with objective and subjective data	3.67	0.63	3.97	0.61
Inference of the consequences of the decision based on self-regulated judgment	3.39	0.48	3.63	0.55

To determine if this change is significant, the Wilcoxon signed-rank test was performed, comparing the pre-test and post-test of each student, finding significant differences in the overall critical thinking analysis (Z=-2.527 and Sig=0.012) as well as in Dimension 2, which assesses judgment in a specific situation with objective and subjective data (Z=-2.027 and Sig=0.043). In both cases, Cohen's d analysis showed that the effect is large (r=0.899 and r=0.696, respectively), as shown in Table 3.

Table 3. Average Ranks for Pretest-Posttest in the Development of Critical Thinking Self-perception. Wilcoxon Signed-Rank Test.

Pretest-postest comparison

		N	Average Ranks	Sum of ranks	Z	Sig	r
Global	Negatives Ranks	4	6.88	27.50	-2.527	0.012	0.899
	Positive Ranks	14	10.25	143.50			
	Tie	1					
Interpretation and analysis of information	Negatives Ranks	8	7.81	62.50	-0.663	0.507	n/a
	Positive Ranks	9	10.06	90.50			
	Tie	2					
Judgment of a specific situation with objective and subjective data	Negatives Ranks	7	6.43	45.00	-2.027	0.043	0.696
	Positive Ranks	12	12.08	145.00			
	Tie	0					
Inference of the consequences of the decision based on self-regulated judgment	Negatives Ranks	5	6.60	33.00	-1.554	0.120	n/a
	Positive Ranks	10	8.70	87.00			
	Tie	4					

Two months after the intervention, students were asked again about their critical thinking perception using the same questionnaire. The results show no significant differences between the post-test and this follow-up (data not shown, in all cases Sig>0.05). Therefore, the self-perception of the development of critical thinking increased immediately after the proposal and was maintained over time.

4.3. Analysis of Student Satisfaction

At the end of the instructional intervention, a questionnaire (Romero-García et al., 2020) was administered to analyse the students' (N=22) evaluation of this new methodology through four dimensions (Table 4). Overall, the level of student satisfaction was high (4.44±0.81), with the highest ratings in the Presentation of Content (4.52±0.68), Planning (4.43±0.86), and Learning (4.51±0.75) dimensions, while the lowest ratings were found in the Interaction with the Group dimension (4.27±0.75).

Specifically, some of the most positive aspects included on the questionnaire:

- The explanations were clear and specific (4.8±0.5)
- The workshop was challenging (4.6±0.7)
- The time dedicated to the workshop was adequate (4.6±0.8)
- It increased my creativity (4.7±0.6)
- It increased my interactions with the teacher (4.7±0.5) and with my classmates (4.7±0.6)

On the other hand, some of the lower ratings were for:

- Students' prior ideas are taken into account (3.9±1.2)

- It improves my understanding of the subject (4.0±1.1)
- The training received met my expectations (4.0±1.2)

Table 4. Descriptive Analysis of the Results from the Satisfaction Survey.

Dimensions	Mean	Standard deviation
Content Presentation	4.52	0.68
The objectives of the workshop are communicated.	4.5	0.6
A challenge related to the main objective of the workshop is posed.	4.4	0.8
Students' prior knowledge is taken into account.	3.9	1.2
Questions are formulated to reflect on the content.	4.2	0.9
The explanations were clear and specific.	4.8	0.5
Theoretical knowledge is related to the activities.	4.5	0.7
Planning	4.43	0.86
The activity was well planned.	4.3	0.6
The workshop allows seeing the application of concepts to real situations.	4.4	0.7
The workshop was challenging.	4.6	0.7
The time dedicated to the workshop was adequate.	4.6	0.8
The proposed objectives were achieved after completing the workshop.	4.2	1.1
Learning	4.51	0.75
The workshop allowed me to work following the scientific method and understand the process.	4.5	0.8
It allowed me to apply theoretical content to solve the proposed challenge.	4.6	0.6
It increased my creativity.	4.7	0.6
It increases my autonomy for learning.	4.6	0.6
It increases my interactions with the teacher.	4.7	0.5
It increases my interactions with my classmates.	4.7	0.6
It allows me to have fun while learning.	4.4	0.8
It increases my interest in the subject.	4.5	0.8
It enhances my learning outcomes.	4.6	0.5
It improves my understanding of the subject.	4.0	1.1
It increases my motivation for the subject.	4.4	0.8
Group Interaction	4.27	0.75
The size of the groups was appropriate.	4.3	1.0
All group members participated.	4.5	0.7
The final product of the workshop was based on the information discussed in the group.	4.5	0.7
Working in the group allowed me to generate a higher-quality final product.	4.6	0.7
Overall Score	4.44	0.81

Finally, three open-ended questions were asked for students to share their opinions on the experience of working with the scientific method, what they liked the most, and what they felt could be improved. Some of the feedback is presented in Table 5.

Table 5. Students' Opinion on the Instructional Experience.

What did you think of working with the Scientific Method in this way?
I liked it because it reflects a real situation. *It seemed much more innovative than just doing a project, as we have to apply what we've learned, but in the form of a challenge.* *It was the best, as there were both theoretical and practical tests.* *It seemed really cool, and we learned more than by just taking an exam.* *I really liked it because, thanks to this method, we learned in a more didactic way and had more fun.* *I loved it because I had a great time and learned a lot.* *Very fun and efficient.* *I liked this project a lot because of how it was developed, learning in a different and more fun way. I loved it!* *It seemed very innovative and fun, balancing teamwork, knowledge, and fun.* *It seemed like a very creative way to capture students' attention, and it also teaches us practical skills that we don't do in a normal class.* *Understanding the DNA extraction process.* *I really liked it. I learned a lot because if we had any doubts, we helped each other. And it's also a form of learning...*
What did you like the most?
Having to design an experiment and write an article. *What I liked the most is that we had complete autonomy to carry out the project since we had to figure out which products to omit and how to extract the DNA fibers.* *We enjoyed working in groups, and we learned a lot while doing this project.* *Doing the experiment.* *Working in a group and experimenting together.* *I liked the lab work because I prefer experimenting to writing reports.* *What I liked most was when the DNA appeared, and we could confirm that our hard work had paid off.* *What I liked the most was learning the content in a different and unique way.* *I think what I liked most was experimenting and testing things, mixing everything.* *What I liked most, without a doubt, was conducting the experiment. But after finishing it and writing the scientific article, I loved discovering the function of each element used to extract the DNA. It was super interesting and made me learn a lot more about the cell and what it does. This project has made me want to choose biology next year.*
What do you think could be improved?
Sometimes, it was difficult to make progress. *More emphasis on the practical side.* *In my opinion, the group work in this project didn't suit me completely. Some people in the group didn't work, so I suggest that next time students should form the groups. I would also give a bit more time in the laboratory.*

5. Discussion

DNA extraction is a common practice in science classes, as it integrates chemical, physical, and biological concepts. However, it is often conducted using an empiricist-inductive approach, limiting the learning depth (Castillo, 2021). Previous experiences have sought to involve students more actively, such as engaging in debates (Esteban et al., 2019) or designing protocols (Susantini et al., 2017). However, these approaches lacked full integration of the scientific method through Inquiry-Based Learning (IBL).

The present study follows the recommendations of Arana-Cuenca et al. (2024), incorporating the ten key aspects outlined by Carrascosa et al. (2006) to orient practice toward inquiry. Students were presented with an open-ended question appropriate to their educational level, fostering reflection and qualitative analysis (e.g., observing whether DNA was obtained). They formulated hypotheses to assess the influence of each step in the DNA extraction process, designed experiments and compiled their findings into a scientific article. This methodology aligns with the work of Irwanto et al. (2019), who highlighted that inquiry-based activities enhance critical and scientific thinking. Furthermore, the inclusion of article writing promotes higher-order thinking, lifelong learning, and effective communication, as demonstrated in studies by Abdurrahman et al. (2019).

The application of IBL in this study resulted in improved academic performance, consistent with prior findings reviewed by Soledispa et al. (2024). The development of students' critical thinking necessitates fostering their scientific literacy (Vázquez-Alonso & Manassero-Mas, 2018), which was effectively achieved through the inquiry process. A self-perception study on critical thinking (Olivares & López, 2017) revealed significant improvement, particularly in Dimension 2 (judgment of a specific situation using both objective and subjective data), mirroring results obtained by Plazas Alvarado (2022) with engineering students. However, Dimensions 1 (interpretation and analysis of information) and 3 (inference of consequences based on self-regulated judgment) exhibited only slight, non-significant improvements. This outcome is expected, given the single-intervention nature of the study. Increasing the frequency of similar didactic approaches could potentially enhance students' self-perception of critical thinking, as suggested by Elera Castillo et al. (2023), enabling them to apply more refined judgment in real-world contexts.

The didactic intervention aligns with expert evaluations of the proposal (Arana-Cuenca et al., 2024), which identified it as engaging and accessible, particularly for students motivated to work in a laboratory. Student satisfaction findings support the work of Aramendi Jauregui et al. (2018), who emphasized the emotional value students place on inquiry, discovery, problem-solving, teamwork, and information searching (e.g., internet use). Notably, one student remarked, "This project made me want to choose biology next year," suggesting that such didactic proposals can foster students' interest and curiosity in science. This is a crucial outcome given the current trend of declining interest in scientific careers (Valero-Matas et al., 2017; Petrucci, 2017).

In summary, the findings demonstrate that inquiry-based methodologies contribute to improved learning outcomes, foster critical thinking, and significantly enhance student engagement and satisfaction. Further implementation of similar approaches could reinforce these results, promoting both scientific literacy and curiosity—essential elements in reversing the decline in scientific vocations.

6. Conclusion

The implementation of the inquiry-based didactic proposal, using DNA extraction as a foundation for applying the scientific method, proved effective in enhancing students' understanding of cellular biology in secondary education. Additionally, this approach contributed to the development of students' self-perception of critical thinking, particularly in their ability to make judgments based on both objective and subjective data.

Beyond content acquisition, the methodology fostered essential scientific competencies such as hypothesis formulation, experimental design, and data analysis. It also promoted collaborative work and effective communication through the writing of scientific articles—key elements in cultivating higher-order thinking, scientific literacy, and lifelong learning.

Student satisfaction was notably high, indicating that the proposal successfully engaged learners and motivated them to further explore science. Such interest and curiosity are crucial in counteracting the ongoing decline in scientific vocations and encouraging students to pursue future studies in scientific fields.

In conclusion, this inquiry-based approach proved to be an effective and engaging teaching strategy, not only improving academic performance but also fostering critical thinking and increasing students' enthusiasm for science. Expanding the implementation of similar proposals could further strengthen these outcomes, supporting the development of informed, reflective citizens equipped with the skills necessary to navigate the challenges of the 21st century.

7. Suggestion

Based on the results of this study, several recommendations are proposed to enhance the observed outcomes. Increasing the frequency of inquiry-based activities throughout the academic year could further strengthen students' critical thinking skills across all dimensions, particularly in interpretation and self-regulated judgment. Expanding the scope of inquiry topics—such as genetic mutations or protein synthesis—would provide additional opportunities for students to apply the scientific method and deepen their scientific literacy. Integrating technology, including virtual laboratories and data analysis tools, could enhance student engagement and improve their data management capabilities. Furthermore, adopting interdisciplinary approaches by linking science education with other subjects, such as mathematics or ethics, could foster a more holistic understanding of real-world problems.

To support the development of students' communication and reflective skills, collaborative evaluation methods—including peer, group, and teacher assessments—should be incorporated. Ensuring the sustainability and scalability of this methodology requires adapting it for larger and more diverse student populations while prioritizing teacher training in inquiry-based learning. These recommendations seek to consolidate the successes of this intervention, fostering scientific literacy, critical thinking, and sustained engagement in the sciences.

Declarations

Author Contributions. A.A.: Proposal design, methodology, data analysis, original manuscript preparation. F.M.: Implementation of the proposal in the classroom and writing methodology section. G.G.: Literature review, conceptualization, review-editing, and writing. All authors have read and approved the final published version of the article.
Conflicts of Interest. The authors declare no conflict of interest.
Data Availability Statement. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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