Scientific Competencies and Research Skills as Common Threads in Science Learning

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ABSTRACT
The research focused on determining the results of a research skills program in the strengthening of cognitive-conceptual scientific competence in high school students of an educational unit in Quito, Ecuador. The methodology of quantitative approach, and quasi-experimental design, a questionnaire of scientific competencies was used as an instrument and had a non-probabilistic sample, for convenience of 85 students, distributed equally between the experimental group (43 students) and the control group (42 students) belonging to the third year of high school. With the implementation of the learning sessions, a significant improvement was observed in the experimental group, evidenced by an increase in the "Achieved" category and a reduction to zero in the "Start" category. Inferential analysis showed that the program had a significant impact compared to the control group, with a significance level of 0.001. In conclusion, the program has proven to be an effective tool to strengthen the cognitive and conceptual dimension in high school students, thus contributing to the achievement of Sustainable Development Goal number 4, focused on quality education.

1. Introduction

The development of scientific competencies in high school students is essential to train individuals capable of facing both the scientific and technological challenges of the twenty-first century. However, traditional science teaching, focused on the transmission of theoretical knowledge, does not provide students with the practical skills needed to formulate questions, design experiments, analyze data, and communicate results effectively. This lack limits the development of comprehensive scientific competencies.

While scientific competencies are essential to form an informed and responsible citizenry, facilitating the identification, interpretation, study, and analysis of natural phenomena (Blanchar, 2022), it is equally crucial to develop research skills. These skills encompass advanced functions of thinking and foster interdisciplinary cognitive processes. In addition, they are cultivated through the acquisition of basic research skills, structural development, socialization, and the dissemination of results (Barbachán et al., 2021).

For Rodríguez and Blanco (2021), the integration of scientific skills in curricula facilitates the connection between different types of knowledge, essential in high school curricula. The teaching of natural sciences connects teachers' methods and strategies with student learning, encouraging the development of scientific thinking (Cifuentes et al., 2020). However, in several educational contexts, science teaching focuses on theory, without providing sufficient opportunities to develop research skills in students.

Estrada et al. (2022) emphasize the importance of science didactics as an independent field, the main approaches that enrich this didactics are learning by discovery, conceptual change, directed research, and the science, technology, and society approach. With advances in neuroscience, the connectionist model of Parallel Distributed Processing emerged, which considers cognitive processes as emerging from neural networks, made up of neurons and synapses, an integrative center that interconnects with other structures to map and represent information. (Pérez & Restrepo, 2022). This model offers a greater understanding of cognitive processes, allowing the development of more effective educational strategies. The understanding of concepts and their replication is achieved through a continuous and gradual reading practice, acquiring basic theoretical knowledge through tasks that include simple and well-defined procedures, such as identifying, remembering, recognizing, and using, to meet cognitive demand (Muñoz & Charro, 2023).

The results of the PISA 2022 tests revealed a disparate performance in science among Latin American countries. While Chile and Uruguay achieved scores close to the OECD average, most countries, including Mexico, Colombia, Costa Rica, Peru, Argentina and Brazil, were below this average. However, Panama and the Dominican Republic showed significant improvements since 2018, underscoring the urgency of educational reforms that improve science instruction in the region (OECD, 2022).

In Ecuador, in the INEVAL report (2018) only 16.2% of students demonstrated a basic understanding of scientific phenomena, reaching minimum levels in science assessments. The lack of integration of practical activities in the didactic units has been identified as a significant barrier to the development of scientific competencies. The problem was aggravated by the lack of well-equipped laboratories, adequate resources and spaces for scientific research in educational units, in addition to a lack of teachers trained in research methodologies. To address these deficiencies, the implementation of a research skills program in an educational unit in Quito was crucial due to the deficiencies in students' scientific competencies.

The relevance of this study lies in its potential to offer a practical and effective solution to the current deficiencies in science education, contributing to forming better informed citizens with a greater capacity to make decisions based on scientific knowledge.

2. Methodology

A. Study design

This research used a quantitative approach and quasi-experimental study design, with the inclusion of a control group to make accurate comparisons. In addition, it focused on determining the influence of a research skills program on the strengthening of cognitive-conceptual scientific competence in high school students, through learning sessions framed in the natural sciences. Consequently, the hypothesis put forward maintained that the program would significantly influence students' conceptual understanding, their interest in science, and their ability to apply theoretical knowledge in practical contexts. Pre-test and post-test measures were used to assess the impact of the program on students' scientific competencies. According to Hernández and Mendoza (2018), in the quantitative route, rigorously following the process and logical norms guarantees that the data generated meet the standards of validity and reliability, which allows the derived conclusions to contribute to the generation of knowledge.

B. Participants and sample

The target population included 135 students in the third year of high school in science from an educational institution in Quito, distributed in morning and afternoon sessions. The inclusion criteria considered students of both genders in the third year of the bachelor's degree in science who regularly attended face-to-face classes. Students with special educational needs stemming from disabilities or medical conditions, those who did not attend regularly, and those who showed disinterest in participating in the study were excluded. The final sample consisted of 85 students, equally distributed between the experimental group (43 students) and the control group (42 students). A non-probabilistic type of sampling was used, for convenience, selecting students with characteristics similar to the target population.

C. Data Procedure and Analysis

Table 1 is presented below, detailing the stages of the procedure and data analysis carried out in the study.

Table 1. Process Stages and Data Analysis

Stages	Description
Stage 1:	Knowledge of the environment and selection of the sample Initially, familiarization was carried out with the selected educational community, identifying the key actors for the implementation of the program. The research skills program was socialized with the participants and informed consent was obtained. The sample included 43 students in the experimental group and 42 in the control group.
Stage 2:	Program Implementation The implementation of the program consisted of 15 learning sessions, developed during an academic quarter and designed to strengthen the scientific competencies of the students. The experimental group participated in practical

activities that allowed them to progressively develop their research projects in the subjects of physics, chemistry, biology and apply the skills acquired in each session.

Each session followed a structure with beginning, development and closure, aligning with the interests of the students and with the curricular objectives of the subjects immersed in the natural sciences, which fostered motivation and commitment. At the end of each session, assessment rubrics or checklists were used to measure student progress. Inquiry-based science teaching (IBS) and project-based learning (PBL) approaches were adopted to promote knowledge integration and the development of scientific competencies. The sessions of the program are briefly detailed below:

Session 1
Topic: "Discovering the Scientific Spirit"
Purpose: To develop fundamental skills for inquiry and discovery.
Methodology: IBSE, experiential learning and collaborative learning.

Session 2
Topic: "Researching for Success"
Purpose: To develop a deep and practical understanding of the different types and levels of research.
Methodology: IBSE, flipped learning, game-based and challenge-based learning.

Session 3
Topic: "Knowing the subject through variables"
Purpose: Effective choice of a research topic and adequate identification of variables.
Methodology: IBSE, flipped learning and collaborative learning.

Session 4
Theme: "Artisans of Knowledge"
Purpose: To develop the ability to formulate relevant research questions, delimit the research problem and justify its importance.
Methodology: IBEB, PBL and collaborative learning.

Session 5
Topic: "Formulating Goals and Assumptions"
Purpose: To develop the ability to formulate clear, precise, achievable research objectives and to propose research hypotheses.
Methodology: IBSE, ABS, flipped learning and collaborative learning.

Session 6
Topic: "Navigating the Ocean of Information"
Purpose: To develop the ability to search for scientific information to find, extract and analyze reliable, relevant and accurate information.
Methodology: IBEB, PBL, experiential learning and collaborative learning.

Session 7
Topic: "Building Concepts and Theories"
Purpose: To develop an in-depth understanding of the importance and structure of the theoretical and conceptual framework in the scientific research process.
Methodology: IBEB, PBL, flipped learning and collaborative learning.

Session 8
Topic: "Scientific Integrity in the Digital Age"
Purpose: To develop the ability to recognize and apply ethical practices in scientific writing.
Methodology: IBEB, PBL, flipped learning and collaborative learning.

Session 9
Topic: "Mastering Scientific Writing"
Purpose: To develop scientific writing skills in research papers.
Methodology: IBSE, ABS, flipped learning, game-based learning and collaborative learning.

Session 10
Topic: "Tools for Discovery"
Purpose: To develop the ability to use bibliographic managers for the application of citation and referencing standards in research works.
Methodology: IBEB, PBL and collaborative learning.

Session 11
Topic: "Communicating findings"
Purpose: To develop the ability to effectively communicate findings both orally and in writing.
Methodology: IBEB, PBL and experiential learning.

	Session 12 Topic: "Methodology: Step by step" Purpose: To develop the understanding and application of research methodology in academic works. Methodology: IBEB, PBL, collaborative learning and game-based learning. Session 13 Topic: "Collecting Data" Purpose: To develop the ability to analyze and interpret research data accurately and effectively. Methodology: IBEB, PBL, experiential learning and collaborative learning. Session 14 Topic: "From Analysis to Action" Purpose: To develop the ability to formulate conclusions and recommendations based on the results of scientific research. Methodology: IBEB, PBL, experiential learning and collaborative learning. Session 15 Theme: "Disseminating science" Purpose To develop the ability to present and publicly support research projects in a clear, coherent and effective manner. Methodology: IBEB, PBL, experiential learning and collaborative learning.
Stage 3:	Initial data collection Sociodemographic data were collected from participants to contextualize the study. Subsequently, pre-test evaluations were carried out to measure the scientific competencies of the students before the intervention. These initial evaluations made it possible to establish a baseline to compare subsequent results and evaluate the impact of the program on the development of scientific competencies.
Stage 4:	Post-intervention data collection At the end of the program, post-test evaluations were carried out in both groups to measure the impact of the intervention. This second data collection made it possible to evaluate the effects of the program on the students' scientific competencies.
Stage 5:	Data analysis and processing A data analysis approach was used at the descriptive and inferential levels. Statistics were used to summarize the distribution of scientific competencies before and after the intervention, using graphs and tables generated in SPSS to facilitate interpretation. A variety of statistical tests were applied, including the Shapiro-Wilk normality test to verify data distribution and the Mann-Whitney U test to compare differences between the experimental group and the control group before and after program implementation.
Step 6:	Interpretation and contextualization of results The results were interpreted based on the objectives of the study, analyzing the data to identify significant findings. These results were contrasted with previous studies and integrated into the existing theoretical framework to contextualize the impact of the program.
Stage 7:	Feedback and dissemination of results Finally, an ethical process was implemented to communicate the results to the study participants and to members of the academic and research community. This step ensured that the findings were shared with stakeholders, promoting transparency and practical application of the results.

Source: own elaboration 2024

D. Materials, techniques and instruments

Data collection was carried out using a questionnaire of scientific competencies, developed and validated for this study, with a reliability coefficient (Cronbach's Alpha) of 0.89. This questionnaire covered the cognitive-conceptual dimension, covering fundamental aspects of scientific knowledge and research skills.

The questionnaire, designed to address descriptive problems and the relationship between variables, made it possible to collect significant information and precisely define the focus of the study. Its validity was guaranteed through an expert judgment procedure, in which five specialists evaluated and approved its content. To support the educational program, didactic and technological tools such as multimedia resources, specific educational software and communication technologies were used.

3. Results

The analysis of the results achieved before and after the implementation of the program is presented below, together with its corresponding quantitative description.

Table 2. Cross-referencing data from groups of the Cognitive-conceptual dimension

Cognitive - conceptual cross-table*Groups

			Groups				Total
			Input control	Experimental Input	Control output	Experimental output	
Cognitive conceptual	-Beginning	fi	4	10	6	0	20
		%fi	9,5%	23,3%	14,3%	0,0%	11,8%
	In process	fi	33	25	28	24	110
		%fi	78,6%	58,1%	66,7%	55,8%	64,7%
	Accomplished	fi	5	8	8	19	40
		%fi	11,9%	18,6%	19,0%	44,2%	23,5%
Total		fi	42	43	42	43	170
		%fi	100,0%	100,0%	100,0%	100,0%	100,0%

Source: own elaboration 2024 (SPSS program).

In the control entry group, 78.6% of the students were placed "In process", 11.9% in "Achieved" and 9.5% in "Beginning". For the experimental entry group, the distribution was more balanced: 58.1% of the students were "In process," 23.3% in "Beginning," and 18.6% in "Achieved."

In the exit evaluation, the control group showed notable progress, with 66.7% of students "In process" and 19.0% in "Achieved", while the percentage in "Beginning" decreased to 14.3%. In the experimental group, even greater progress was observed: 44.2% of students reached the "Achieved" level and 55.8% remained "In process", with no students at the "Start" level.

This analysis suggests that the research skills program showed a positive impact on improving cognitive-conceptual scientific competence, especially in the experimental group. The significant reduction in the number of students at the "Start" level and the increase in the "Achieved" level show the positive effect of the intervention. On the other hand, it is observed that in the control group, without the application of the experimental treatment, the students did not show significant changes, they remained mostly at the initial and process levels, with only a slight improvement in the level achieved.

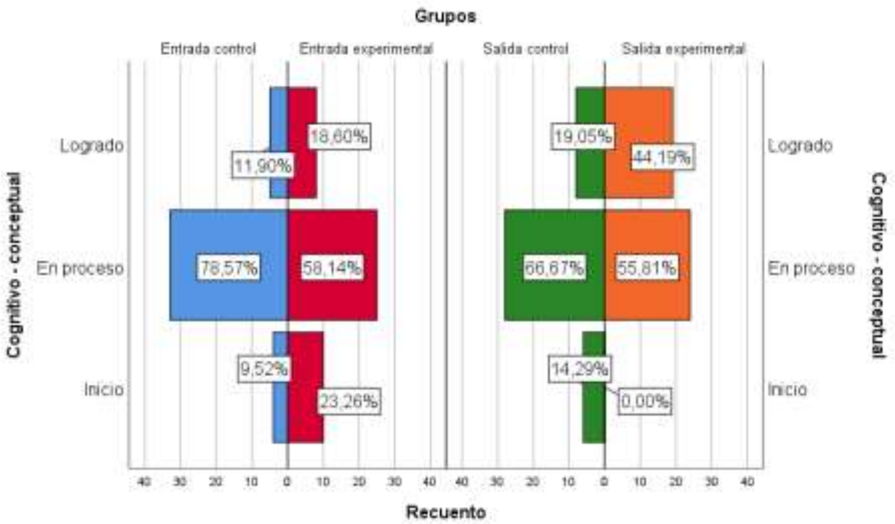

Figure 1. Cross-referencing of group data on the cognitive-conceptual dimension

Note: Developed by the SPSS program. In original language Spanish

Figure 1 compares the cognitive-conceptual competence of the control and experimental groups. The distribution of students in the "Beginning", "In process" and "Achieved" levels before and after the intervention is shown. The figure reinforces the findings presented in table (2), visually showing the progress in the cognitive-conceptual competence of the students. The notable increase in the proportion of students who achieved the "Achieved" level in the experimental group highlights the effectiveness of the program.

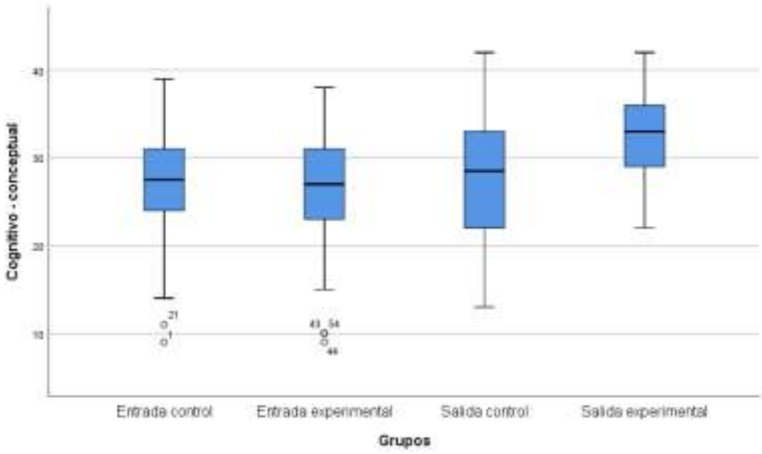

Figure 2. Comparison of cognitive-conceptual competence of control and experimental groups.

Source: Prepared by the SPSS program. In original language Spanish

Figure 2 illustrates the comparison of cognitive-conceptual competence between the input and output groups, both control and experimental, and provides a clear view of the percentage distribution of students in each category and group. The data show that, while both groups (control and experimental) started with comparable medians, the experimental exit group exhibits a significantly higher median and lower dispersion compared to the control group. This indicates not only an improvement in proficiency, but also a greater uniformity in the achievements of the students in the experimental group. The absence of outliers in the experimental exit group highlights the effectiveness of the program, suggesting that the benefits of the program were consistent among participants.

Regarding the inferential results, a hypothesis test was performed using the non-parametric Mann-Whitney U statistic, see table (3) to evaluate the impact of the research skills program on the strengthening of scientific competencies.

Table 3. U Mann Whitney hypothesis test of the Cognitive-conceptual dimension

Ranges

Groups		N	Average Range	Sum of ranks	Test statisticians	
Cognitive conceptual	Input control	42	43.87	1842.50	U de Mann-Whitney	866.500
	Experimental Input	43	42.15	1812.50	Z	-0.321
	Total	85			Asymptotic Sig.	0.748
	Control output	42	34.04	1429.50	U de Mann-Whitney	526.500
	Experimental output	43	51.76	2225.50	Z	-3.315
	Total	85			Asymptotic Sig.	0.001

Source: Prepared by the SPSS program.

The inferential results obtained using the Mann-Whitney U test clearly demonstrate the effectiveness of the research skills program in strengthening students' cognitive-conceptual competence. Although the control and experimental groups started with similar levels of scientific competence, the significant differences observed in the exit evaluation, with a p-value of 0.001, show that the experimental group experienced substantial improvements thanks to the intervention. These findings validate the hypothesis that the research skills program has a positive impact on the development of scientific competencies, highlighting the need to integrate this type of program into the educational curriculum to promote deeper and more effective learning in high school students.

4. Discussion

The most significant finding of this research is that the implementation of the research skills program showed a positive influence on the strengthening of students' cognitive-conceptual scientific competence. Statistical tests showed statistically significant differences in the performance of students in the experimental group compared to control groups, confirming the effectiveness of the intervention. This result is crucial, as it evidences the effectiveness of the research-based pedagogical approach, highlighting its potential as an effective educational tool.

These results suggest that research skills programs are an effective strategy to improve scientific competencies in students. When comparing and contrasting the findings of this study with previous research, a remarkable consonance is observed with the results of Guamán et al. (2020), who emphasize that scientific competencies imply an efficient combination of different levels of performance and complexity, encompassing behavioral, cognitive, and behavioral elements. This study reaffirms this perspective by demonstrating how the program strengthens cognitive-conceptual scientific competence in secondary school students.

Likewise, the findings are aligned with those of Lu et al. (2020), who argue that the integration of cognitively demanding learning tasks, such as criticism and reflection, is effective in fostering critical thinking and competence in scientific research. The results reinforce the idea that these practices promote a deeper understanding of scientific concepts. Therefore, integrating activities that cognitively challenge students should be a priority in curriculum design.

Regarding scientific competence, Arrieta and López (2021) highlight the importance of effective planning in the classroom, evidencing significant improvements in scientific inquiry, although with basic competencies in the explanation of phenomena and the comprehensive use of scientific knowledge. In contrast, Villamizar (2024) points out that there is a low level of strategic and extended scientific competencies in students, with a predominance of rote and conceptual knowledge. These findings underscore the need for educational programs that strengthen both inquiry and understanding as well as strategic skills, essential for intellectual autonomy in a technologically advanced society.

Additionally, the importance of specific pedagogical approaches is highlighted, consistent with the research of Petermann and Vorholzer (2022), who point out that explicit instruction and the integration of concepts of scientific inquiry in lessons significantly improve students' ability to formulate scientific questions and carry out research. However, they differ from the results of González et al. (2021), who found that students face difficulties in extracting key ideas and arguing coherently, which may be related to variations in educational contexts and teaching methodologies used. Therefore, it is crucial to adapt pedagogical approaches to the particularities and needs of each group of students in order to optimize the benefits of research skills programs.

In terms of research skills, the program implemented in the experimental group has been shown not only to strengthen students' cognitive-conceptual scientific competence, but also to improve their ability to make informed choices and address problems effectively. These findings highlight how scientific research contributes to the formation of competencies in students, developing their critical thinking and their capacity for inquiry (Romero et al., 2022), confirming that scientific research competencies imply the ability to use scientific knowledge to identify problems, acquire new knowledge, explain phenomena, and draw conclusions based on evidence (Hernández et al., 2021).

On the other hand, the positive results obtained highlight the academic need to continue implementing formative research to strengthen research skills in students, which is confirmed by Hernández et al. (2021) who consider that this approach not only facilitates the acquisition of theoretical knowledge, but also allows students to apply it in practice. In addition, Charumbira et al. (2021) underline the need to define a clear set of core competencies in research to improve training in research methods. In this way, it is ensured that students not only gain theoretical knowledge, but also cultivate practical skills essential for their academic and professional future.

Similarly, Iovu and Bărbuță (2022), point out that the selection of specific tasks should be based on students' previous experiences and knowledge to achieve a deeper and more multifaceted understanding of relationships in the social environment. In addition, Khan et al. (2019) suggest that prior knowledge plays a crucial role in the development of scientific competencies. These studies support the hypothesis that a pedagogical approach that considers prior knowledge and uses updated methodologies can significantly enhance scientific competencies in students, thus corroborating the results obtained in this study.

In this context, Ciraso et al. (2022) point out that there are shortcomings in the scientific training of students, especially in the knowledge of the state of the art, content, and communication skills, which highlights the need to improve these aspects. Similarly, Narváez and Bravo. (2022) state that traditional pedagogical practices limit the development of scientific skills, suggesting the adoption of critical and innovative pedagogical approaches to foster curiosity and critical thinking.

Similarly, the position of Mendoza (2024) is reaffirmed, who emphasizes the importance of teacher updating and the use of educational technologies to meet students' expectations in a modern learning environment. Taken together, these studies support the conclusion that the implementation of research skills programs, together with continuous teacher training and innovative methodologies, is crucial to improve students' cognitive-conceptual scientific competence.

In short, it is imperative that educational programs focused on strengthening scientific competencies through research skills not only transmit theoretical knowledge of the natural sciences, but also train students in the practical implementation of this knowledge in real situations. This aspect is similar to what Erneta and Casas (2020) have argued, who stress that facing contemporary challenges requires a complex task, and it is essential that citizens receive solid scientific literacy, develop practical skills, and acquire values that foster critical judgment.

5. Conclusions

The results of the study show that the research skills program implemented had a positive and significant impact on strengthening the cognitive-conceptual scientific competence of high school students. Inferential analyses show substantial improvements in the experimental group, validating the effectiveness of the program.

The findings of this study contribute significantly to the field of science education, providing empirical evidence on the effectiveness of specific research skills programs, which underscores the importance of incorporating innovative educational strategies that promote the development of cognitive competencies in students, thus preparing future researchers and professionals with a solid foundation in scientific methods. The students who participated in the program showed a notable improvement in their cognitive-conceptual competence, going from initial levels comparable to the control group to significantly higher levels in the exit evaluation. This suggests that the program not only facilitates the acquisition of knowledge, but also the deep understanding and effective application of scientific concepts.

The lower dispersion observed in the results of the experimental exit group indicates that the research skills program promotes a more uniform improvement among students. Likewise, a small group of students did not show significant improvements in their cognitive and conceptual skills. This anomalous result could be explained by individual factors such as motivation or interest in science, knowing this is particularly relevant to reduce learning gaps and ensure that all students achieve an adequate level of scientific competence. The integration of research skills programs into the educational curriculum is revealed as an effective strategy to enhance the development of scientific competencies. This approach not only better prepares students for higher education and for future careers in scientific and technological fields, but also fosters critical thinking and problem-solving skills, essential skills in the contemporary world.

However, it is important to recognize some limitations related to the sample used in this research. The use of non-probabilistic convenience sampling may have introduced biases in the selection of participants, which limits the generalization of the results to the total population of high school students in science. This limitation suggests the need for future studies that incorporate probabilistic sampling methods and consider a more diverse and inclusive sample to validate and expand the results obtained.

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