

Chemical Laboratory on Context: Input for Development of Critical Thinking Skills

- Laboratório de química sob contexto: entrada para o desenvolvimento de habilidades de pensamento crítico
- Laboratorio de química bajo contexto: insumo para el desarrollo de habilidades de pensamiento crítico

Abstract

In university education, of professionals related to chemistry, there has been a concern for the development of critical thinking skills. However, it is clear that during the performance as professionals, some difficulties are identified in using this skill when trying to solve situations own of his professional work. A probable explanation to this problem is that, despite the effort made by teachers to design new teaching strategies, these have not been entirely effective, and on the other hand, it is identified that still persists in some teachers the traditional conception of teaching based on a rote process. In order to contribute in the study of the exposed problems, this research shows the results of a study in which activities and strategies are applied around the chemistry of food. We worked with a group of students registered in the subject of Chemistry Agroalimentaria of the Degree Program in Chemistry of the National Pedagogical University, located in Bogotá - Colombia, who worked on some experiments under certain contexts. As a result, a favoring in the development of critical thinking skills is observed, evidenced by the evaluation of a series of mini-projects.

Keywords

critical thinking; didactic; teaching of science; problem-solving; teaching-learning; mini-projects

Resumo

No ensino universitário, dos profissionais ligados à química, tem havido uma preocupação com o desenvolvimento de habilidades de pensamento crítico. Porém, fica claro que durante a atuação como profissionais, algumas dificuldades são identificadas no uso dessa habilidade ao tentar resolver situações próprio de seu trabalho profissional. Uma provável explicação para este problema é que, apesar dos esforços feitos pelos professores para projetar novas estratégias de ensino, estes não têm sido totalmente eficazes, e em segundo

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lugar, identifica-se que a concepção tradicional de educação ainda persiste em alguns professores baseado em um processo de memorização. A fim de contribuir no estudo dos problemas expostos, esta pesquisa mostra os resultados de um estudo em que atividades e estratégias são aplicadas em torno da química da alimentação. Trabalhamos com um grupo de alunos matriculados na disciplina de Química Agroalimentar do Programa de Licenciatura em Química da Universidade Pedagógica Nacional, ubicada em Bogotá - Colômbia, quem trabalharam em algumas experiências em determinados contextos. Como resultado, observa-se um favorecimento no desenvolvimento de habilidades de pensamento crítico, evidenciado pela avaliação de uma série de mini projetos.

Palavras-chave

pensamento crítico; didático; ensino de ciências; resolução de problemas; ensino-aprendizagem; mini projetos

Resumen

En la formación universitaria de profesionales afines a la química ha existido la preocupación por el desarrollo de la habilidad de pensamiento crítico; sin embargo, es claro que durante el desempeño como profesionales se identifican algunas dificultades en valerse de esta habilidad al tratar de resolver situaciones propias de su quehacer profesional. Una explicación probable a esta problemática es que, a pesar del esfuerzo de los docentes por diseñar nuevas estrategias de enseñanza, estas no han sido del todo efectivas, y por otro lado, se identifica que aún persiste en algunos profesores la concepción tradicional de enseñanza basada en un proceso memorístico. A fin de aportar al análisis de la problemática expuesta, este artículo de investigación, tipo mixta, muestra los resultados de un estudio en el que se aplican actividades y estrategias en torno a la química de los alimentos. Se trabajó con un grupo de estudiantes registrados en la asignatura de Química Agroalimentaria de la Licenciatura en Química de la Universidad Pedagógica Nacional, ubicada en Bogotá (Colombia), quienes adelantaron algunos experimentos bajo contextos determinados. Como resultado, se observa un favorecimiento en el desarrollo de habilidades de pensamiento crítico, evidenciado mediante la evaluación de una serie de mini proyectos.

Palabras clave

pensamiento crítico; enseñanza superior; resolución de problemas; enseñanza/ aprendizaje; miniproyectos

Introduction

The importance of learning to learn in students is undeniable, and to this extent, improving the quality of thinking emerges as one of the significant challenges for teachers today. Thus, competency-based education represents a valid strategy for students to develop skills to face a world governed by uncertainty (Ortiz et al., 2015).

In this sense, competency-based training suggests that education should enable the construction of knowledge as the axis for the development of thinking; however, it seems not to guarantee the development of critical thinking skills, as some research from the 1980s indicates (Whimbey, 1985; Perkins, 1985; Glaser, 1984).

Recently, some authors have mentioned the importance of curriculum proposals to break away from the memorization trend in educational processes, as this seems to hinder the development of critical thinking skills (Castillo and Martínez, 2017). Therefore, there is currently an open explosion of information, where the immediate availability of it, not necessarily valid, requires people to develop critical thinking to select relevant information effectively. It is essential to replace the memorization trends still present in education (Santiago, 2016) with methodologies that encourage it.

In this way, it is crucial to focus the efforts of teachers on structuring and developing proposals that promote such skills through systematized actions in relevant academic spaces. In this context, this article presents the results of a classroom intervention with ninth-semester students in the Chemistry Education program at the Universidad Pedagógica Nacional. They were enrolled in the agri-food chemistry emphasis course to develop interpretative and argumentative skills of critical thinking within

the framework of activities contextualized to problems related to food chemistry.

Theoretical Framework

Critical Thinking Skills

Memory-centered learning has been widely criticized, especially in the 1980s. Researchers discussed developing thinking skills in the school environment (Fancione, 1990), including reflective, rational, and critical.

Some authors have tried to define critical thinking: Robert Ennis and Millman (1985) understand it as rational and reflective thinking focused on what to do or believe at a specific moment. In other words, it privileges reason over different dimensions of thinking, showing a tendency toward action, and from which the resolution of problems arises as the context that conditions critical thinking to understand the nature of problems rather than generating solutions to them.

Later, Ennis (2011) expands the definition of critical thinking in terms of skills (cognitive component) or dispositions (affective component). This includes skills that allow the individual to make reliable judgments about the credibility of a statement or the appropriateness of an action (Campos, 2007). Other authors refer to critical thinking as metacognitive and epistemological evaluation competencies with implications for the teaching process (Saiz and Fernández, 2012; Kuhn and Weinstock, 2002).

On the other hand, from a psychological perspective, the concept of critical thinking skills has two components: one of cognitive order and another more of the self-regulatory domain, framed in complex high-level thinking skills, including skills such as comprehension, deduction, categorization, and the issuance of

evaluative judgments, among others, all necessary to achieve critical decisions in a situation. In this sense, Paul et al. (1995) and Díaz-Barriga (2001) agree that thinking is not equivalent to the sum of specific skills separated from their content and contexts.

Boisvert (2004) defines critical thinking from three dimensions: a thinking strategy, an investigation, and a process. A thinking strategy is about the coordinated operations necessary to perform any activity, whether making decisions, solving problems, or understanding a concept or construct.

On the other hand, Kurfiss (1988) interprets critical thinking as a research process in which questioning, hypothesis construction, and conclusions that can justify various phenomena are presented as essential for individuals to develop critical thinking skills.

Finally, several authors conceive it as an active process where appropriate attitudes (open-mindedness and intellectual honesty) and a series of reasoning and research abilities condition the development of critical thinking skills (Zechmeiser and James, 1992). Brookfield (1991) considers it a process consisting of an alternation between a series of phases of analysis and action fundamental to such a process. These phases are:

1. The emergence of a situation that was not addressed.
2. Evaluation of the situation.
3. Search for explanations or solutions to the situation under study.
4. Conception of different perspectives regarding the situation.
5. Resolution of the situation.

Facione (2007) discriminates interpretation, analysis, evaluation, inference, explanation, and self-regulation as essential cognitive skills for developing critical thinking. He also determines curiosity about a wide range of issues, concern for being and staying well-informed, and alertness to opportunities to use such thinking.

Similarly, he considers confidence in reasoned research processes, self-confidence in one's reasoning abilities, openness to divergent worldviews, and flexibility in considering alternatives and opinions from others as necessary attitudes for a person to have critical thinking. Table 1 summarizes each skill proposed by Facione (2007).

Table 1. Cognitive skills

Skill	Goal	Subskill
<i>Interpretation</i>	Understanding and expressing the meaning or relevance of various experiences, situations, data, events, judgments, beliefs, rules, procedures, or criteria.	Categorization, decoding of meaning, and clarification of sense.
<i>Analysis</i>	Identifying the relationships of real and assumed inferences between statements, questions, concepts, or other forms of representation intended to express judgment, experiences, reasons, information, or opinions.	Examine ideas, detect, and analyze arguments.
<i>Evaluation:</i>	Assessing the credibility of statements and the logical strength of actual or assumed inference relationships between statements, descriptions, or questions.	
<i>Inference</i>	Identifying and ensuring the necessary elements to draw reasonable conclusions, formulate conjectures and hypotheses, and draw consequences from data, statements, principles, evidence, judgments, opinions, concepts, descriptions, or questions.	Questioning evidence, proposing alternatives, and drawing conclusions.
<i>Explanation:</i>	Ability to present the results of one's reasoning reflectively and coherently.	Describing methods and results, justifying procedures.
<i>Self-regulation:</i>	Self-aware monitoring of one's cognitive activities and the results obtained, particularly applying analysis and evaluation skills, with the idea of questioning, confirming, or correcting one's reasoning.	Self-examination and self-correction.

Source: Taken from Facione (2007)

Instruments for Assessing Critical Thinking

One of the significant challenges in assessing critical thinking is the development of instruments that can incorporate all the inherent skills. However, several instruments are related to this in documents from the Association of American Colleges and Universities (Butler, 2012).

Nevertheless, they have been criticized regarding their validity and reliability, with arguments of both conceptual and methodological nature (Saiz and Rivas, 2011). In some cases, the criticisms stem from the plurality of concepts related to critical thinking. In contrast, in others, they are related to the type of closed-response format, as it goes against the principles of critical thinking.

Another instrument developed is the Cornell Test of Critical Thinking, created by Ennis

and Millman (1985) and applied by various researchers such as Calle (2013). This instrument is limited as it is designed for individuals aged 9 to 18, has a multiple-choice structure, and assesses skills such as induction, source credibility, observation, semantics, deduction, and hypothesis identification.

On the other hand, the California Critical Thinking Skills Test (Facione, 1990) is designed for the university context and evaluates five cognitive skills: interpretation, analysis, evaluation, explanation, and inference. The theoretical construct of the instrument aligns with the conceptualization of critical thinking promoted by the California State University System (Calle, 2013).

In this context, the present research aims to validate, through expert judgments, an instrument composed of open-ended questions focused on identifying critical thinking skills,

particularly interpretation, and argumentation, among a group of university students enrolled in the last two semesters of the Bachelor's program in Chemistry. Additionally, practical activities are developed in the classroom, framed within the concept of mini-projects contextualized in the specific problems of food chemistry.

Rationale

As an experimental science, chemistry requires individuals with developed critical thinking skills to analyze, interpret results, propose hypotheses, infer, evaluate, and suggest explanations for phenomena arising in the transformations of matter. Therefore, there is a need for educational research at the university level focused on the explicit development of critical thinking skills.

This research is justified in developing interpretation, analysis, and inference skills as part of critical thinking based on practical work in the chemistry laboratory, supported by experiments in the context of food chemistry.

Additionally, it is crucial to design an instrument that identifies critical thinking skills for a population with the characteristics defined in this research, as existing instruments are generic and do not consider the particularities of the population.

Methodological Design

The methodological framework aligns with pre-experimental research, involving the design and implementation of instruments to diagnose the development of interpretation and argumentation skills in the target population. Subsequently, experimental work is conducted in the laboratory through mini-projects, addressing problems related to the composition of foods, especially parameters such as moisture, fat, carbohydrates, fiber, and proteins. Finally, the initial instrument is applied to demonstrate the effect of the activities on the promotion of critical thinking skills.

The methodological design consists of situations, activities, and experiences from which knowledge is constructed and reconstructed, adjusting to the socio-cultural context. For this research, two stages are used: the initial stage, where the initial diagnostic instrument is designed, validated, and applied, and the second stage, which involves the development of structured experimental practical work in the form of mini-projects, monitored and evaluated from the perspective of promoting critical thinking skills.

Stage 1: Initial Diagnostic Instrument

Here, data is collected to identify the level of development of critical thinking skills in students enrolled in the Bachelor's program in Chemistry, specifically in the specialization cycle (last three semesters). It is important to note that one of the program's objectives during this cycle is to develop research competencies.

The process begins with applying an initial instrument (appendix) previously validated by experts. This instrument consists of six open-ended questions that assess the degree of development of interpretation and argumentation skills. The questions are designed to evaluate these skills through problem situations in the context of food chemistry.

Stage 2. Development of Teaching Material, Experimental Work in the Chemistry Laboratory, and Evaluation of Critical Thinking Skills

A type of work is proposed using mini-projects based on problem-solving as a didactic strategy. The aim is to promote the development

of interpretative and argumentative skills, characteristic of critical thinking, by presenting problem situations in the context of food chemistry.

The collected data are systematized and analyzed using statistical packages such as SPSS and *Atlas.ti* to statistically identify indicators of correlation between the activities carried out and the development of skills. Additionally, the texts presented in the laboratory reports are analyzed to identify the concepts' families and networks. This way, the goal is to determine the level of development of critical thinking skills. The methodology used is summarized in Figure 1.

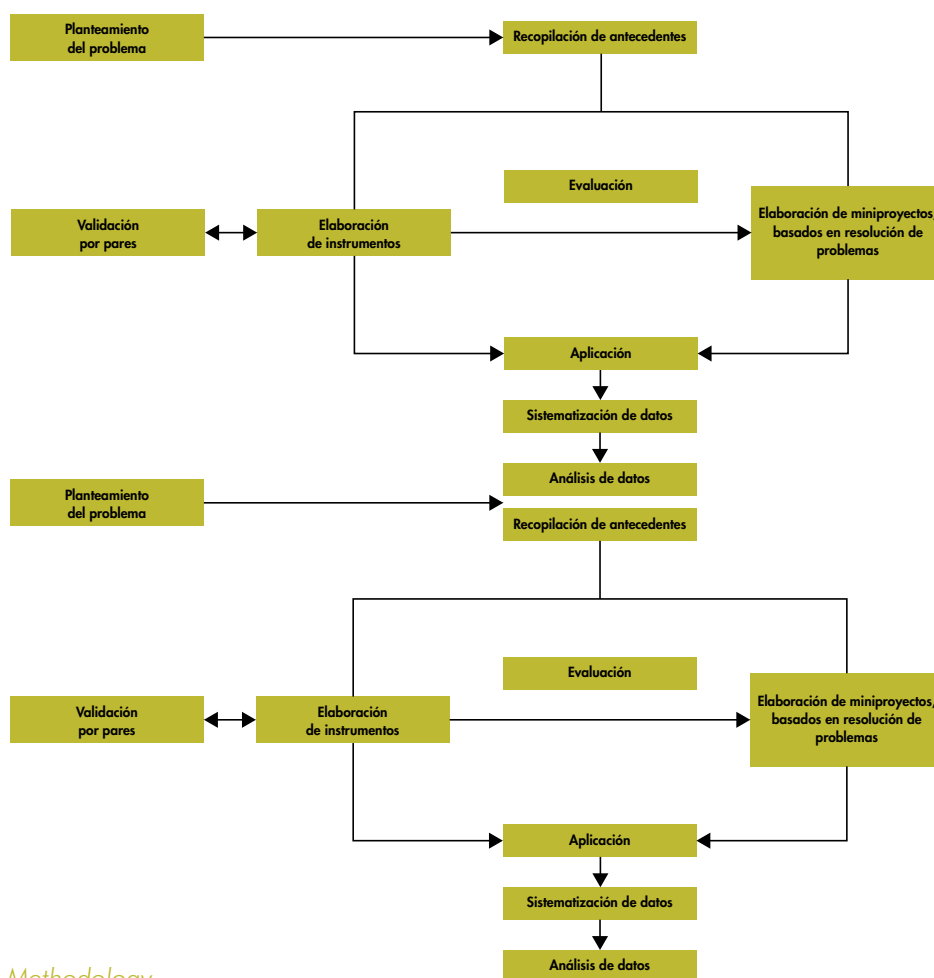


Figure 1. Methodology

Source: Own elaboration.

Population

The study focused on 32 students from the Bachelor's program in Chemistry at the Universidad Pedagógica Nacional, enrolled in the deepening cycle and have completed at least seven academic semesters.

This research is based on the parameters of a pre-experimental model, under the postulates of a mixed research design in which data are collected through chronological series with a single group, without a control group, aimed at analyzing the influence of problem-solving on the development of specific critical thinking skills proposed by Facione (2007).

Results and Discussion

During the second half of the 20th century, there were recurring questions about education practices based on memorization, leading society to perceive the need to innovate educational processes. Likely, the influence of the Industrial Revolution prompted educational research to focus on promoting reflective activities (Santiago, 2016), where students play a much more participative role in their education.

In this context, an initial instrument with six open-ended questions (appendix) was designed to inquire about the level of development of argumentation and interpretation skills, using the theme of proteins in the context of food. This instrument was previously validated by five experts, all with doctoral studies in education and experience in university education in chemistry. One expert specialized in food chemistry, and another with teaching experience in analytical chemistry. They evaluated each question using an evaluative matrix (where they were asked to mark the value they considered with an "X", considering that 1 is very low and 5 is very high), as shown in Table 2.

Table 2. *Evaluative Matrix for Instrument Validation*

Question	Level of interpretation needed in order to respond					Argumentation level necessary to respond				
	1	2	3	4	5	1	2	3	4	5
1										
2										
3										
4										
5										
6										

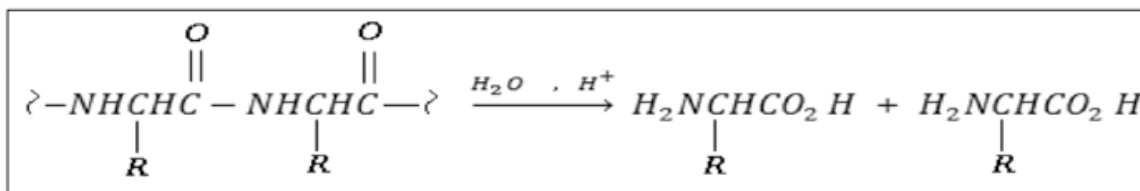
Note: Mark with an "X" the value you consider, considering that 1 is very low and 5 is very high.

Source: Own elaboration.

Cronbach's alpha values of 0.803 for interpretation and 0.702 for argumentation were obtained, indicating good instrument reliability in identifying these critical thinking skills.

Once the initial instrument was validated, it was applied to the group of students and evaluated with the matrix presented in Table 2. Figure 2 shows the result for the first question.

- a. Proteins are amino acids, which, by hydrolysis, produce polyamides linked by a characteristic bond called a peptide bond. This structural property allows measuring the formation of ammonia present in a food sample due to the nitrogen content, carrying out an oxidation reaction and thus determining the so-called crude protein.



According to the previous reaction, do you think there is any expression that invalidates the text? Justify your answer.

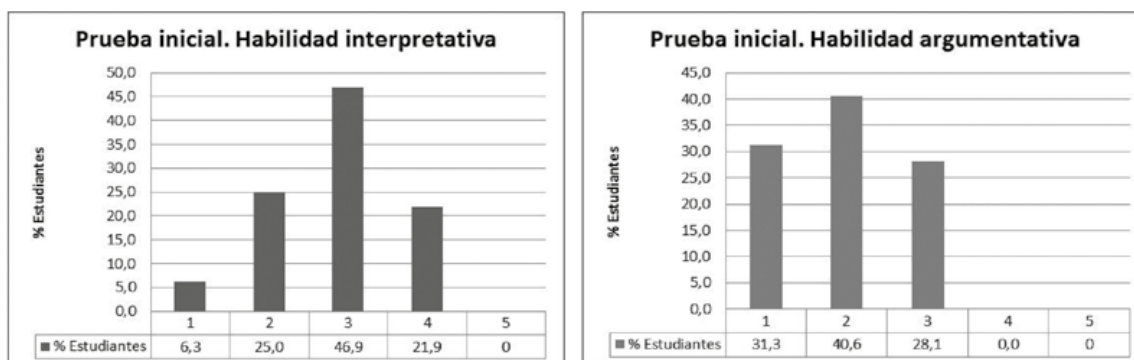


Figure 2. Results for question 1 pretest

Source: Own elaboration.

The trends observed in the development of the two studied skills suggest that students tend to interpret the statement and propose a response to the presented problem, as confirmed by almost 69% of students receiving a rating between 3 and 4 for this skill (Figure 2). However, they lack strong arguments to explain the given response, as 100% of the students are rated between 1 and 3 for this skill.

Question 2 aims to identify the question's interpretation level and the argumentation performed by students using chemical concepts.

- b. For the quantification of proteins, oxidation is carried out with concentrated H_2SO_4 in the presence of a catalyst. The product obtained reacts with an excess of strong alkali to release NH_3 , and the latter is collected in a solution of H_3BO_3 to form $\text{NH}_4\text{H}_2\text{BO}_3$. Finally, the previous solution is titrated with standardized HCl , resulting in the regeneration of H_3BO_3 . Formulate the described reactions. Is it possible to determine only phenylalanine content in a food sample? Explain your answer. The results are shown in Figure 3.

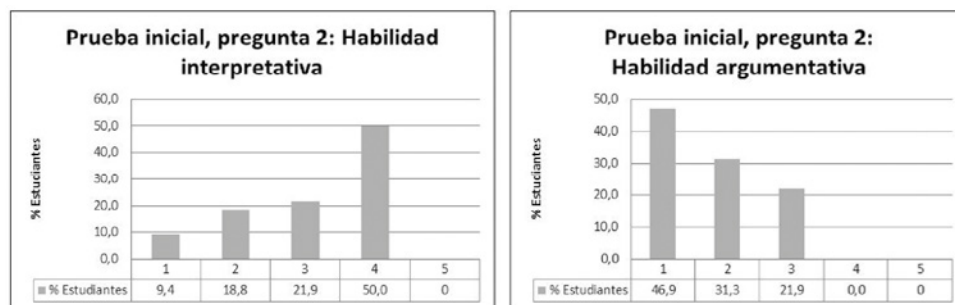


Figure 3. Results for question 2 pretest

Source: Own elaboration.

Considering that a rating equal to or greater than 4 is assumed to indicate a good level in the evaluated skill, these results show that students interpret the question reasonably well but cannot provide arguments using chemical concepts. In many cases, they do not even answer the question.

In general, the same trend is observed in the other pretest questions, where interpretative and argumentative skills show low development. It is noteworthy that, overall, the interpretative skill achieves a higher level. Figure 4 illustrates the result of the arithmetic median of the value obtained for each skill in each student.

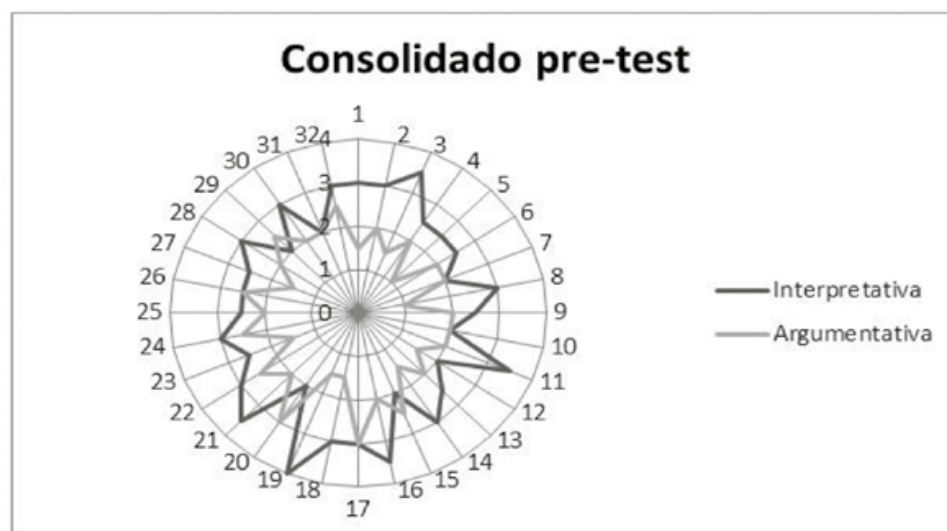


Figure 4. Arithmetic median, skill assessment for each student

Source: Own elaboration.

With these results, activities are developed in the classroom through mini-projects proposed by the students and adjusted according to the teacher's guidance. These are suggested in the context of food chemistry, specifically in the themes of proximate analysis. This facilitates each group of students to analyze a food they select, encouraging the formulation of group activities that develop critical

thinking. They need to interpret the proposed activities and their conceptual references and analyze theories and results in the practical work of the mini-projects, leading them to draw conclusions.

This methodology allows monitoring the progress of students through quantitative and qualitative assessment, according to the parameters established in Table 3, evaluated in the reports of each mini-project supported by each subgroup:

Table 3. Quantitative and qualitative assessment of the development of mini-projects

Intervals	Descriptor
0 to 2.9	Further reinforcement is needed for the development of skills
3.0 to 3.9	The student shows a moderate development of the proposed skills
4.0 to 5.0	The student demonstrates a good development of the skills

Source: Own elaboration.

The mini-projects were designed considering the structure presented in Table 4, proposed by Cárdenas (2001).

Table 4. Report Structure

Sections	Identification
Section A	Title
Section B	Names and date
Section C	Statement and conditions
Section D	Discussion of the statement: through questions to be solved where the student must carry out a theoretical review
Section E	Interpretation of the statement: space for the student to design a practical work in the laboratory based on the discussion of the statement
Section F	Materials, reagents, and equipment: list proposed by the students to carry out the designed practical work
Section G	Final report: space designed for the student to analyze and infer about the results obtained in the laboratory practical work

Source: Own elaboration.

Proteins Miniproject

For the development of this miniproject, a guiding question is proposed, aiming to motivate students to outline a methodology for analyzing and quantifying protein in a food item. Similarly, various questions are posed around the topic, especially regarding the amino acid and protein dichotomy, the chemistry of amino acids, and their relationship with nutrition. Finally, the miniproject asks the student to interpret the guiding question and analyze the results after completing the practical activity.

As illustrated in Figure 5, students face difficulties in interpretation skills, as they do not easily

describe the problem situation or the results, requiring significant support from the teacher.

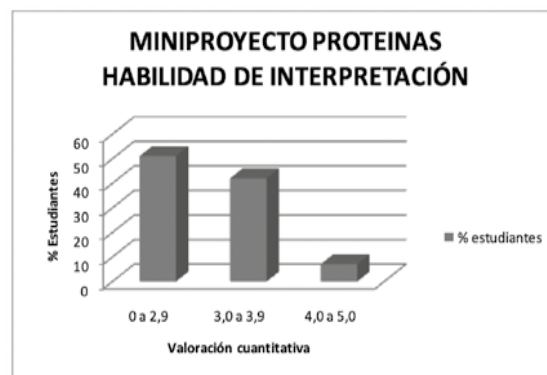


Figure 5. Development of Interpretative Skills in the Protein Miniproject

Source: Own elaboration.*

According to the previous results, it is essential for the teacher to guide students in interpreting the problem and analyzing the results. This involves reading laboratory reports and articles to enhance the level of scientific reading with concepts related to proteins. On the other hand, students present the results in a laboratory report, reflecting a critical analysis.

Fats Miniproject

This miniproject follows the same structure, and the questions focus on the properties of solvents to extract the lipid fraction from food and different analytical methods for extracting and quantifying fats in foods.

After evaluating the reports, a better result in critical thinking skills is observed; students better interpret the results, use scientific language, and support their analyses with various bibliographic sources, indicating the reading of articles and books (figure 6).



Figure 6. *Development of Interpretative Skills in the Fat Miniproject*

Source: Own elaboration.

The implementation of miniprojects allows the development of specific critical thinking skills. Pawluk (2012) notes that students engaged in this methodology exhibit favorable attitudes, initiative, creativity, autonomy, critical thinking, and collaborative work, making them active participants in their learning process. Similarly, the application of miniprojects on carbohydrates and fiber indicates an increased interest in reading scientific materials such as articles and reference books, as well as an improvement in critical thinking skills, possibly due to the ease of integrating theoretical, experimental, and methodological aspects in the laboratory while attempting to address questions (Flores, Caballero, and Moreira, 2009). After developing and evaluating all practical assignments, the evolution of students'

critical thinking skills is observed. In the first mini-project, 60% of students showed a moderate development of critical thinking skills. However, as the practical assignments progressed, the trend changed, reaching 70% of students with a good development of skills (Figure 7). This outcome suggests that by using laboratory work grounded in experiments within specific contexts and guided by exploratory questions, it is possible to foster or develop the skills that constitute critical thinking, especially interpreting, analyzing, and inferring abilities. This is significant considering that some researchers highlight the challenges of promoting critical thinking in educational settings, despite recognizing its importance in academic processes (Solbes and Torres, 2013).



Figure 7. Evolution of Critical Thinking Skills Development

Source: Own elaboration.

Thus, the need to develop laboratory work that integrates theoretical and practical activities, with greater student involvement in planning, designing, and implementing the laboratory, based on guiding questions to be addressed, is emphasized. This approach is known as a *third-level labo-*

ratory, grounded in phenomenology, and focused on comprehension and learning (Sandi-Urena and Chrzanowski, 2016). The application of the posttest shows that students improved their interpretative skills, but there is a more pronounced development in argumentation. As Figure 8 indicates, laboratory work in context, where students are engaged in its design and implementation, enables them to acquire scientific language. This, in turn, allows them to analyze results and articulate conclusions and hypotheses.

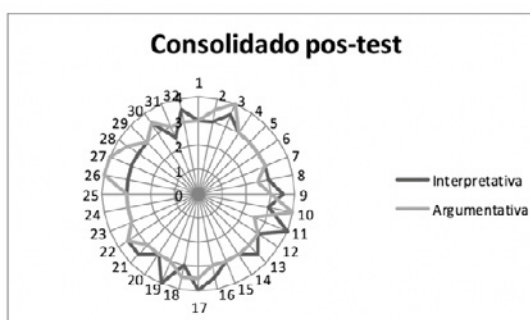


Figure 8. Arithmetic mean, the assessment of skills in each student

Source: Own elaboration.

In this regard, a need emerges to design didactic material that supports students' inquiry development as a practical activity in the laboratory, avoiding decontextualization and the disconnection between theoretical and experimental aspects (Toma and Greca, 2015). Furthermore, using the statistical package SPSS and comparing the arithmetic means of the skills addressed in the pretest and posttest, a strong correlation is found between the assessment of interpretative skills. Table 5 details Kendall's τ_b and Spearman's ρ bivariate correlation results.

Table 5. Bivariate Correlation of Interpretative Skill

Statistics	Variables		Posttest interpretative skill
Kendall's τ b	Pretest interpretative skill	Correlation coefficient	0,583**
		Significance (bilateral)	0,001
		Number of data (N)	32
Spearman's ρ	Posttest interpretative skill	Correlation coefficient	0,608**
		Significance (bilateral)	0,000
		Number of data (N)	32

** Correlation is significant at the 0.01 level

Source: Own elaboration.

As seen in Table 5, the statistical coefficients show a strong correlation between the initial state of interpretative skills assessed in the pretest and the posttest result. This result may indicate that students evolve in their interpretative skills without disregarding their abilities before the intervention.

Figure 9 illustrates a concept network obtained through documentary analysis of a final report using the Atlas.ti software.

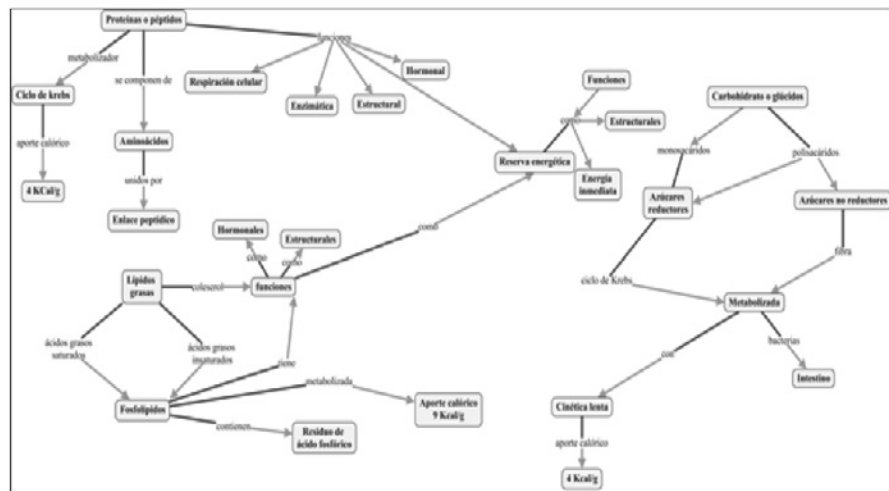


Figure 9. Network of codes from the laboratory report

Source: Own elaboration.

The network is complex due to the high number of relationships between various concepts. However, there is also a high coherence, which may indicate an evolution in interpretative skills, considering that students had to analyze results. In this way, it can be concluded that practical work promotes the evolution of interpretative skills in students and the construction of concepts, as mentioned by Rodríguez-Cepeda (2016). On the other hand, while an improvement in argumentative skills was observed, a defined correlation was not found through statistical analysis (Table 6). This trend could signify that the initial arguments do not influence the evolution or development of this skill. Still, practical work framed in contextualized mini-projects facilitates the development of this ability.

Table 6. Bivariate correlation. Argumentative skill

Statistics	Variables		Posttest interpretative skill
Kendall's τ b	Pretest interpretative skill	Correlation coefficient	0,132
		Significance (bilateral)	0,453
		Number of data (N)	32
Spearman's ρ	Posttest interpretative skill	Correlation coefficient	0,135
		Significance (bilateral)	0,462
		Number of data (N)	32

Source: Own elaboration.

Conclusions

Considering that critical thinking involves various skills such as inference, interpretation, and analysis, among others, it is crucial for professional training programs to develop these skills in their students, especially in teacher training schools, as their graduates are responsible for shaping competencies in primary, basic, and vocational middle schools. As demonstrated by this research, the target population had low levels of development in interpretative and argumentative skills, which could be a consequence of using didactic strategies that are disconnected from the students' interests. Consequently, the design of classroom activities, contextualized and of interest to the students, appears to significantly impact the degree of development of critical thinking skills. According to the results, it is feasible to assume that practical work contextualized with reading exercises on specific topics and mini-projects promotes argumentative and interpretative skills. Therefore, these activities should be taken into account in the design of teacher training programs. It is presumed that practical work within mini-projects supports the development of interpretative skills. Still, it is essential to consider that its evolution strongly correlates with the initial state of this skill. In this scenario, it is assumed that classroom activities based on an initial assessment of critical

thinking skills will facilitate the guidance of education from a different perspective.

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References

- Boisvert, J. (2004). *La formación del pensamiento crítico. Teoría y práctica*. 1a. ed. México: Fondo de Cultura Económica.
- Brookfield, S. (1991). *Developing critical thinkers: Challenging adults to explore alternative ways of thinking and acting*. Londres: Wiley.
- Butler, H. (2012). Halpern critical thinking assessment predicts real-world outcomes of critical thinkings. *Applied Cognitive Psychology*, 26, 721-729.

- Calle, G. (2013). La evaluación de las habilidades del pensamiento crítico asociadas a la escritura digital. *Revista Virtual Universidad Católica del Norte*, 40, 68-83.
- Campos, A. (2007). *Pensamiento crítico. Técnicas para su desarrollo*. 1a. ed. Bogotá, Colombia: Cooperativa Editorial Magisterio.
- Cárdenas, F. (2001). Miniprojects: An alternative to improve general Chemistry Teaching in higher education. *Journal of Science Education*, 2(2), 102-105.
- Castillo, J. y Martínez, L. (2017). Caracterización de capacidades de pensamiento crítico en futuros profesores de química. *Tecné, Episteme y Didaxis: TED*, (número extraordinario), 504-511. <http://revistas.pedagogica.edu.co/index.php/TED/article/view/4567>.
- Díaz-Barriga, F. (2001). Habilidades de pensamiento crítico sobre contenidos históricos en alumnos de bachillerato. *Revista Mexicana de Investigación Educativa*, 6(13), 1-19.
- Ennis, R. (2011). The nature of critical thinking: an outline of critical thinking dispositions and abilities. Cambridge: MIT. https://education.illinois.edu/docs/default-source/faculty-documents/robert-ennis/thenatureofcriticalthinking_51711_000.pdf
- Ennis, R. y Millman, J. (1985). *Cornell critical thinking test level*. Pacific Grove C.A.: Midwest Publication.
- Facione, P. (1990). Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction. *ERIC Doc.*, ED 315 423, 1-3. San José: The Complete American Philosophical Association Delphi Report, The California Academic Press.
- Facione, P. (2007). *Pensamiento crítico: ¿Qué es y por qué es importante?* Insight Assessment. [https://www.insightassessment.com/About-Us/Measured-Reasons/pdf-file/Pensamiento-Critico-Que-es-y-por-que-es-importante/\(language\)/esl-ES](https://www.insightassessment.com/About-Us/Measured-Reasons/pdf-file/Pensamiento-Critico-Que-es-y-por-que-es-importante/(language)/esl-ES)
- Flores, J., Caballero, M., y Moreira, M. (2009). El laboratorio en la enseñanza de las ciencias: una visión integral en este complejo ambiente de aprendizaje. *Revista de Investigación*, 68, 75-111.
- Glaser, R. (1984). The role of knowledge. *American Pshycologist*, 39, 93-104.
- Kuhn, D. y Weinstock, M. (2002). What is epistemological thinking and why does it matter? En B. Hofer y P. Pintrich (eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 121-144). New Jersey: Lawrence Erlbaum Associates Publishers.
- Kurfiss, J. (1988). *Critical Thinking: Theory, research, practice and possibilities*. ASHEERIC Higer Education Reports. Washington, D.C.: Association for the Study of Higher Education, eric Clearinghouse on Higher Education.
- Ortiz, J., Fonseca, G., Cantín, M., Huitzil, E., y Lucena, J. (2015). Competencias genéricas para la educación en odontología forense: pensamiento crítico y

- responsabilidad social. *International Journal of Odontostomatology*, 9(2), 263-272.
- Paul, R., Brinker, A., Martín, D., Veterano, C. y Kreklau, H. (1995). *Critical Thinking Handbook: 6th and 9th grades. A guide for remodeling lesson plans in language arts*. Social Students & Science. Santa Rosa: Foundation for Critical Thinking.
- Pawluk, D. (2012). *Implementación de mini-proyectos de investigación: una forma no convencional en los trabajos prácticos de práctica profesional de bioquímica*. Santa Fe, Argentina: Universidad Nacional del Litoral.
- Perkins, D. (1985). Postprimary education has little impact on informal reasoning. *Journal of Educational Psychology*, 77, 562-570.
- Rodríguez-Cepeda, R. (2016). Aprendizaje de conceptos químicos: una visión desde los trabajos prácticos y los estilos de aprendizaje. *Revista de Investigación, Desarrollo e Innovación*, 7(1), 63-76.
- Saiz, C. y Fernández, S. (2012). Pensamiento crítico y aprendizaje basado en problemas cotidianos. *Revista de Docencia Universitaria*, 10(3), 325-346.
- Saiz, C. y Rivas, S. (2011). Evaluation of the AR-DEOS program: An initiative to improve critical thinking skills. *Journal of the Scholarship of Teaching and Learning*, 11(2), 34-51.
- Sandi-Urena, S. y Chrzanowski, M. (2016). Learning in the Tertiary Level Chemistry Laboratory: What We Have Learned from Phenomenology Research. *Science Education Research and Practical Work*, 181-192.
- Santiago, J. (2016). La acción didáctica de las ciencias sociales y el desarrollo del pensamiento crítico. *Revista Educación y Humanismo*, 18(31), 241-256.
- Solbes, J. y Torres, N. (2013). ¿Cuáles son las concepciones de los docentes de ciencias en formación y en ejercicio sobre el pensamiento crítico? *Revista Tecné, Epistémé y Didaxis: TED*, 33, 61-85.
- Toma, R. y Greca, I. (2015). Enseñanza de las ciencias naturales a través de la metodología de indagación: un estudio de las unidades didácticas elaboradas por el alumnado del grado en Maestro de Educación Primaria. En M.C. Caballero, J.A. Meneses y M.A. Moreira (coords.), *Actas del V Encuentro Iberoamericano sobre Investigación en Enseñanza de las Ciencias* (pp. 479-490). Burgos: Universidad de Burgos.
- Whimbey, A. (1985). You don't need a special reasoning test to implement and evaluate reasoning training. *Educational Leadership*, 43(2), 37-39.
- Zechmeiser, E. y James, J. (1992). *Critical Thinking. A functional approach*. California: Brooks/Cole Publishing Company Pacific Grove.

How to cite

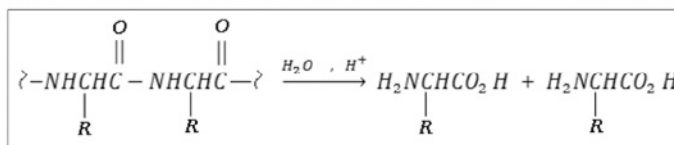
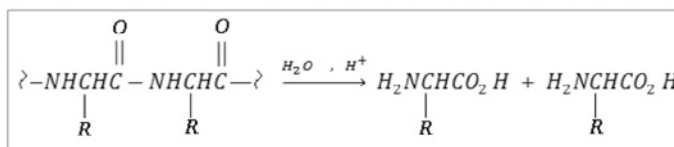
- Rodríguez-Cepeda, R., Casas-Mateus, J. y Martínez-Cárdenas, D. (2020). Chemical Laboratory on Context: Input for Development of Critical Thinking Skills. *Tecné, Epistémé y Didaxis, TED*, (47), 33-51. <https://doi.org/10.17227/ted.num47-11334>

Annex

Universidad Pedagógica Nacional Facultad de Ciencia y Tecnología Departamento de Química Diagnostic Test on Proteins

1. Read the following passage:

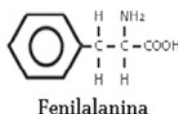
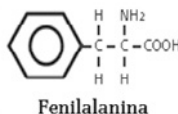
Proteins are amino acids, which, through hydrolysis, produce polyamides linked by a characteristic bond known as the peptide bond. This property allows measuring the formation of ammonia by reacting the protein with acid and subsequently with a strong base. In this way, it is possible to quantify the protein present in a food sample and assess its caloric contribution.



According to the previous outline, do you think there is any invalid argument in the text? State it.

2. The peptidic structure of proteins can be differentiated from other organic compounds through various chemical tests, such as the hydrolysis of proteins with acids, bases, or enzymes to generate peptides and, ultimately, amino acids.

Is it possible to determine the phenylalanine content in a food sample if the sample is oxidized with concentrated H₂SO₄ in the presence of a catalyst, the resulting product reacts with an excess of solid alkali to release ammonia, which reacts with a solution of H₃BO₃ to form NH₄H₂BO₃, and finally titrated with standardized HCl? Indicate why or why not and formulate the equations for the described reactions.



3. The previous analytical method is based on measuring the ammonia formed by all the nitrogen present in a sample; consequently, would it be possible to assert that the percentage of total nitrogen obtained is solely due to the protein content in food? Why?

4. A student of agri-food chemistry initiates a series of experimental practices in triplicate to determine the protein content in a sample of paprika, obtaining the following experimental values in the final titration of the process with HCl (0.100 N):

Sample	Sample mass (g)	Volume (ml)
White	—	0,1
1	7,62	1,1
2	7,60	1,1
3	7,65	1,2

$$\% N = \frac{V (mL) \cdot N \cdot \frac{14}{1000}}{W (g)} * 100 \quad \text{besides that: } \% \text{ Protev?na} = \% N * 6,25$$

With V = hydrochloric acid used in titration (ml)

N = normality of standard acid

W (g) weight in grams of the sample

To determine the percentage of protein present in the sample, a student applied the previous formulas and determined that in 100 g of this sample, there are 0.02 g of total nitrogen and 0.15 g of protein. According to this information, what are the chemical units used in this mathematical treatment?

5. A chemical analyst finds that the total nitrogen content in a sample of wheat and beans is the same. Still, when determining the protein nitrogen, he finds that he must use factors according to the following table:

Food	Factor
Meat, fish, egg, legumes	6,25
Cereals and soy derivatives	5,7
Milk	6,38
Jelly	5,55
Rice	5,95

What is the reason for using different factors in this type of food analysis?

6. Students in Food Chemistry discover a method to determine the protein content in a food sample. In the first phase, they are asked to perform digestion with concentrated H₂SO₄, a catalyzing mixture, and the sample to be analyzed, with temperatures between 370-410 °C. This is done to minimize the loss of ammonia during digestion. What is the role of sulfuric acid and the catalyzing mixture at the specified temperature?