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The brain of critical thinking: a systematic review of neural networks and associated cognitive processes

El cerebro del pensamiento crítico: revisión sistemática de redes neuronales y procesos cognitivos asociados

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Abstract

Critical thinking is the ability to analyze, evaluate, and synthesize information objectively and logically. For this reason, it involves questioning ideas, recognizing biases, and making informed decisions to effectively address complex problems. The objective of this review was to examine the current state of knowledge on neural networks and cognitive processes associated with critical thinking during the period from 2019 to 2024. To this end, a systematic review was conducted following the PRISMA methodology. Several databases were consulted, including ProQuest, Dialnet, ScienceDirect, and SciELO. After identifying relevant articles, they were categorized, resulting in a total of 38 studies. The findings indicate that most of the research on neural networks and cognitive processes related to critical thinking during this period originated in Asia (11%), with the highest number of publications in 2023 (26%). Furthermore, the predominant study designs were quasi-experimental and descriptive, both representing 26% of the reviewed articles. In conclusion, this review broadened our understanding of the brain processes involved in critical thinking, encompassing everything from neural networks to the cognitive functions that facilitate informed decision-making and the resolution of complex problems.

Keywords: brain, neuroscience, critical thinking, cognitive processes, neural networks.

Resumen

El pensamiento crítico es la capacidad que permite analizar, evaluar y sintetizar información de manera objetiva y lógica. Por esta razón, implica cuestionar ideas, reconocer sesgos y tomar decisiones informadas para abordar problemas complejos con eficacia. El objetivo de esta revisión fue examinar el estado actual del conocimiento sobre las redes neuronales y los procesos cognitivos asociados al pensamiento crítico durante el período comprendido entre 2019 y 2024. Para ello, se llevó a cabo una revisión sistemática siguiendo la metodología PRISMA. Se consultaron diversas bases de datos, entre ellas ProQuest, Dialnet, ScienceDirect y SciELO. Luego de identificar los artículos pertinentes, se procedió a categorizarlos, seleccionando un total de 38 estudios. Los hallazgos indican que la mayoría de las investigaciones sobre redes neuronales y procesos cognitivos relacionados con el pensamiento crítico en este período se originaron en Asia (11%), con un mayor número de publicaciones en el año 2023 (26%). Además, los diseños de estudio predominantes fueron los cuasiexperimentales y descriptivos, ambos representando un 26% de los artículos revisados. En conclusión, esta revisión permitió ampliar la comprensión de los procesos cerebrales implicados en el pensamiento crítico, abarcando desde las redes neuronales hasta las funciones cognitivas que facilitan la toma de decisiones informadas y la resolución de problemas complejos.

Palabras clave: cerebro, neurociencia, pensamiento crítico, procesos cognitivos, redes neuronales.

Introduction

Neuroscience is defined as the study of brain neurophysiology, encompassing its development from early stages to full maturity. Currently, this field is rapidly expanding, involving research that encompasses both animal and human subjects. In this context, the use of magnetic resonance imaging has played a crucial role in visualizing the brain, thereby facilitating the analysis of active neural networks during various cognitive tasks (Peña-Troncoso et al., 2019).

Historically, thought has occupied a central place in disciplines such as philosophy and psychology, serving as a principal engine for educational systems. Scientific and technological advances have propelled numerous investigations into the nature of thought, with particular attention directed toward the intricate brain functions that underlie it (Montes et al., 2018).

From an international perspective, educational quality policies have prioritized coverage, albeit with limited focus on the effectiveness of critical thinking development and insufficient attention to the structural changes that the system requires. For instance, in 2018, Colombia reported a 72.3% coverage rate in secondary education and 42.6% in upper secondary education, yet faced high dropout rates attributed to a lack of a critical approach to the completion of studies (Zuluaga et al., 2022).

A study conducted at a university in southeastern Mexico investigated the impact of a training program through the application of the California Critical Thinking Skills Test at the beginning and end of the semester. The results demonstrated significant improvements in critical thinking and skills among students who received guidance from trained tutors involved in the program (Núñez-López et al., 2019).

For decades, national educational policies have been anchored in a memorization-centered teaching approach, prevalent at all levels. This enduring practice has been referred to as traditional learning, characterized by the mere accumulation of knowledge (Benavides & Ruíz, 2022). Additionally, the Ministry of Education (Minedu) in its 2016 document asserts that one of the eleven learning outcomes expected in the profile of graduates from regular basic education is the promotion of autonomous learning processes. This approach aims for students to achieve both individual and collaborative learning, emphasizing the importance of constructing knowledge and experiences that foster critical thinking.

Moreover, neuroscience offers valuable insights for understanding human brain function, facilitating the study of the complex cognitive processes that underpin thought and behavior. This discipline is fundamental for comprehending the intricate nature of critical thinking and its relation to brain activity.

Essential cognitive functions of the brain are conceived as the functional and temporal outcomes of the dynamic interaction between genetically determined brain structures and their environment. According to cognitive psychologists and neuropsychologists, mental or cognitive activity directly reflects neural activity. Therefore, the representation and storage of knowledge, as cognitive processes, must be closely tied to the activation of the central nervous system (Escobar, 2024).

Although the relationship between cognitive processes and neuronal activity is crucial, much of the research in cognitive neuroscience has focused on demonstrating the correlation between specific areas of the central nervous system and certain cognitive activities (Araya-Pizarro & Espinoza, 2020).

In this regard, artificial neural networks present a significant advantage in their design and functioning, as they emulate many characteristics inherent to the human brain. This allows them to learn from previous experiences, abstract essential features, generalize information based on past cases, and adapt to new situations, even when initial information is limited or irrelevant (Sánchez-Heredia & Álvarez-Medina, 2022).

According to Gagné (1986), interaction with the environment occurs through the senses, which are integrated into cognitive processes that organize information. Just as external actions allow the manipulation of objects, internal cognitive processes encode environmental information by means of encoding, synthesis, storage, and retrieval of data. This phenomenon, known as metacognition, is defined as the capacity to process information, influenced by personal needs, expectations, and values (Manrique, 2020).

Among the most relevant cognitive theories, constructivist learning theory, as posited by authors such as Piaget (1973) and Vygotsky (1978), stands out for asserting that learning is an active process in which knowledge is constructed from prior experiences. Complementarily, Bruner (1998), in his theory of discovery learning, emphasizes the importance of acquiring knowledge through exploration and experimentation.

Current theoretical support also allows for the consideration of new perspectives in learning, such as adaptive learning models grounded in constructivism. This model posits that cognitive processes must adjust to individual needs and characteristics. Accordingly, knowledge is actively constructed through interaction with the

environment and personal experience, enhancing motivation, retention, and content comprehension (Bolaño-García & Duarte-Acosta, 2024).

Critical thinking is described as the ability to reason with the aim of enhancing the quality of ideas related to any topic or problem. This process results in an individual with developed critical thought, capable of formulating essential questions clearly, gathering and evaluating relevant information, employing abstract concepts, and reaching effective conclusions and solutions (Vendrell & Ramírez, 2020).

According to Fierro and Di Doménico (2017), critical thinking is an active metacognitive process that combines skills, dispositions, and specific knowledge to make reflective judgments. This approach is oriented toward action and the efficient resolution of problems. Kuhn (2018) emphasizes the importance of critical thinking in both theoretical and pedagogical contexts.

To develop effective critical thinking, it is essential to establish a clear purpose and formulate appropriate questions that define the problem to be resolved. The characteristics of a critically thinking individual manifest in their intellectual resources, which include prior knowledge, understanding of standards for sound reasoning, and mastery of fundamental critical concepts (Mackay et al., 2019).

For these reasons, this research aims to analyze the current state of the art regarding neural networks and the cognitive processes involved in critical thinking during the period from 2019 to 2024.

Methodology

A systematic review of the scientific literature was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, which guided the study's development. The primary objective was to evaluate the current state of knowledge regarding neural networks and the cognitive processes involved from 2019 to 2024.

To ensure broad coverage, articles indexed in recognized databases in both Spanish and English were included, such as ProQuest, Dialnet, ScienceDirect, and SciELO. Publications within the specified timeframe that addressed topics related to neural networks and cognitive processes were selected, employing a range of methodologies from descriptive and applied studies to quantitative, qualitative, and experimental approaches. This diversity contributed to the construction of a robust and comprehensive reference framework.

Only indexed articles were considered, excluding books, theses, and reports. Articles that did not meet the established objectives or lacked relevance, particularly those that failed to include keywords related to the study variables, were also discarded. This selection was carried out through an exhaustive review of the texts retrieved from the aforementioned databases.

The search was designed to generate relevant and specific results, utilizing keywords such as “brain,” “cognition,” “education,” “neural networks,” and “critical thinking.” Combinations of these keywords were applied using Boolean operators to refine the results: [("brain" OR "cognition") AND ("neural networks" OR "thinking") AND ("education" OR "cognition" OR "neural networks") AND ("brain")].

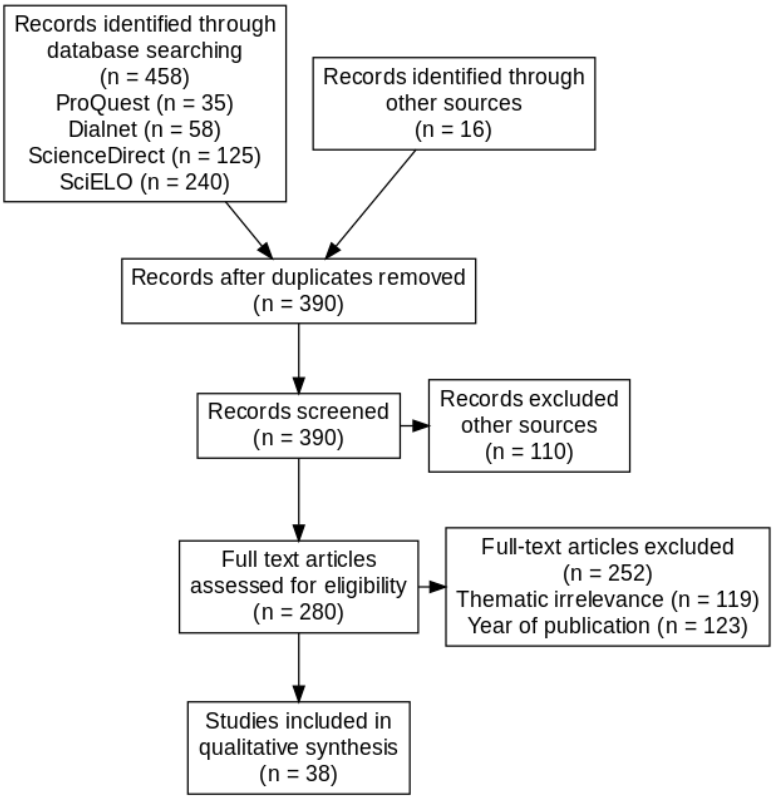
The retrieved articles were exported in Excel format to facilitate their organization, removal of duplicates, and filtering of less relevant documents. The search and selection process took place between October and December 2024.

After rigorously applying the eligibility criteria and search strategy, 38 articles were selected for analysis, all sourced from indexed databases and conforming to the established parameters.

Finally, data collection was carried out systematically, combining retrieval, organization, and consultation of the aforementioned academic databases. To optimize the process, specific filters based on the initially defined criteria were applied.

The flow diagram according to the PRISMA methodology employed in the article collection is presented below.

Figure 1
PRISMA flow diagram



Results

Following a thorough systematic literature review, a total of 38 articles from various countries were selected. These works met the previously established inclusion and exclusion criteria, ensuring the relevance and quality of the sources chosen for analysis.

To facilitate the organization and comprehension of the data, the articles were categorized according to authorship and year of publication, ABI (Bibliometric Analysis of Information) modality, and institutional context, including the university and country of origin. This categorization allowed for the identification of geographical, methodological, and temporal trends in research on neural networks and cognitive processes related to critical thinking.

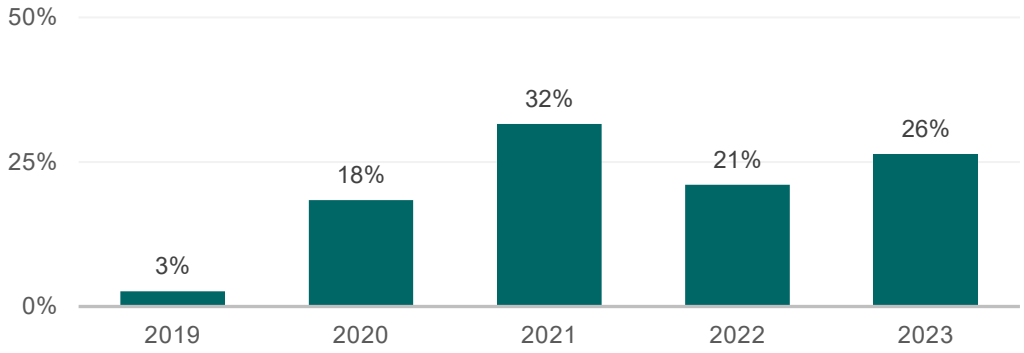
Table 1 outlines the articles included in the systematic review, highlighting the diversity and scope of the analyzed studies.

Table 1
Articles included in the systematic review

No.	Authors	ABI Modality	University/Country
1	Amin et al. (2020)	Research-based	Universitas Negeri Malang / Indonesia
2	Gulbahor & Surayo (2021)	Research-based	Bukhara State University / Uzbekistan
3	Lapuz & Fulgencio (2020)	Research-based	Ramon Magsaysay State University / Philippines
4	Makhrus & Hidayatullah (2021)	Research-based	Universitas Mataram / Indonesia
5	Mundt et al. (2023)	Research-based	Goethe University, Theodor-W.-Adorno-Platz / Germany
6	Sari et al. (2021)	Research-based	Samudra University / Indonesia
7	Groyecka, et al. (2020)	Research-based	University of Leeds / United Kingdom

8	Varveris et al. (2023)	Research-based	Hellenic International University / Greece
9	Yu et al. (2019)	Research-based	National Normal University of Taiwan / Taiwan
10	Malfert (2023)	Research-based	Tomás Frías Autonomous University / Bolivia
11	Phérez et al. (2020)	Research-based	Adventist University Corporation / Colombia
12	Lin et al. (2022)	Research-based	Columbia University / United States
13	Zorzos et al. (2023)	Research-based	University of Athens / Greece
14	Pedraza et al. (2023)	Research-based	University of Atlántico / Colombia
15	Quimi et al. (2023)	Research-based	University of Zaragoza / Spain
16	Gómez-León (2020)	Research-based	International University of La Rioja / Spain
17	Símon & Rodríguez (2021)	Research-based	Libertador Experimental Pedagogical University IPMAR / Venezuela
18	Escribano et al. (2024)	Research-based	University of Manizales / Colombia
19	Bati (2022)	Research-based	National University of Tucumán / Argentina
20	Pazos-Yerovi & Aguilar-Gordón (2024)	Research-based	Armed Forces University ESPE / Ecuador
21	López (2020)	Research-based	Metropolitan University of Guayaquil / Ecuador
22	Cifuentes-Castañeda & Marín-Gutierrez (2024).	Research-based	Catholic University of Uruguay / Uruguay
23	Rivas et al. (2022)	Research-based	University of Bío Bío / Chile
24	Warsah et al. (2021)	Research-based	State Islamic University Sultan Syarif Kasim Riau / Indonesia
25	Derseh & Shifere (2020)	Research-based	University of Woldia / Ethiopia
26	Campo et al. (2023)	Research-based	University of Deusto / Spain
27	Suryana & Yulia (2021)	Research-based	Universitas Negeri Padang / Indonesia
28	Ossa et al. (2023)	Research-based	Diego Portales University / Chile
29	Lestari & Setyarsih (2021)	Research-based	Universitas Negeri Surabaya / Indonesia
30	İlaslan et al. (2023)	Research-based	Akdeniz University / Turkey
31	Putra et al. (2023)	Research-based	De La Salle University
32	Demir (2022)	Research-based	Bandırma Onyedi Eylül University / Turkey
33	Susetyarini & Fauzi (2020)	Research-based	Muhammadiyah University of Malang / Indonesia
34	Luoise (2019)	Research-based	National Taiwan University of Science and Technology / Taiwan
35	Septiany et al. (2024)	Research-based	State University of Surabaya / Indonesia
36	Chesire et al. (2022)	Research-based	Norwegian Institute of Public Health / Norway
37	Putri et al. (2023)	Research-based	Universitas Negeri Medan / Indonesia
38	Isvida et al. (2024)	Research-based	Universitas PGRI Madiun / Indonesia

Figure 2
Percentage of publication years of analyzed articles



As shown in Figure 2, in 2019, 3% (1 out of 38) of the reviewed articles were recorded. This percentage increased to 18% (7 out of 38) in 2020. The highest percentage was observed in 2021, with 32% (12 out of 38), followed by 2022 with 21% (8 out of 38), and finally, 2023 with 26% (10 out of 38).

Table 2
Cognitive strategies of the reviewed articles

Strategies	Quantity	Percentage
Analysis of cognitive tasks	10	26%
Argument analysis	9	24%
Metacognitive analysis	12	32%
Cognitive flexibility	7	18%
Total	**38**	**100%**

Regarding the information presented in Table 2, the data are distributed among cognitive strategies such as analysis of cognitive tasks (26%), argument analysis (24%), metacognitive analysis (32%), and cognitive flexibility (18%). These results indicate that metacognitive analysis is the most predominant strategy, followed by the analysis of cognitive tasks and argument analysis, while cognitive flexibility is the least frequent. This suggests a tendency to prioritize reflection on one's mental processes and organization of tasks, rather than focusing on flexible adaptation to new circumstances.

Table 3
Cognitive processes of the reviewed articles

Processes	Quantity	Percentage
Evaluation of arguments and evidence	10	26%
Identification and understanding of the problem	13	34%
Communication and argumentation	8	21%
Problem-solving	7	18%
Total	**38**	**100%**

In relation to the information reflected in Table 3, it can be observed that the distribution includes evaluation of arguments and evidence (26%), identification and understanding of the problem (34%), communication and argumentation (21%), and problem-solving (18%). The predominance of activities oriented toward identifying and understanding the problem (34%) and evaluating arguments and evidence (26%) highlights a preliminary and foundational focus, establishing the basis for sound decision-making and effective resolution. Therefore,

deepening the understanding of the problem and assessing the available evidence are essential steps before progressing to argumentation or conflict resolution.

The analysis of scientific production reveals a growing global interest in research as a driver of knowledge advancement. In Asia, there is a notable concentration of studies, particularly in Indonesia, where authors such as Amin et al. (2020), Makhrus and Hidayatullah (2021), Sari et al. (2021), Warsah et al. (2021), Suryana and Yulia (2021), Lestari and Setyarsih (2021), Susetyarini and Fauzi (2022), Septiany et al. (2024), Putri et al. (2023), and Isvida et al. (2024) have developed significant research. Other Asian countries contribute relevant findings, such as Gulbahor and Surayo (2021) from Uzbekistan, Lapuz and Fulgencio (2020) in the Philippines, and Yu et al. (2019) and Luoise (2019) in Taiwan. This production reflects a sustained commitment to empirical research across various fields of knowledge.

In Europe, scientific output exhibits considerable geographic and institutional diversity. Germany is represented by Mundt et al. (2023), while the United Kingdom has contributions from Groyecka et al. (2020). Greece stands out with the research activities of Varveris et al. (2023) and Zorzos et al. (2023). Spain contributes with the works of Quimi et al. (2023), Gómez-León (2020), and Campo et al. (2023), while Turkey offers research from İlaslan et al. (2023) and Demir (2022). Moreover, Lin et al. (2022) from the United States and Chesire et al. (2022) from Norway broaden the spectrum to North America and Scandinavia, demonstrating the global reach of this type of research.

Latin America also makes significant contributions to the global landscape. Bolivia is represented by Malfert (2023), while Colombia stands out with works by Phérez et al. (2020), Pedraza et al. (2023), and Escribano et al. (2023). Argentina contributes with Bati (2022), Ecuador with Pazos-Yerovi and Aguilar-Gordón (2024) and López (2020), and Uruguay with Cifuentes-Castañeda and Marín-Gutierrez (2024). Chile features contributions from Rivas et al. (2022) and Ossa et al. (2023), while Venezuela is represented by Símon and Rodríguez (2021). Lastly, Putra et al. (2023) from De La Salle University complement the Latin American panorama. Finally, Africa is represented by Wale and Bishaw (2020) from Ethiopia, showcasing how evidence-based research transcends continental boundaries.

This geographic and cultural diversity enriches research on critical thinking. "Research-based" studies allow exploration of the neural networks involved in key processes such as analysis, inference, and evaluation, fundamental elements of critical thinking. For example, the mentioned studies could analyze how various research-based teaching methodologies influence the activation of the prefrontal cortex, a brain area central to decision-making and complex thought. Similarly, these researchers provide empirical data from their respective cultural contexts and areas of study, illustrating how educational, sociocultural, and methodological variables affect cognitive processes. This perspective enhances this systematic review of the brain in critical thinking.

Ultimately, scientific production in the "research-based" modality constitutes a broad and solid foundation for the systematic study of neural networks and cognitive processes linked to critical thinking. The convergence of research from multiple regions and perspectives, as evidenced by the cited authors, facilitates the construction of more robust and comprehensive knowledge in this fascinating field.

Discussion

Critical thinking is recognized as one of the most valued cognitive skills for solving complex problems, making informed decisions, and evaluating information in a data-saturated world (Amin et al., 2020). However, understanding the underlying processes that sustain this type of reasoning remains a challenge within cognitive neuroscience. In recent years, advances in research on neural networks and their interactions have begun to clarify how the brain organizes and regulates processes associated with critical thinking (Gulbahor & Surayo, 2021; Chesire et al., 2022).

According to the review conducted, the regions with the highest scientific output related to neural networks and cognitive processes of critical thinking are Asia (26%) and Europe (11%). In this regard, Símon de Astudillo and Rodríguez (2021) point out that research in neuroeducation, particularly that developed in Europe, transcends traditional perspectives of pedagogy and didactics. These disciplines recognize that learning is not merely an intellectual process; rather, understanding is fully enriched through experience and emotion, akin to how language functions.

Thus, while classical perspectives consider learning as a strictly intellectual process aimed at acquiring knowledge and skills, neuroeducation harmoniously integrates cognitive, emotional, and social aspects, offering a more comprehensive approach to the educational process.

Concerning the strategies employed to identify the cognitive processes associated with critical thinking, it was found that metacognitive analysis was predominant among the reviewed articles. According to Rivas et al. (2022), critical thinking significantly depends on the proper functioning of metacognitive mechanisms, which

involves greater awareness of one's own processes, actions, and emotions. Additionally, Putra et al. (2023) highlight that metacognitive aspects are fundamental for developing transversal competencies, facilitating problem identification in various situations and underscoring the importance of recognizing the limitations individuals face when resolving them.

Hence, the most prominent strategies for identifying cognitive processes related to critical thinking include metacognitive analysis, establishing itself as the prevailing approach in the selected studies, promoting a fuller awareness of the elements involved in critical reasoning, essential for tackling and resolving complex problems.

Regarding the temporal distribution of the articles, a higher number of publications was observed in 2021 (32%) and 2023 (26%). In this context, Gómez-León (2020) reviewed 116 articles published between 2014 and 2019, of which 81% corresponded to original studies and the remaining to reviews. Of these, 40 works were selected, including 34 originals and 6 reviews; 29 of them related creativity to psychobiological aspects, while the other 11 primarily addressed cognitive, behavioral, and emotional factors.

Moreover, among the primary cognitive processes reported in the articles, problem identification and understanding were the most frequently addressed, regardless of study design. In line with this, Lapuz and Fulgencio (2020) noted that during formative assessment, significant progress in students' critical abilities was observed, attributed to problem-based learning, which evidenced better academic performance. Conversely, Pedraza et al. (2023) indicated that while weaknesses were detected at the inferential level and in the critical analysis of narrative texts, such activities could strengthen foundational cognitive processes like attention and memory, aiding students in maintaining focus and retaining more information.

In conclusion, the most relevant cognitive processes identified in this review are problem identification and understanding, which are frequently utilized in the analyzed studies. Additionally, it is noteworthy that these activities strengthen essential cognitive functions that enhance concentration and information retention, key aspects for the development of critical thinking.

Conclusions

The literature review on neural networks and cognitive processes associated with critical thinking, covering the period from 2019 to 2024, demonstrates a dynamic landscape with clear geographical and methodological trends. A significant finding is the notable concentration of scientific output in Asia, particularly in Indonesia, which accounts for 26% of the studies analyzed. Europe also emerges as a significant hub, with Spain leading 11% of this activity. This geographical distribution indicates that strengthening critical thinking skills is a priority in the educational systems of these regions.

The temporal analysis reveals a growing interest in the field, with peaks in production in 2021 (32%) and 2023 (26%). Methodologically, quasi-experimental and descriptive designs are predominant, each representing 26%, reflecting a trend toward evaluating specific interventions and characterizing the current state of cognitive skills in various student groups.

As for pedagogical strategies, metacognitive analysis (32%) and cognitive task analysis (26%) are highlighted as the primary tools for identifying and enhancing critical thinking. This underscores the importance of metacognition, understood as the student's ability to reflect on their mental processes, an essential aspect for recognizing problems and transferring solutions to new contexts. Within this framework, problem-based learning (PBL) emerges as one of the most effective methodologies.

Finally, when breaking down specific cognitive processes, it is confirmed that most research focuses on problem identification and understanding (34%) and evaluating arguments and evidence (26%). The results support that PBL has a positive and significant impact on enhancing students' critical capacity. Although some weaknesses are identified, such as in the analysis of narrative texts, the activities associated with this approach show great potential for strengthening essential cognitive processes, such as attention and memory, thereby solidifying itself as a promising pathway for developing sharper and more reflective thinkers.

References

Amin, S., Utaya, S., Syamsul, B., & Singgih, S. (2020). Effect of problem based learning on critical thinking skill and environmental attitude. *Journal for the Education of Gifted Young Scientists, 8*(2), 743–755. https://doi.org/10.17478/jegys.650344

Araya-Pizarro, S., & Espinoza, L. (2020). Aportes desde las neurociencias para la comprensión de los procesos de aprendizaje en los contextos educativos. *Propósitos y Representaciones, 8*(1), e312. https://doi.org/10.20511/pyr2020.v8n1.312

Bati, K. (2022). A systematic literature review regarding computational thinking and programming in early childhood education. *Education and Information Technologies, 27*(2), 2059–2082. https://doi.org/10.1007/s10639-021-10700-2

Benavides, C., & Ruíz, A. (2022). El pensamiento crítico en el ámbito educativo: Una revisión sistemática. *Revista Innova Educación, 4*(2), 62–79. https://doi.org/10.35622/j.rie.2022.02.004

Bolaño-García, M., & Duarte-Acosta, N. (2024). Una revisión sistemática del uso de la inteligencia artificial en la educación. *Revista Colombiana de Cirugía, 39*(1), 51–63. https://dialnet.unirioja.es/servlet/articulo?codigo=9530809

Brunner, J. (1998). *Desarrollo cognitivo y educación* (5a ed.). Morata.

Campo, L., Galindo-Domínguez, H., Bezanilla, M. J., Fernández-Nogueira, D., & Poblete, M. (2023). Methodologies for fostering critical thinking skills from university students' points of view. *Education Sciences, 13*(2), 132. https://doi.org/10.3390/educsci13020132

Chesire, F., Ochieng, M., Mugisha, M., et al. (2022). Contextualizing critical thinking about health using digital technology in secondary schools in Kenya: A qualitative analysis. *Pilot and Feasibility Studies, 8*, 227. https://doi.org/10.1186/s40814-022-01183-0

Cifuentes-Castañeda, P. A., & Marín-Gutierrez, A. (2024). Funcionamiento ejecutivo de estudiantes universitarios y rendimiento académico: Revisión sistemática. *Revista de Psicología y Educación, 19*(2). https://doi.org/10.23923/rpye2024.02.259

Demir, E. (2022). An examination of high school students' critical thinking dispositions and analytical thinking skills. *Journal of Pedagogical Research, 6*(4), 190–200. https://eric.ed.gov/?id=EJ1349887

Escobar, R. (2024). Redes neuronales, procesos cognoscitivos y análisis de la conducta. *Conductual, 2*(1), 23–43. https://dialnet.unirioja.es/servlet/articulo?codigo=9463677

Escribano, C., Gil-Fernández, R., & Calderón, D. (2024). Confluencias entre pensamiento crítico y redes sociales en el ámbito educativo: Mapeo de experiencias y detección de desafíos a través de una revisión sistemática. *Revista Complutense de Educación, 35*(2), 363–379. https://diposit.ub.edu/dspace/handle/2445/220433

Fierro, C., & Di Doménico, M. C. (2017). Enseñanza y formación universitaria en Psicología en Argentina: Caracterización de una taxonomía del pensamiento crítico. *Cuadernos de Neuropsicología, 11*(1), 30–67. https://doi.org/10.7714/CNPS/11.1.202

Gagné, R. (1986). *La instrucción basada en la investigación sobre el aprendizaje*. Universidad Iberoamericana.

Gita Isvida, M., Sunandar, A., & Mukti Rahayu, H. (2024). Effect of problem-based learning integrated with ethnoscience on critical thinking skills in SMA Negeri 01 Kubu. *Quagga: Jurnal Pendidikan Dan Biologi, 16*(1), 51–57. https://doi.org/10.25134/quagga.v16i1.54

Gómez-León, M. I. (2020). Bases psicobiológicas de la creatividad en los niños con altas capacidades. *Psiquiatría Biológica, 27*(1), 28–33. https://doi.org/10.1016/j.psiq.2020.01.004

Groyecka, A., Gajda, A., Jankowska, D. M., Sorokowski, P., & Karwowski, M. (2020). On the benefits of thinking creatively: Why does creativity training strengthen intercultural sensitivity among children. *Thinking Skills and Creativity, 37*, 100693. https://doi.org/10.1016/j.tsc.2020.100693

Gulbahor, A., & Surayo, A. (2021). Pedagogical and psychological conditions of preparing students for social relations on the basis of the development of critical thinking. *Psychology and Education Journal, 58*(2), 4889–4902. https://doi.org/10.17762/pae.v58i2.2886

İlaslan, E., Adıbelli, D., Teskereci, G., & Üzen Cura, Ş. (2023). Development of nursing students' critical thinking and clinical decision-making skills. *Teaching and Learning in Nursing, 18*(1), 152–159. https://doi.org/10.1016/j.teln.2022.07.004

Kuhn, D. (2018). A role for reasoning in a dialogic approach to critical thinking. *Topoi, 37*(1), 121–128. https://doi.org/10.1007/s11245-016-9373-4

Lapuz, A., & Fulgencio, M. (2020). Improving the critical thinking skills of secondary school students using problem-based learning. *International Journal of Academic Multidisciplinary Research, 4*(1), 1–7. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3543211

Lestari, D., & Setyarsih, W. (2021). Analysis of students' scientific literacy skills and the relationship with critical thinking skills on global warming materials. *Journal of Physics: Conference Series, 1805*(1), 012040. https://doi.org/10.1088/1742-6596/1805/1/012040

Lin, Z., Akin, H., Rao, R., Hie, B., Zhu, Z., Lu, W., ... & Rives, A. (2022). Evolutionary-scale prediction of atomic-level protein structure with a language model. *Science, 379*, 1123–1130. https://doi.org/10.1126/science.ade2574

López Ayala, J. M. (2020). El aprendizaje basado en problemas y el desarrollo de las habilidades del pensamiento crítico. *Educa UMCH, (15)*, 61–70. https://dialnet.unirioja.es/servlet/articulo?codigo=7539914

Luoise, I. S. Y. (2019). The effect of problem based learning model on critical thinking skills in the context of chemical reaction rate. *Journal of Education and Learning (EduLearn), 13*(3), 395–401. https://doi.org/10.11591/edulearn.v13i3.13887

Mackay Castro, M. R., Franco Cortazar, M. D. E., & Villacis Pérez, M. P. W. (2018). El pensamiento crítico aplicado a la investigación. *Universidad y Sociedad, 10*(1), 336–342. https://rus.ucf.edu.cu/index.php/rus/article/view/803

Makhrus, M., & Hidayatullah, Z. (2021). El papel del enfoque cognitivo del conflicto para mejorar las habilidades de pensamiento crítico y la comprensión conceptual en ondas mecánicas. *FORMATIF: Jurnal Ilmiah Pendidikan MIPA, 11*(1). https://journal.lppmunindra.ac.id/index.php/Formatif/article/view/8142

Malfert, K. G. (2023). La complejidad del pensamiento crítico y su relación con la neurociencia. *593 Digital Publisher CEIT, 8*(4), 499–511. https://dialnet.unirioja.es/servlet/articulo?codigo=9124344

Manrique, M. (2020). Tipología de procesos cognitivos. Una herramienta para el análisis de situaciones de enseñanza. *Educación, 29*(57), 163–185. https://doi.org/10.18800/educacion.202002.008

Ministerio de Educación [Minedu]. (2016). Educación Básica Regular. Programa curricular de Educación Secundaria. https://www.ugelsanchezcarrion.gob.pe/wordpress/wp-content/uploads/2019/06/programa-secundaria-17-abril.pdf

Montes Gonzáles, J. A., Ochoa Angrino, S., Baldeón Padilla, D. S., & Bonilla Sáenz, M. (2019). Videojuegos educativos y pensamiento científico: análisis a partir de los componentes cognitivos, metacognitivos y motivacionales. *Educación y Educadores, 21*(3), 388–408. https://doi.org/10.5294/edu.2018.21.3.2

Mundt, M., Hong, Y., Pliushch, I., & Ramesh, V. (2023). A wholistic view of continual learning with deep neural networks: Forgotten lessons and the bridge to active and open world learning. *Neural Networks, 160*, 306–336. https://doi.org/10.1016/j.neunet.2023.01.014

Núñez-López, S., Ávila-Palet, J., & Olivares-Olivares, S. (2019). El desarrollo del pensamiento crítico en estudiantes universitarios por medio del Aprendizaje Basado en Problemas. *Revista Iberoamericana de Educación Superior, 8*(23), 84–103. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-28722017000300084&lng=es&tlng=es

Ossa, C. J., Rivas, S. F., & Saiz, C. (2023). Relation between metacognitive strategies, motivation to think, and critical thinking skills. *Frontiers in Psychology, 14*, 1272958. https://doi.org/10.3389/fpsyg.2023.1272958

Pazos-Yerovi, E. I., & Aguilar-Gordón, F. del R. (2024). El Aprendizaje Basado en Problemas como estrategia metodológica para el desarrollo del Pensamiento Crítico. *Revista de Estudios y Experiencias en Educación, 23*(53), 313–340. https://doi.org/10.21703/rexe.v23i53.2658

Pedraza, S., Santander, P., & Cuentas, H. (2023). Estrategias neurodidácticas para el fortalecimiento de los niveles de comprensión lectora. *Revista InveCom, 4*(1), 1–19. https://doi.org/10.5281/zenodo.8317408

Peña-Troncoso, S., Toro-Arévalo, S., Osses-Bustingorry, S., Beltrán-Véliz, J., & Navarro-Aburto, B. (2019). Neurociencia y ejercicio: un indicador de salud y aprendizaje en el contexto educativo. *Revista de Salud Pública, 21*(4), 1–3. https://doi.org/10.15446/rsap.v21n4.66794

Phérez Gómez, G. A., Pérez Pulido, G., Martínez Cudriz, E., & Tiusabá, S. M. (2023). Potenciando la creación, actualización e innovación del proyecto educativo institucional-PEI del sistema educativo adventista de Colombia [Tesis de grado, Corporación Universitaria Adventista]. Repositorio Institucional de la Corporación Universitaria Adventista – UNAC. http://repository.unac.edu.co/handle/123456789/1230

Piaget, J. (1973). *To understand is to invent: The future of education*. Grossman Publishers.

Putra, P. D. A., Sulaeman, N. F., Supeno, et al. (2023). Exploring students' critical thinking skills using the engineering design process in a physics classroom. *The Asia-Pacific Education Researcher, 32*, 141–149. https://doi.org/10.1007/s40299-021-00640-3

Putri, A. S., Prasetyo, Z. K., Purwastuti, L. A., Prodjosantoso, A. K., & Putranta, H. (2023). Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills. *International Journal of Evaluation and Research in Education (IJERE), 12*(1), 44. https://doi.org/10.11591/ijere.v12i1.22506

Rivas, S., Saiz, C., & Ossa, C. (2022). Metacognitive strategies and development of critical thinking in higher education. *Frontiers in Psychology, 13*, 1–13. https://doi.org/10.3389/fpsyg.2022.913219

Sánchez-Heredia, N., & Álvarez-Medina, G. (2022). Impacto de la neurociencia cognitiva en los aprendizajes. *Polo del Conocimiento, 7*(6), 2382–2405. https://dialnet.unirioja.es/servlet/articulo?codigo=9042467

Sari, D. K., Amelia, R., Dharmajaya, R., et al. (2021). Positive correlation between general public knowledge and attitudes regarding COVID-19 outbreak 1 month after first cases reported in Indonesia. *Journal of Community Health, 46*, 182–189. https://doi.org/10.1007/s10900-020-00866-0

Septiany, L. D., Puspitawati, R. P., Susantini, E., Budiyanto, M., Purnomo, T., & Hariyono, E. (2024). Analysis of high school students' critical thinking skills profile according to Ennis indicators. *IJORER: International Journal of Recent Educational Research, 5*(1), 157–167. https://doi.org/10.46245/ijorer.v5i1.544

Símon de Astudillo, M., & Rodríguez Símon, M. (2021). "Aprender a aprender" y "aprender a hacer" a través de la neurodidáctica. *Revista EDUCARE, 25*(1), 398–420. https://doi.org/10.46498/reduipb.v25i1.1368

Suryana, D., & Yulia, R. (2021). Model of questioning skill teacher for developing critical thinking skill in early childhood education in West Sumatra, Indonesia. *Educational Sciences: Theory & Practice, 21*(2), 101–114. https://www.proquest.com/openview/d15176850436a00d269fb3b9400ff3fe/1?pq-origsite=gscholar&cbl=28575

Susetyarini, E., & Fauzi, A. (2020). Trend of critical thinking skill researches in biology education journals across Indonesia: From research design to data analysis. *International Journal of Instruction, 13*(1), 535–550. https://doi.org/10.29333/iji.2020.13135a

Quimi Varas, M., Zambrano Alcivar, L., Saltos Alcívar, E., & Rodríguez Ruiz, M. (2023). Inclusión educativa y diversidad: Desarrollo de habilidades sociales y emocionales en estudiantes de educación básica. *Conocimiento Global, 8*(2), 68–81. https://doi.org/10.70165/cglobal.v8i2.322

Varveris, D., Saltas, V., & Tsiantos, V. (2023). Exploring the role of metacognition in measuring students' critical thinking and knowledge in mathematics: A comparative study of regression and neural networks. *Knowledge, 3*(3), 333–348. https://doi.org/10.3390/knowledge3030023

Vendrell, M., & Rodríguez, J. (2020). Pensamiento crítico: Conceptualización y relevancia en el seno de la educación superior. *Revista de la Educación Superior, 49*(194), 9–25. https://www.scielo.org.mx/pdf/resu/v49n194/0185-2760-resu-49-194-9.pdf

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wale, B. D., & Bishaw, K. S. (2020). Effects of using inquiry-based learning on EFL students' critical thinking skills. *Asian-Pacific Journal of Second and Foreign Language Education, 5*, 9. https://doi.org/10.1186/s40862-020-00090-2

Warsah, I., Morganna, R., Uyun, M., Hamengkubuwono, H., & Afandi, M. (2021). The impact of collaborative learning on learners' critical thinking skills. *International Journal of Instruction, 14*(2), 443–460. https://doi.org/10.29333/iji.2021.14225a

Yu, Y., Chen, J., Gao, T., & Yu, M. (2019, May). DAG-GNN: DAG structure learning with graph neural networks. In *36th International Conference on Machine Learning* (Vol. 97, pp. 7154–7163). PMLR. https://proceedings.mlr.press/v97/yu19a.html

Zorzos, I., Kakkos, I., Miloulis, S. T., Anastasiou, A., Ventouras, E. M., & Matsopoulos, G. K. (2023). Applying neural networks with time-frequency features for the detection of mental fatigue. *Applied Sciences, 13*(3), 1512. https://doi.org/10.3390/app13031512

Zuluaga Marín, M., Botero Suaza, J. C., Martínez Romero, A. M., & Lopera Ortega, Y. (2022). Neurodidáctica y pensamiento crítico: perspectivas para la educación actual. *Educación y Educadores, 25*(2), e2522. https://doi.org/10.5294/edu.2022.25.2.2