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Implications of scientific inquiry for learning: a systematic review

Implicancias de la indagación científica para el aprendizaje: una revisión sistemática

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Tania Mirtha Garcia Soller
https://orcid.org/0000-0002-6106-8936
tgarciaso@ucvvirtual.edu.pe
Universidad César Vallejo. Lima, Peru

Rony Guillermo Prada Hernández
https://orcid.org/0000-0001-9813-3861
Rony.prada@upsjb.edu.pe
Universidad Privada San Juan Bautista. Ica, Peru

Marilia Ysabel Florez Cueva
https://orcid.org/0000-0002-6082-0882
mflorezcu12@ucvvirtual.edu.pe
Universidad César Vallejo. Lima, Peru

César Iván Torres Sotelo
https://orcid.org/0000-0003-0880-7602
cesar.sotelo@movistar.pe
Universidad Privada San Juan Bautista. Ica, Peru

Abstract

The objective of this study was to analyze the implications of scientific inquiry on student learning. A systematic review methodology was used, applying the PRISMA method. For the search, keywords in English and Spanish were used: “scientific inquiry” AND “students” AND “learning” and “indagación científica” AND ‘estudiantes’ AND “aprendizaje.” The inclusion criteria considered articles available in open access, in English and Spanish, from the Scopus and SciELO databases, and that complied with search equations using the Boolean operator AND. Likewise, the period of analysis was established as 2020 to 2025. As for the exclusion criteria, articles published before 2020, restricted-access articles, and information from books or theses were discarded. As a result, 108 articles were initially identified in the Scopus and SciELO databases; of these, after applying the inclusion and exclusion criteria, 21 articles were selected for analysis (11 from Scopus and 10 from SciELO). It is concluded that scientific inquiry is a fundamental axis for meaningful learning in science and for the continuous training of teachers. In addition, the importance of the environment as an educational agent is highlighted. In this sense, the incorporation of digital technologies into the learning process can increase student motivation and engagement. It is also evident that, when addressing socio-scientific topics, tasks become more open-ended, allowing students to explore and evaluate evidence. Furthermore, scientific inquiry broadens its impact by providing information on the neural mechanisms involved in learning. Finally, it is highlighted that the use of visual tools that present different perspectives on the same concept encourages debate, understanding of scientific thinking, and critical reflection among students.

Keywords: scientific inquiry, learning, strategies.

Resumen

El objetivo del presente estudio fue analizar las implicancias de la indagación científica en el aprendizaje de los estudiantes. Se utilizó una metodología de revisión sistemática, aplicando el método PRISMA. Para la búsqueda, se emplearon palabras clave en inglés y español: “scientific inquiry” AND “students” AND “learning” e “indagación científica” AND “estudiantes” AND “aprendizaje”. Los criterios de inclusión consideraron artículos disponibles en acceso abierto, en inglés y español, provenientes de las bases de datos Scopus y SciELO, y que cumplieran con ecuaciones de búsqueda mediante el operador booleano AND. Asimismo, se estableció como periodo de análisis los años 2020 a 2025. En cuanto a los criterios de exclusión, se descartaron artículos publicados antes de 2020,

artículos de acceso restringido, así como información proveniente de libros o tesis. Como resultado, se identificaron inicialmente 108 artículos en las bases Scopus y SciELO; de los cuales, tras aplicar los criterios de inclusión y exclusión, se seleccionaron 21 artículos para el análisis (11 de Scopus y 10 de SciELO). Se concluye que la indagación científica constituye un eje fundamental para el aprendizaje significativo en ciencias y para la formación continua del profesorado. Además, se resalta la importancia del ambiente como agente educativo. En este sentido, la incorporación de tecnologías digitales en el proceso de aprendizaje puede incrementar la motivación y el compromiso estudiantil. También se evidencia que, al abordar temáticas socio-científicas, las tareas se vuelven más abiertas, lo que permite a los estudiantes explorar y evaluar evidencias. Asimismo, la indagación científica amplía su impacto al ofrecer información sobre los mecanismos neuronales involucrados en el aprendizaje. Por último, se destaca que el uso de herramientas visuales que presentan distintas posturas sobre un mismo concepto fomenta el debate, la comprensión del pensamiento científico y la reflexión crítica entre los estudiantes.

Palabras clave: indagación científica, aprendizaje, estrategias.

Introduction

In secondary education, particularly in the subjects of Biology and Geology, there persists a school culture focused on memorization and a superficial understanding of content, which limits the development of scientific skills in students. Therefore, it is necessary to incorporate more complex practical activities and methodologies such as Inquiry-Based Science Education (IBSE) to foster genuine research competencies in the classroom (Teixeira de Sousa et al., 2025).

Teaching continues to be disconnected from students' real experiences, making it difficult to achieve meaningful comprehension of the content. In this context, it is essential to apply pedagogical strategies like Contextualized Learning (CTL), which links academic knowledge with social, cultural, and everyday experiences, thus promoting active, collaborative, and meaningful learning (Tulung et al., 2024).

Science education remains centered on memorization, neglecting the development of key skills such as argumentation, creativity, and critical thinking. It is crucial to guide student training toward the development of both scientific and generic competencies that enable them to face the challenges of their environment reflectively and innovatively (Silva et al., 2024).

Although contemporary pedagogy is grounded in constructivist theories, the practical application of these approaches remains limited in educational settings. Many educators continue to employ traditional methods focused on information transmission and memorization, hindering students from actively constructing their knowledge, developing critical thinking, and connecting what they have learned with their social and cultural reality (Rodríguez et al., 2022).

While there are international frameworks promoting inquiry-based science education, many teachers in Latin America lack the necessary training to implement them. This situation is reflected in the low results of students in scientific competencies, according to international assessments such as those by the Organisation for Economic Co-operation and Development (OECD) (Culqui-Rojas et al., 2024). Although the importance of an education that integrates cognitive, emotional, and social aspects is recognized, there remains a lack of school programs that strengthen social skills such as empathy, self-esteem, and communication, which limits the holistic development of the student (Parra et al., 2024).

In this context, the objective of the present study was to analyze the implications of scientific inquiry on students' learning.

Methodology

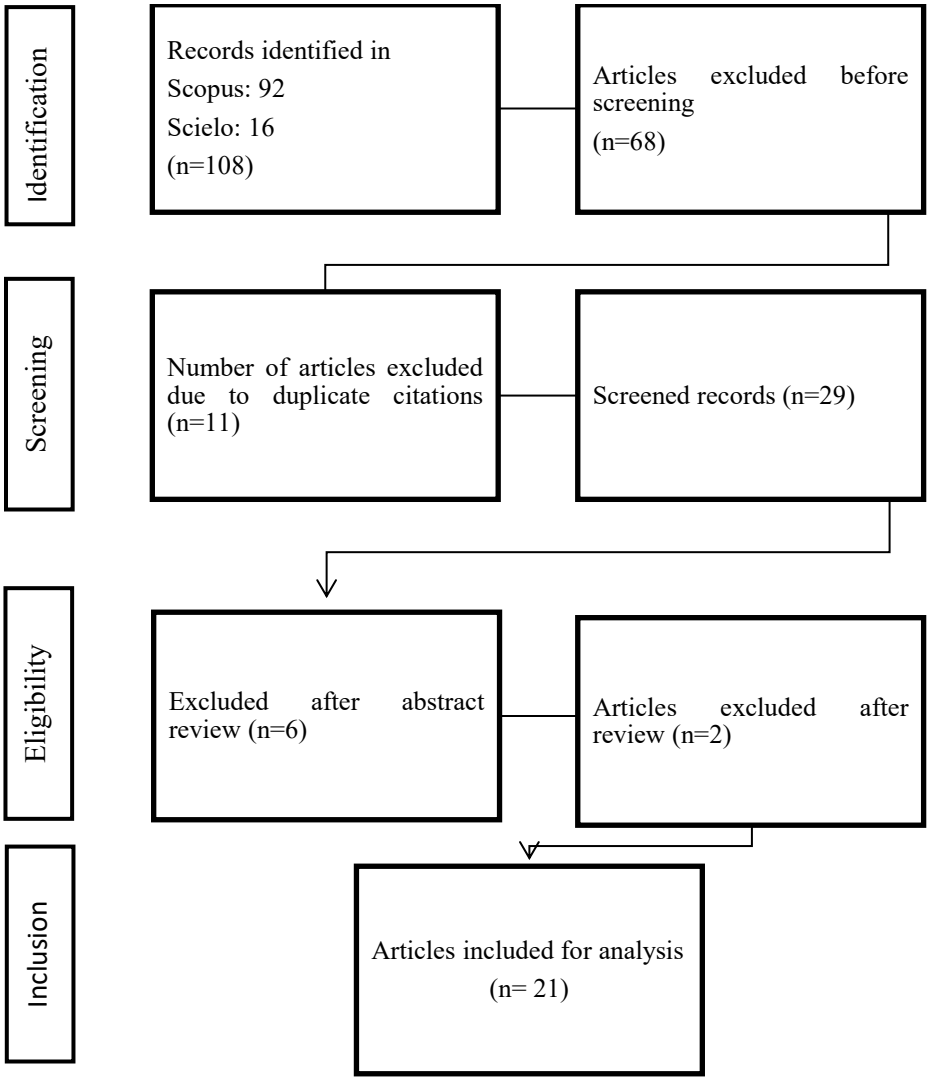
The study adopted a systematic review methodology, utilizing the PRISMA protocol. For the information search, keywords in both English and Spanish were employed, such as: “scientific inquiry” AND “students” AND “learning,” and “indagación científica” AND “estudiantes” AND “aprendizaje.”

Inclusion criteria included open-access articles in English and Spanish, sourced from the Scopus and SciELO databases, that utilized search equations with the Boolean operator AND. The analysis period was set between the years 2020 and 2025. Exclusion criteria eliminated articles published before 2020, those not available in open access, as well as books and theses. As a result of the selection process, a total of 108 articles from the Scopus and SciELO databases were initially considered. After applying the inclusion and exclusion criteria, a total of 21 articles were selected for analysis: 11 from Scopus and 10 from SciELO (see Table 1).

Table 1
Search keywords from database articles

Database	Search term	Results	Selected
Scopus	“scientific inquiry” AND “learning”	92	11
Scielo	“scientific inquiry” AND “learning”	16	10
	Total	108	21

Figure 1
PRISMA flow diagram



* Table formatted according to PRISMA with original data

Results

Table 2
Implications of scientific inquiry for learning

No.	Authors	Implications of scientific inquiry for learning
1	Zárate-Moedano et al. (2023).	The use of remote laboratories as a teaching strategy has significantly improved learning and scientific literacy among secondary school students. A quasi-experimental study demonstrated that those who utilized these laboratories improved their performance on scientific tests compared to the control group. While they do not replace traditional laboratories, their ease of use and accessibility make them a valuable option in resource-limited contexts, promoting inquiry and experimental learning.
2	Pezoa-Carrasco & Muñoz-Zamora (2022).	Scientific literacy from early childhood requires teachers to integrate inquiry into their practices. The Reggio Emilia philosophy, emphasizing the environment as a teacher, classroom projects, and the teacher as a researcher, offers an effective strategy for developing research skills in future basic education teachers, fostering active and experiential learning.
3	Carrasco et al. (2022).	Various studies indicate that personal, social, and educational factors influence the continuous learning of science teachers. A biographical study with teachers participating in the ICEC Program showed how the pandemic enhanced professional learning and redefined the teacher's role, highlighting the importance of inquiry and collective learning in crisis contexts for their professional development.
4	Mokotso (2022).	In collaboration with the Japanese government, UNESCO organized seminars for teacher trainers and secondary school teachers to strengthen their capacities in peace education. This education utilizes transformative pedagogy that fosters critical thinking and reflection in both teachers and students, promoting positive changes in their local and global environments.
5	Mendioroz et al. (2022).	Research competence is key to fostering a scientific culture from childhood, enabling the construction of explanations based on inquiry and theory. However, a study with 208 student teachers revealed that they overestimate their research skills and do not identify their own deficiencies, which hinders the development of autonomous and critical learning.
6	Manrique-Alvarez et al. (2021).	Based on meaningful learning and constructivism, an experimental study with 120 schoolchildren evaluated the impact of cognitive conflict applied through specific pedagogical strategies (motivation, feedback, and learning construction) in science and technology. The results show that these strategies significantly improve learning, especially in inquiry, explanation, and problem-solving in technology.
7	Rodríguez et al. (2021)	Various studies indicate that students show greater motivation and engagement when using the Internet in their learning. However, empirical research is needed to understand how these emotions affect the teaching of digital competencies, as there are no validated instruments to measure these affective aspects in teachers and their relation to teaching online inquiry skills.
8	Gonçalves & Bretones (2021)	This experimental study analyzes the teaching of the Moon and its phases in a second-grade group in a public school. Direct observation of the celestial body was the main focus of learning, complemented with drawings and group discussions—strategies accessible to young children. The objective was to identify the ideas and questions that arise when observation is central and to evaluate the understanding students

		develop according to Vygotsky's scientific concept formation for childhood. The results show that students learned about the visible movements of the Moon and its shape changes over the nights.
9	Cobo-Huesa et al. (2020)	Scientific literacy among citizens requires teaching that enables an understanding of how science functions in relation to society. To achieve this, it is crucial to strengthen teacher training from early stages. A study showed that a pedagogical proposal based on the history of science, incorporating inquiry in diverse and reflective scenarios, generated significant improvements in understanding the Nature of Science (NdC) among future primary education teachers. Advances were observed in both the epistemological and sociological dimensions of NdC compared to a control group, highlighting the value of these strategies in initial training.
10	Magalhães et al. (2020).	Ongoing research with third-grade students analyzed how skills and attitudes develop during learning about the concept of heat and its effects on state changes. Using an inquiry-based methodology grounded in the Theory of Significant Critical Learning, the case study demonstrated that this strategy promotes greater motivation and interest in science, expands scientific vocabulary, facilitates the acquisition of new concepts, and strengthens social interaction, questioning, and understanding of basic scientific procedures.
11	Gyllenpalm et al. (2021).	A study based on data from the international VASI instrument, applied to Swedish students, reveals that most do not possess an informed understanding of key aspects of scientific inquiry, even by the end of secondary education. Although final-year students show progress compared to seventh graders, average results remain low, with less than 50% of answers being correct. This research emphasizes the need to strengthen the school focus on the explicit teaching of inquiry processes, differentiating between knowing scientific inquiry and being able to execute it.
12	Khaokhajorn & Srisawasdi (2024)	Strengthening inquiry-based science education is key to sustainable teacher training. A study conducted with 278 future science teachers in Thailand revealed that most have a partial understanding of the Nature of Scientific Inquiry (NOSI), particularly regarding questions, methods, and conclusions.
13	Arnold et al. (2021).	Scientific thinking is a central objective in science education and can be developed through inquiry-based learning. Two studies analyzed students' ideas about this understanding using Concept Cartoons, a visual tool that presents different perspectives on a concept to activate and foster debate among students.
14	Jones et al. (2022).	The effects of a pilot intervention conducted at home to strengthen conceptual understanding and scientific inquiry skills in deaf and hearing children are presented. Despite an observed learning gap by age five, the proposal involved guiding caregivers to integrate scientific language into daily routines. After 13 months of follow-up and five evaluations, all caregivers reported progress in their children's conceptual understanding. Notably, caregivers of deaf children reported greater advances in inquiry skills. These preliminary results suggest that prolonged interventions could reduce the learning gap in scientific education.
15	Pols eet al. (2022).	A study with secondary school students showed that they typically apply scientific inquiry rules only when prompted, without understanding their purpose. The most impactful phase was one that positioned them as critical consumers of knowledge, promoting a deeper appreciation of

		scientific standards and motivating improvements in their own inquiry processes.
16	Silverio et al. (2024).	Various guiding documents in biology, chemistry, and mathematics underscore the importance of students developing common skills in STEM, such as scientific inquiry, collaborative work, and communication. An interdisciplinary comparison of these competencies allows teachers and faculties to integrate approaches, facilitate the transfer of learning across disciplines, and promote institutional educational changes.
17	Xu et al. (2024).	In science classrooms in China, teaching is limited by a partial understanding of scientific inquiry, low intrinsic motivation among students, and an environment that does not favor divergent thinking or creativity. Cultural and pedagogical factors, such as the pursuit of harmony and a lack of suitable spaces, hinder the authentic practice of scientific inquiry.
18	Cirkony (2023).	A study on the implementation of a multimodal approach to guided inquiry in science, with ninth-grade Australian students, demonstrated that this strategy fostered authentic epistemological practices. Students designed their own experiments, collaboratively constructed knowledge, and used specific disciplinary tools to support their research.
19	Andersson-Bakken et al. (2020).	Overall, activities favor closed responses and do not promote authentic scientific inquiry. Only topics with socio-scientific questions present more open tasks for exploring and evaluating evidence.
20	Janssen et al. (2023).	The case of a future biology teacher who initially taught practices rigidly, in a "recipe-book" style, is presented. Through a support approach called GSR, she was able to redesign her activities toward more open scientific inquiry. This method helps teachers identify the gap between their current and ideal practices and offers concrete strategies to advance toward the latter, improving their educational objectives.
21	Aldhaheri et al. (2024).	Brain-computer interfaces and neurolinguistics are key areas for understanding the neural mechanisms involved in language acquisition. This study analyzes EEG signals from eight participants learning Arabic and Hindi as second languages, using machine learning models to identify cognitive and functional differences in brain activity. The findings provide evidence regarding the neural processes involved in language learning and offer a basis for designing more effective teaching strategies.

Importance of scientific inquiry for learning

Various studies have highlighted the importance of scientific inquiry as a fundamental axis for meaningful learning in science and for the continuous training of teachers. For example, a biographical study with teachers from the ICEC Program demonstrated that during the pandemic, professional learning was enhanced through inquiry and collective work, redefining the teacher's role in crisis contexts and strengthening their professional development (Carrasco et al., 2022). This approach is vital for fostering a scientific culture from early stages, enabling the construction of evidence-based explanations and theories.

However, challenges in initial teacher training have been identified. It has been shown that many teachers overestimate their research skills and do not recognize their shortcomings, which limits the development of autonomous and critical learning (Mendioroz et al., 2022). Furthermore, it was evidenced that, even upon completing secondary education, the majority of students do not adequately understand the processes of scientific inquiry. Although improvements are observed at advanced levels, less than half provide correct answers, underscoring the need for explicit teaching that not only transmits knowledge but also facilitates the practical application of inquiry (Gyllenpalm et al., 2021).

Moreover, the incorporation of digital technologies in learning can increase student motivation and engagement; however, further research is needed to understand how emotions and affective skills influence the teaching of digital competencies and the autonomous search for information. Currently, there is a lack of validated instruments to measure these aspects in teachers and their relationship with teaching (Rodríguez et al., 2022).

This situation is not exclusive to the West. In science classrooms in China, teaching faces limitations stemming from a partial understanding of inquiry, low intrinsic motivation among students, and an environment that does not promote divergent thinking or creativity. Cultural factors, such as an emphasis on social harmony and restrictions in the physical and temporal context, hinder the authentic practice of scientific inquiry (Xu et al., 2024).

Curriculum-wise, it has been detected that school activities tend to promote closed and traditional responses, without fostering authentic inquiry. Only in topics addressing socio-scientific questions do tasks become more open, allowing students to explore and evaluate evidence (Andersson-Bakken et al., 2020).

Additionally, scientific literacy depends on teacher training that strengthens understanding of how science functions in relation to society. A pedagogical proposal that incorporates the history of science and promotes inquiry in diverse contexts has shown significant improvements in understanding the Nature of Science (NdC) among future primary school teachers, highlighting the value of these strategies in initial training (Cobo-Huesa et al., 2020).

Finally, recent research in neuroscience applied to learning, such as studies using brain-computer interfaces to analyze second language acquisition, shows how scientific inquiry can broaden its impact by providing evidence about the neural mechanisms involved. By identifying cognitive and functional differences during the learning of languages such as Arabic and Hindi, these findings contribute to the design of more effective pedagogical strategies, thus evidencing the relevance of scientific inquiry in various educational domains (Aldhaheri et al., 2024).

Strategies for scientific inquiry in learning

Scientific inquiry is a key pedagogical strategy for promoting meaningful and profound learning in science, from basic education to teacher training. Various studies demonstrate that inquiry-based methodologies favor the development of research skills, critical thinking, and motivation toward scientific learning. An effective example is the use of remote laboratories as a teaching tool for secondary school students. A quasi-experimental study revealed that those who utilized these laboratories significantly improved their performance on scientific tests compared to a control group. While they do not replace the experience of a traditional laboratory, their accessibility and ease of use position them as a valuable strategy for resource-limited contexts, fostering inquiry and experimental learning (Zárate-Moedano et al., 2023).

In parallel, the pedagogical approach of the Reggio Emilia philosophy emphasizes the importance of the environment as a teacher, project work, and the teacher as an active researcher. This methodology has proven effective in training future basic education teachers, promoting active, experiential, and inquiry-oriented learning from early ages (Pezoa-Carrasco et al., 2022).

Peace education, promoted in seminars organized by UNESCO and the Japanese government, also incorporates inquiry strategies to foster critical thinking and reflection in teachers and students, aiming to positively transform their local and global environments (Mokotso et al., 2022). This perspective aligns with the principles of meaningful and constructivist learning, which, in experimental studies, have shown that the implementation of cognitive conflict through strategies such as motivation, feedback, and learning construction significantly improves performance in inquiry, explanation, and technological problem-solving (Manrique-Álvarez et al., 2021).

An applied example in early education is the direct observation of celestial bodies with second-grade students, complemented by drawings and group discussions. This accessible and interaction-based strategy allowed children to construct scientific concepts about the movements and phases of the Moon, relying on Vygotsky's concept formation theory (Gonçalves et al., 2021). Similarly, in basic education, ongoing research using inquiry grounded in the Theory of Significant Critical Learning to teach the concept of heat has shown an increase in motivation, an expansion of scientific vocabulary, and a strengthening of questioning and social interaction (Magalhães et al., 2020).

To strengthen sustainable teacher training, it is essential that future teachers have a deep understanding of the Nature of Scientific Inquiry (NOSI). However, it has been evidenced that the majority possess a partial understanding of NOSI, particularly in key aspects such as questions, methods, and conclusions (Khaokhajorn et al., 2024). Tools like Concept Cartoons, which visually present different perspectives on a concept to activate debate, have proven useful in improving students' understanding of scientific thinking, fostering discussion and critical reflection (Arnold et al., 2021).

Advancements in scientific inquiry also benefit groups with specific needs. For example, caregivers of deaf children reported significant progress in inquiry skills following prolonged interventions, suggesting that these strategies may help reduce gaps in scientific learning (Jones et al., 2022). In secondary school students, although they often apply inquiry rules only when prompted, programs that position them as critical consumers of knowledge

have succeeded in enhancing their appreciation of scientific standards and the quality of their inquiry processes (Pols et al., 2022).

In an interdisciplinary context, guiding documents in Biology, Chemistry, and Mathematics highlight the importance of developing common competencies in STEM, such as scientific inquiry, collaborative work, and communication. The comparison and articulation of these competencies facilitate the transfer of learning across disciplines and promote educational transformations at the institutional level (Silverio et al., 2024). Additionally, the implementation of a multimodal approach to guided inquiry among ninth-grade Australian students demonstrated that this strategy promotes authentic epistemological practices, where students design their own experiments and collaboratively construct knowledge using specific tools (Cirkony, 2023).

Finally, supporting teachers in transforming their practice is essential. The case of a future biology teacher who transitioned from rigid teaching to inquiry-based instruction using the GSR method (Gap, Strategy, Result) exemplifies how educators can identify gaps in their practice and apply concrete strategies to move toward more open and effective teaching (Janssen et al., 2023).

Conclusions

The study concluded that scientific inquiry constitutes a fundamental axis for meaningful learning in science and for the continuous training of teachers. Professional learning was enhanced through inquiry and collective work, allowing for a redefinition of the teacher's role in crisis contexts and strengthening their professional development.

The importance of the environment as an educator, project work, and the teacher as an active researcher is emphasized. This methodology has proven effective in training future basic education teachers, promoting active, experiential, and inquiry-oriented learning from early ages. In this regard, the incorporation of digital technologies in the learning process can increase student motivation and engagement; however, further research is needed to understand how emotions and affective skills influence the teaching of digital competencies and the autonomous search for information.

Additionally, it is recommended to address socio-scientific themes in educational practices, as they allow tasks to be more open, facilitating exploration and evaluation of evidence by students. Scientific inquiry can further amplify its impact by providing evidence about the neural mechanisms involved in learning. Finally, the use of visual tools that present different perspectives on the same concept has proven useful in improving students' understanding of scientific thinking by fostering debate, discussion, and critical reflection.

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