

Technological innovation in inquiry learning to enhance critical thinking skills: A bibliometric analysis

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Abstract

Studies on the integration of inquiry-based learning, reflective practice, and critical thinking in physics education remain relatively limited and have not been comprehensively described. This study aims to analyze research trends in inquiry learning and technology to improve critical thinking skills in 21st-century practices. This study employed a bibliometric review, combined with the PRISMA framework, to systematically identify research trends, thematic developments, and knowledge structures in the field. Based on 185 documents from 2021 to 2025, there was a significant increase in publications and citations. Furthermore, there is a correlation between the application of the inquiry learning model and technology integration in improving students' critical thinking skills. Inquiry learning, which positions students as active agents in discovering and constructing knowledge through questions, investigations, and reflection, is highly effective in improving critical thinking skills, especially in fields that require an understanding of complex concepts, such as physics. This effectiveness is further optimized when integrated with reflective practice, which helps students consciously review the learning process, identify strengths and weaknesses, and formulate improvement strategies. The importance of utilizing technology, particularly AI in the form of AR, VR, and interactive simulations, is evident in its significant support for both aspects through adaptive, interactive learning environments. It is recommended to develop technology-based learning tools that comprehensively integrate inquiry syntax with the stages of reflective practice to support the sustainable development of critical and reflective thinking skills in the 21st century.

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1. Introduction

The development of globalization and digital transformation has driven a paradigm shift in education, emphasizing the mastery of 21st-century skills. Various studies have shown that critical thinking skills are one of the most needed competencies to face the complexity of modern problems (Martinez, 2022). However, research findings on the effectiveness of learning in developing critical thinking skills still show mixed results. Some studies report that the implementation of active, technology-based learning models can improve students' analytical, evaluation, and decision-making skills (Lintangesukmanjaya et al., 2024), while other studies find that these improvements are inconsistent due to the influence of teacher readiness, learning design, and student characteristics (Mutohhari et al., 2021). These differing findings indicate that the development of critical thinking skills depends not only on the use of technology or specific learning models but also on how learning strategies are designed and implemented. Therefore, more in-depth studies are needed to develop effective learning approaches to developing critical thinking skills in the digital age.

The learning expectation of fostering students' critical thinking skills can be realized by integrating technology. Technological innovation is expected to strengthen the learning process to make it more interactive, reflective, and contextual (Alam & Mohanty, 2023; Hajirasouli et al., 2024). Adopting technology and engaging in meaningful learning activities can enhance students' 21st-century skills. This is an effort to create ideal learning in the modern era. Ideal learning is also related to learning that implements reflective practice, which encourages students to evaluate their thinking processes and actions (Howell, 2021; Yaacob et al., 2020). Reflective practice learning can also foster learning awareness (metacognition). Metacognitive awareness is a person's ability to recognize, monitor, and regulate their own thinking and learning processes (Rivas et al., 2022). Learning that emphasizes reflective practice aims to effectively enhance learning awareness through meaningful and independent learning evaluation.

The current reality is that many students struggle to independently assess their learning capacity. Furthermore, several international studies have found that many students have not demonstrated adequate mastery of critical thinking skills in school learning, particularly in science and physics (Anisah et al., 2025; Lintangesukmanjaya, Prahani, & Jatmiko, 2025). This is related to the suboptimal use of technology to support reflective learning (Budiono et al., 2025). Few learning practices truly implement the reflective-practice principle in physics. There is a lack of systematic integration between technology and reflective learning in learning. These impacts learning activities that have not been implemented in accordance with a student-centered approach. Furthermore, learning difficulties are relatively high, especially in physics (Saphira et al., 2022). Physics learning is considered difficult not only because the material is complex, but also because the way students interact with abstract material leads to a lack of visualization understanding (Mustofa et al., 2024). Physics material is also very difficult to understand if relying solely on mathematics and theory without the aid of relevant media and methods. Therefore, it is important to know the learning mapping trends that prioritize the use of technology and visualization, especially in meaningful learning.

One form of meaningful learning using a reflective-practice approach is the Inquiry learning model, which is considered effective in encouraging independent exploration, investigation, and discovery of concepts (Brown et al., 2021; Chen, 2022). Inquiry learning has the potential to be a form of learning that implements reflective practice, emphasizing student learning independence. The limited research mapping linking technology to 21st-century reflective-practice learning is a constraint (Heymann et al., 2022). Furthermore, due to the limited implementation of inquiry learning as reflective practice learning utilizing modern technology, a Systematic Literature Review (SLR) approach is needed to analyze current research trends and maps, namely the potential of inquiry with integrated technology applications to improve critical thinking skills (Cabrera et al., 2023). This is reinforced by previous bibliometric studies that have focused solely on discovery-based learning (Derman & Bezen, 2025; Shidiq et al., 2025). There has been no research integrating reflective practice, AI/technology, and physics education, as well as mapping the evolution of keywords or thematic trends. This effort is important to understand the mapping of the relationship between inquiry learning, technology, and the development of critical thinking skills.

Based on these expectations and problems, the purpose of this research is to analyse research trends related to inquiry learning and technology in improving critical thinking. The research objectives specifically explain research trends, mapping and analysis of new paradigm approaches in critical thinking, inquiry and educational technology. The mapping results can be used to identify the relationship between inquiry learning and 21st-century reflective-practice learning and the influencing indicators. The correlation between meaningful learning models and a student-centered approach through reflective practice is also investigated. In addition, an investigation of the implementation of the types of technology used in inquiry learning on physics material and adjustments to 21st-century skills-based learning is carried out.

The novelty of this research lies in its bibliometric study, which integrates inquiry-based learning and critical thinking into reflective practice in the education sector. This contrasts with previous bibliometric studies that focused more on inquiry-based learning or problem-based learning separately and the limitations of technology (Derman & Bezen, 2025; Heymann et al., 2022). Therefore, this study analyses the knowledge structure, the development of themes, and research directions that connect the use of technology with the development of critical thinking skills and reflective practice. The findings can be an important reference for educators, researchers, and policymakers to develop adaptive and reflective physics learning for the times. This research can be a useful study in improving the quality of innovative 21st-century learning planning, especially in physics education.

2. Method

2.1. Type of Research

The research used is quantitative descriptive research that aims to systematically, factually, and accurately describe a phenomenon or characteristic of a particular population through the collection and analysis of numerical data (Kawar et al., 2024; Nurhayati, 2020). The research was conducted using a Systematic Literature Review (SLR) through bibliometric analysis called systematic bibliometric review. Bibliometric analysis aims to quantitatively identify research trends, developments, and patterns in a scientific field (Lintangesukmanjaya, Prahani, & Bergsma, 2025; Prahani et al., 2023). Through this analysis, researchers can identify the most productive authors, document sources, or institutions, as well as the most frequently studied topics. In addition, systematic bibliometric review also helps uncover research gaps, research correlations, and directions for future study development. Systematizing the literature through bibliometric analysis can serve as a basis for decision-making or further research findings. The research design can be seen in Figure 1 below.

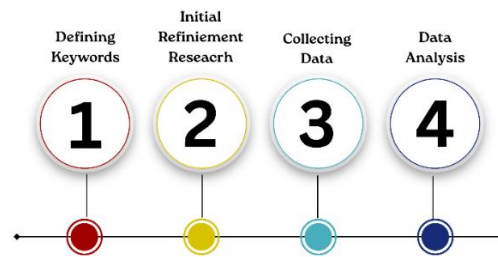


Figure 1. Research Design

The first stage is defining keywords, which involves determining keywords relevant to the research topic to ensure the literature search aligns with the study's focus. The initial search results are then processed based on established inclusion and exclusion criteria to obtain literature relevant to the research objectives. Next, in the data collection stage, articles meeting the criteria are collected and documented as research data sources. The final stage is data analysis, which is conducted using a Systematic Literature Review (SLR) approach combined with bibliometric analysis to identify publication trends, research theme developments, relationships between keywords, collaboration patterns, and the structure of knowledge within the field of study (Cabrera et al., 2023). The combination of these two approaches allows for a more comprehensive understanding of research developments and future study directions.

2.2. Data Source and Search Strategy

The data sources and search strategy for this study were obtained based on the results of a bibliometric analysis conducted using the international database Scopus over the past five years (Prahani et al., 2022). Data retrieval and filtering were carried out in a SLR study using the Scopus database. Data were obtained quantitatively in CSV format so that scientific developments could be evaluated statistically. The data sample for the systematic bibliometric analysis was 185 documents indexed by Scopus between 2021 and 2025. This data includes all documents indexed by Scopus, filtered based on the agreed Title-Abstract-Key (*technology AND inquiry AND learning AND critical AND thinking*).

2.3. Data Analysis Techniques

Data analysis was conducted using the Systematic Literature Review (SLR) instrument, a systematic, transparent, and structured literature review method to identify, evaluate, and synthesize all relevant research on a specific topic or research question (Cabrera et al., 2023). This SLR is used in bibliometric data processing to measure, observe distribution maps, visualize, and analyze relationships between words using VOSViewer (Hijriyah et al., 2024). Using the PRISMA chart approach, the SLR is conducted according to the selected topic with the aim of minimizing bias by following clearly documented search, selection, and analysis procedures. From the data, document sources, most affiliations, research citations, countries, fields of study, best title sources, countries, authorship, and keywords will be sought. The results of the bibliometric analysis are generalized to obtain findings on integrated learning development in digital technology over the past 5 years. It also seeks to build a strong theoretical foundation and summarize empirical evidence. PRISMA Chart can be seen in Figure 2.

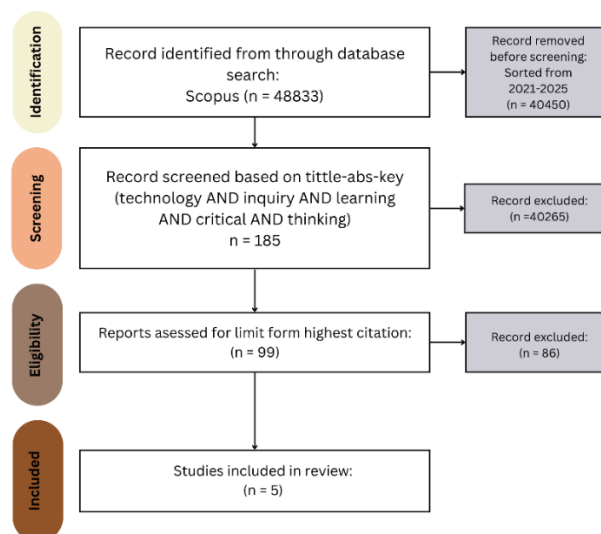


Figure 2. PRISMA Chart

3. Results and Discussion

Based on the results of data collection through the Scopus database over the past 5 years collected with keywords limited to "*technology AND inquiry AND critical thinking AND physics AND reflective-practice*" obtained 185 data. The filter results of the topics studied are limited to inquiry learning only 99 documents with high citations as shown in Figure 3. Based on Figure 3, there is a visible trend of increasing number of documents published in inquiry learning to improve critical thinking skills. Every year, the number of documents continues to increase. From 2022-2024 is the year with the most significant increase in documents with the most documents of 59 documents in 2025 even though the research was still conducted in August 2025.

3.1. Research Trends in the Last 5 Years

Through the existing framework and in line with 21st-century skills, integrating technology into inquiry learning can achieve in-depth learning in education, specifically critical thinking skills. The number of citations from publications in the field of inquiry learning to improve critical thinking skills increased from 2021 to 2025. Even in 2025, the number of citations did not decrease. There was a surge in citations in 2023 to 2024, indicating increased interest in research on technology integration to support inquiry learning as an approach to improving critical thinking skills through meaningful learning (Lintangesukmanjaya et al., 2024; Wen et al., 2023). The following results of the number of documents and citations each year can be seen in Figure 3.

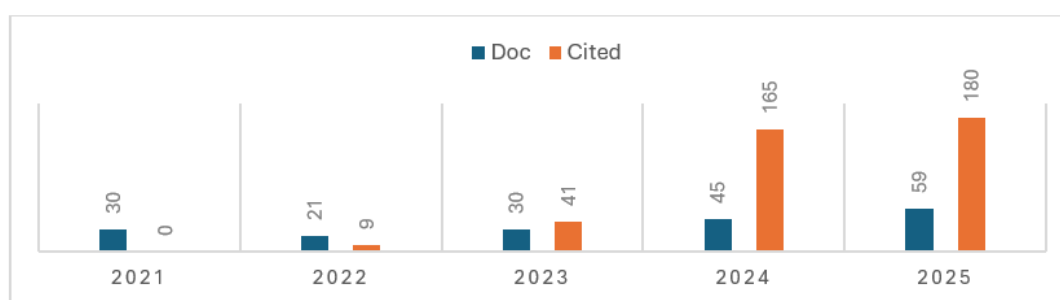


Figure 3. Documents and Citations Per Year

Figure 3 shows a surge in citations from 2021 to 2024, followed by an ongoing surge in citations in 2025. Furthermore, Figure 4 shows research trends based on the types of sources found. The most frequently used sources are articles, with a total of 93 documents, and conference papers, with 46 documents. Based on the number of documents above, it is clear that there has been a significant surge in educational technology research in the post-pandemic era. Research addressing digital learning is particularly accelerating. During the period of distance learning, educational institutions worldwide were forced to adopt various digital technologies to maintain the continuity of the teaching and learning process. This experience demonstrates that technology not only serves as an emergency solution but also has the potential to increase the flexibility, accessibility, personalization, and effectiveness of learning. This increase is evident from various sources and research scopes. Furthermore, Figure 5 also shows documents with different subject areas, each with the five highest levels of coverage: science, computer science, engineering, physics, and humanities, with a total of 174 documents.

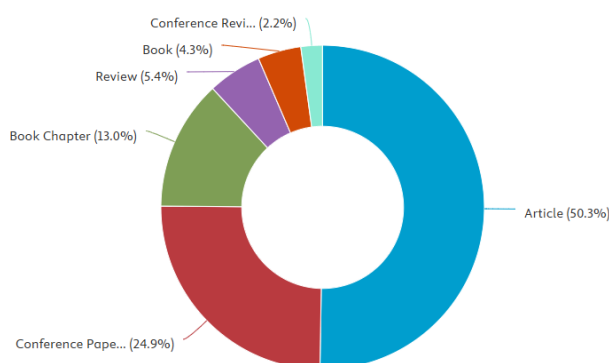


Figure 4. Document Types

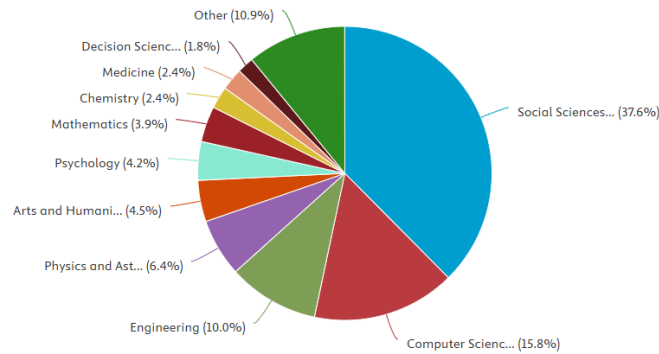


Figure 5. Subject Area Types

In the last 5 years, the top 10 countries contributing to technological innovation research in inquiry learning to improve critical thinking skills as effective learning were found to be the United States, China, Indonesia, India, Australia, Malaysia, Turkey, Canada, the Philippines, and the United Arab Emirates. The data obtained is visualized in Figure 6. From the data obtained, in first place is the United States with 34 documents, followed by China and Indonesia with 25 documents. From these data, it is known that researchers in the United States, China, and Indonesia are very interested in technological innovation research in inquiry learning to improve critical thinking skills. Based on the number of publications made, it can be seen that almost the entire world population is aware of the importance of technology integration in education through meaningful learning such as the current inquiry model. The following is a mapping of countries that can increase their contribution to technological innovation in inquiry learning to improve critical thinking skills. A mapping of the top 10 countries contributing to the research can be seen in Figure 6 below.

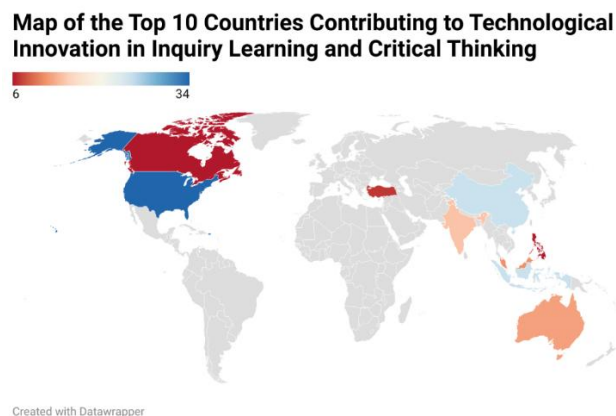


Figure 6. Distribution of the TOP 10 Countries Contributing to Research

The high publication productivity in the United States, China, and Indonesia indicates that research on technology integration in inquiry learning is growing rapidly in countries investing in digital educational transformation. The United States and China dominate due to their strong research capacity, access to cutting-edge technology, and national policies that support technology-based educational innovation. Indonesia's high contribution, on the other hand, can be attributed to the accelerated post-pandemic digitalization of education and its strong focus on developing 21st-century skills. These findings suggest that research development is influenced not only by a country's academic capacity but also by the need to adapt its education system to the demands of the digital era and the knowledge-based economy.

Of several other countries not listed in the data mapping above, the majority of the entire population of countries in the world have implemented meaningful learning such as inquiry learning. When viewed from existing document sources, top document sources/journals were found that support technological innovation in inquiry learning to improve critical thinking skills. The largest publication is in the Journal of Physics Conference Series (Q4) with a total of 9 documents. From the distribution of data in each source, this study found many different clusters with 3 highest clusters. In cluster 1 there are 180 items with the most significant appearance, namely student learning. Furthermore, in cluster 2 there are 169 items with the most significant appearance including inquiry-based learning. Then in cluster 3 consists of 122 items, the keyword with the most appearance is critical thinking. Visualization of the relationship between all keywords that frequently appear in the study forms large and small related groups. Network visualization can be seen in Figure 7 below.

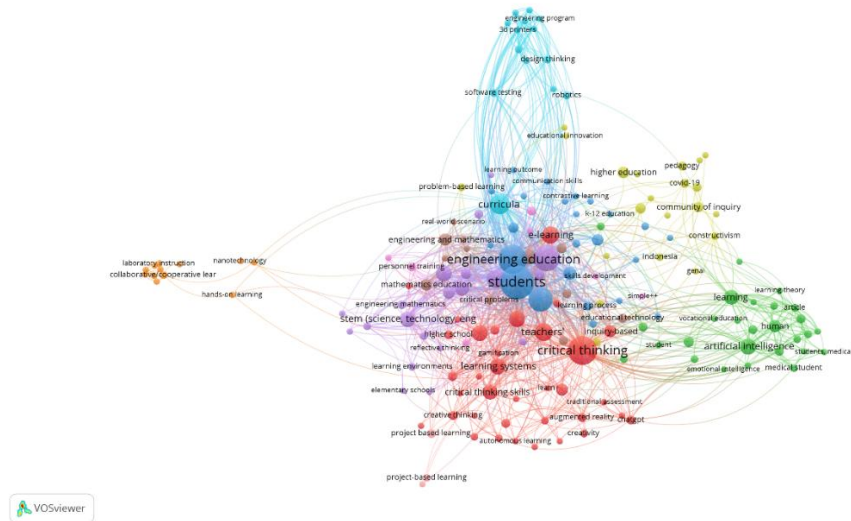


Figure 7. Network Visualization

The network visualization results show that the keywords students, engineering education, critical thinking, and learning are the main nodes with the strongest connections to other keywords. Six main clusters form the research structure. The red cluster centers on critical thinking, which relates to learning systems, learning methods, teachers, assessment, creativity, and project-based learning, indicating a research focus on developing critical thinking skills through various learning strategies. The blue cluster centers on students and engineering education, illustrating the dominance of studies on the implementation of educational technology to improve student learning outcomes. The green cluster focuses on learning and artificial intelligence, which indicates the increasing integration of artificial intelligence in the learning process. The yellow cluster connects topics such as higher education, community of inquiry, pedagogy, constructivism, and COVID-19, reflecting the development of digital and collaborative learning, especially in the post-pandemic period. The purple cluster contains the themes of STEM education, demonstrating the relationship between STEM-based learning and the development of higher-order thinking skills. Meanwhile, the orange cluster consists of laboratory instruction, collaborative cooperative learning, which emphasizes the importance of practice-based learning and direct experience in supporting the inquiry process. The results of this mapping are all relevant to keywords that support the application of technology through inquiry-based learning to improve critical thinking skills. The data distribution revealed the highest occurrence value of 53 for the word "Students," and the top 10 keywords based on the distribution were as follows on Table 1.

Table 1. Top 10 Keywords by Author

Rank	Keyword	Total Link Strength
1	students	426
2	engineering education	353
3	teaching	300
4	critical thinking	231
5	inquiry-based learning	185
6	curricula	176
7	science technologies	123
8	teachers	116
9	stem (science, technology, engineering and mathematics)	115
10	education	114

The most significant keywords determine trends that have become the main topics attracting research attention in the last 5 years (Donthu et al., 2021). Meanwhile, keywords with fewer occurrences indicate that several studies focus on the subtopic "technology integration in supporting inquiry learning as an approach to improving critical thinking skills." Therefore, to find new research with technology integration focused on education, an investigation will be conducted using the related topic visualization in Figure 8. The relationship between learning is inseparable from student activities, where the word "student" often appears with top link strengths related to several keywords such as critical thinking, education, teacher, engineering, learning, inquiry, and others. This proves that research trends are often found in the use of learning on students. This also symbolizes that inquiry learning is one of the student-centered learning (Novitra et al., 2021; Tsivitanidou et al., 2021). The following Figure 8 shows the correlation between inquiry and critical thinking in student subjects.

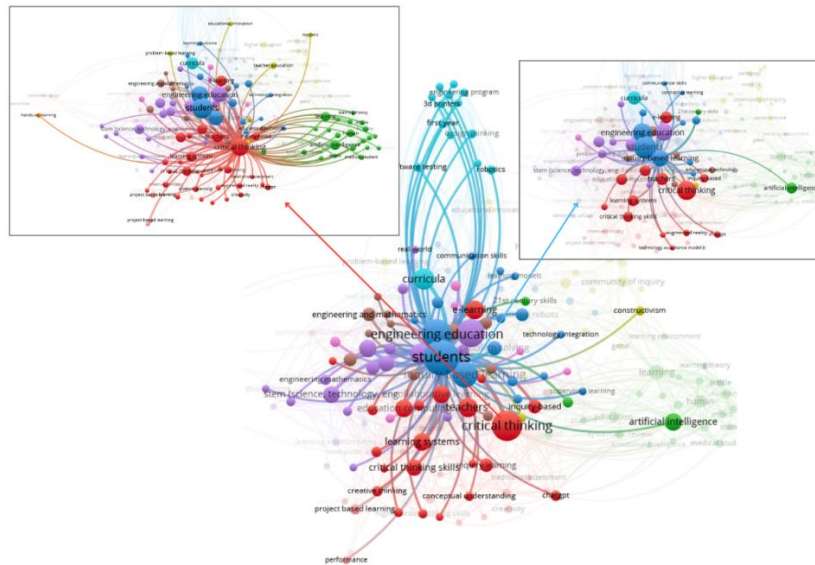


Figure 8. Correlation Between Inquiry Learning-Critical Thinking-Student

The network visualization shows that the keywords critical thinking, students, and inquiry-based learning are strongly interconnected and centrally positioned in the research map. This indicates that students are the primary subjects in developing higher-order thinking skills through various learning approaches. Furthermore, critical thinking is at the center of the network, with extensive connections to learning systems, teachers, learning methods, and inquiry-based learning, indicating that critical thinking skills are one of the primary outcomes expected from modern learning processes (Martinez, 2022). Critical thinking skills are integral to student capacity development because they determine their ability to understand concepts, solve problems, and navigate complex situations. Meanwhile, the direct link between inquiry-based learning and critical thinking indicates that inquiry learning conceptually requires critical thinking activities at every stage (Jamaludin et al., 2022). These visualization findings reinforce that the development of critical thinking skills and the application of inquiry learning are two interrelated and inseparable aspects in the effort to create meaningful, learner-centered learning.

Inquiry learning has the potential to be developed as a learning process that supports reflection and evaluation activities. This underlies the correlation between inquiry learning and the emphasis on student-centered processes. Therefore, the inquiry model is related to reflective practice within a student-centered approach. Inquiry learning and reflective practice complement each other as approaches that encourage in-depth learning (Brown et al., 2021; Howell, 2021). In inquiry learning, students actively ask questions, formulate hypotheses, conduct investigations, and draw conclusions based on evidence. Research trends are emerging, particularly in integrated learning processes through student-centered learning. Furthermore, student-centered inquiry learning is linked to critical thinking skills (Bako et al., 2024; Jamaludin et al., 2022). Critical thinking is influenced by the learning model, approach, learning media, and even the technology used. Furthermore, correlations between inquiry learning and critical thinking and the use of technology have been found, including clusters related to STEM, engineering education, artificial intelligence, learning systems, and others. Mapping of technology in learning through bibliometric visualization can be seen in Figure 9 below.

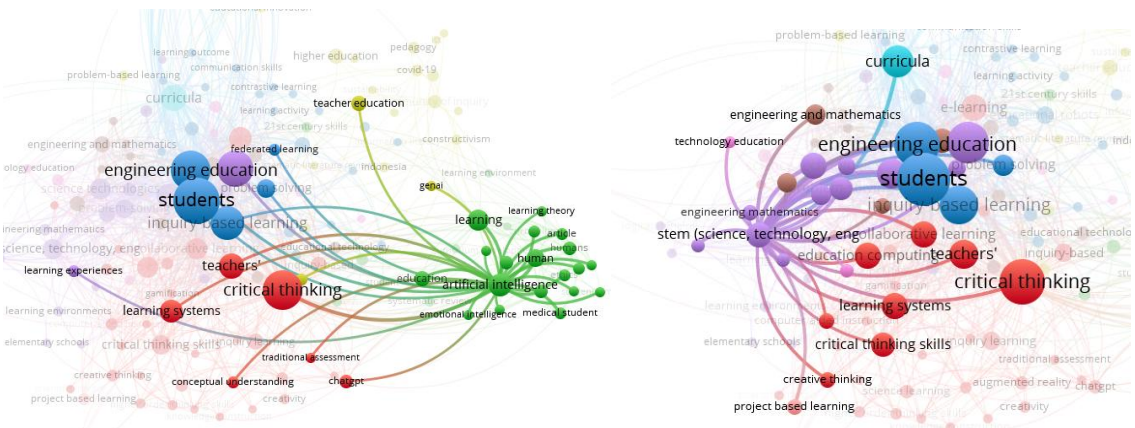


Figure 9. Use of Technology in Learning

The technology frequently used today is Artificial Intelligence (AI), which has a correlation as shown in Figure 9. The application of technology in inquiry learning is important because it can enrich the exploration process, expand access to information sources, and increase learning effectiveness. Technology provides various tools such as interactive simulations, virtual laboratories, digital data collection devices, and collaborative platforms that enable students to conduct investigations, making the learning process more accurate, efficient, and contextual (Karataş et al., 2024; Putra et al., 2025). In addition, technology facilitates collaboration and communication, both in class and online, so that the process of discussion, reflection, and strategy improvement becomes more dynamic. This supports the reflective practice learning approach (Kamarudin et al., 2024; Sun et al., 2022). In inquiry learning, various technologies can be utilized to enrich the investigation and discovery process, as found in current trends, including simulations and virtual laboratories (PhET, Labster) that enable safe and flexible experiments, digital data collection devices such as data loggers and sensors to record measurement results in real-time, data visualization and analysis applications (Excel, Logger Pro) to process and interpret findings, online collaboration platforms (Google Workspace, Padlet) to share ideas and compile reports together, digital learning resources such as scientific journals and educational videos to expand references, as well as augmented reality and virtual reality technologies (Merge Cube, Google Expeditions) that provide immersive experiences in understanding complex concepts.

3.2. Overview of Most Cited Papers

From the results of the systematic literature review that has been carried out, the top 5 articles with the highest citations were obtained which are related to the use of technology in inquiry learning to improve critical thinking skills. Analysis of the 5 articles with the highest citations can be seen in Table 2 below.

Table 2. Top 5 Article Overview

SJR: Cited	Author (Years)	Findings
0.688 (Q1): 53	Zhang, W., Wang, Z.(2021)	With a consistent theoretical foundation and affordable yet sophisticated technology, VR/AR-based inquiry learning can more effectively foster critical thinking skills through immersive, contextual learning experiences that encourage students to ask questions, test hypotheses, and draw conclusions based on evidence.
2.336 (Q1): 46	Zhi, R., Wang, Y. (2024)	EFL students' positive attitudes toward AI, supported by Teacher Immediacy and Teacher-Student Rapport, can create a learning environment that encourages inquiry and practical reflection. AI integration has the potential to facilitate the analysis, evaluation, and synthesis of information, thereby strengthening students' critical thinking skills. This synergy between technology and teacher-student interpersonal relationships fosters active engagement, which is the foundation for developing a Willingness to Communicate.
2.513 (Q1): 36	Nash, B.L., Brady, R.B. (2022)	The integration of multimedia such as simulations and video games into ELA learning can serve as inquiry tools that encourage students to analyze, design, produce texts, and research, while expanding their literacy practices. This process not only increases engagement and collaboration but also develops critical and analytical thinking skills, which are at the heart of practical reflective learning.
1.429 (Q1): 33	Wen, Yu., et al. (2023)	The integration of AR with the QIMS inquiry learning framework not only enhances self-directed learning and creative thinking skills, but also significantly develops critical thinking skills and knowledge creation abilities. This approach aligns with practical reflective learning, as it encourages students to explore, reflect, and construct understanding independently, providing significant benefits for students with low academic achievement.
0.531 (Q2): 27	Suwono, H., et al. (2023)	Interactive Socio-Scientific Inquiry (ISSI), which combines socio-scientific issues as a learning context and digital technology as an interaction platform, significantly improves students' scientific literacy, biological knowledge, and critical thinking skills. This approach aligns with practical reflective learning, as it encourages students to analyze, evaluate, and solve problems based on evidence, making biology learning more creative and oriented toward developing higher-order thinking skills.

The findings from the literature review focused primarily on the relationship (Ningrum et al., 2025), that it between inquiry-based learning and practical reflective learning through the use of modern technology. The literature review results from the most popular articles, in Table 2, indicate that integrating advanced technology with inquiry-based learning has significant potential for enhancing critical thinking skills. Affordable yet sophisticated VR/AR, when supported by a consistent theoretical foundation, can create immersive and contextual learning experiences, encouraging students to ask questions, test hypotheses, and draw evidence-based conclusions (Zhang & Wang, 2021). Zhi & Wang (2024) added that the application of AI in an EFL context, coupled with Teacher Immediacy and Teacher-Student Rapport, creates a learning environment that facilitates the analysis, evaluation, and synthesis of information. Similar findings were also reported, where multimedia such as simulations and video games in ELA learning can serve as inquiry tools to develop analytical and critical skills while increasing student engagement (Nash & Brady, 2022). Meanwhile, the integration of AR with the QIMS framework not only enhances self-directed learning and creativity, but also significantly strengthens critical thinking skills and knowledge creation, especially for low-achieving students (Wen et al., 2023).

All articles position technology as a means to encourage students to engage in inquiry and reflective practice. These findings indicate that the focus of current research is no longer simply measuring the effectiveness of technology in improving learning outcomes, but also exploring how technology can support the development of critical thinking and metacognitive skills, such as the expansion of AI. AI, in the context of Industry 5.0, has given rise to a new paradigm in educational research: the integration of inquiry learning, reflective practice, and intelligent technology (Wen et al., 2023). This paradigm positions technology not merely as a tool for conveying information but as a cognitive partner that helps students explore, reflect, and make decisions. This development demonstrates a shift toward more personalized, adaptive, learner-centered learning, supported by artificial intelligence (Luo et al., 2025). Thus, future research could potentially focus on developing AI-, AR-, and VR-based learning ecosystems that integrate inquiry and reflective practice sustainably to support 21st-century critical thinking skills.

In the context of science, Suwono et al (2023) demonstrated that Interactive Socio-Scientific Inquiry (ISSI), which combines socio-scientific issues with digital technology, can significantly improve scientific literacy, content mastery, and critical thinking skills. Overall, these findings suggest that technology-enhanced inquiry learning, ranging from VR/AR, AI, multimedia, to digital platforms, not only optimizes material mastery but also fosters higher-order thinking skills through exploration, idea testing, and evidence-based evaluation. Furthermore, the integration of practical reflective learning into inquiry is crucial to ensuring that the resulting learning experience not only sparks curiosity (Agustini et al., 2024) but also trains students to consciously reflect on their thinking processes, re-evaluate arguments, and continuously refine problem-solving strategies.

3.3. Discussion

Bibliometric analysis based on the Scopus database shows a trend of increasing students' critical thinking skills through inquiry learning (Lintangesukmanjaya et al., 2025). The data demonstrates a correlation between the application of the inquiry learning model and technology integration to improve students' critical thinking skills. Ninety-nine documents with high citations out of 185 documents in 2021-2025 experienced an increase in publications and overview citations. This demonstrates that in the past five years, inquiry learning has been highly sought after as a student-centered learning effort in several subjects such as science, physics, engineering, and so on. The number of contributing countries is also relatively large, with almost every continent producing publications on this topic, particularly the United States with 34 documents. China and Indonesia, with 25 documents, are among the top document producing countries in the past five years. Based on the clusters formed in the network visualization, as shown in Figure 7, all keywords with high link strength are related. This link lies within the scope of the inquiry model as a student-centered learning that can improve critical thinking skills with the integration of 21st-century technology. In Figure 10 below is a conceptual framework that can be found based on analysis of the literature synthesis,

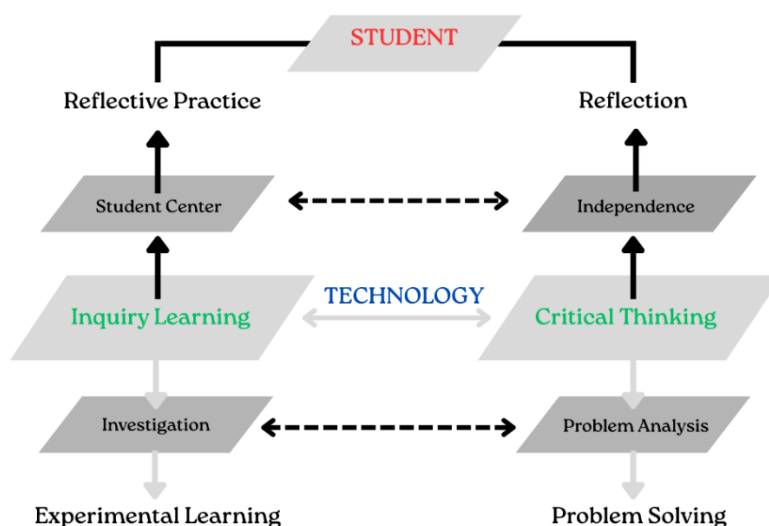


Figure 10. Design Correlation Learning with Critical Thinking Skills

The conceptual framework in the correlation of critical thinking and inquiry learning finds the same cognitive direction, namely the process of student reflection. Inquiry learning is often referred to as experiential learning. It emphasizes the process of discovering knowledge through questioning, investigation, and analysis, which aligns with experiential learning because both position students as active participants who learn from direct engagement with real-world phenomena. From Figure 10, inquiry learning is also referred to as a learning approach that places students at the center of the learning process (student-centered learning) by emphasizing their active involvement in discovering, exploring, and constructing knowledge through questioning,

investigation, and reflection (Mohzana et al., 2023; Rafiq et al., 2023). In this learning, the teacher acts as a facilitator who guides the search for answers, not simply as a transmitter of information, so students have the freedom and responsibility to direct their own learning process. The connection with student-centered learning lies in its primary focus: inquiry-based learning encourages independence, collaboration, and the development of critical thinking skills (Sari et al., 2021; Tang, 2023), so students become active subjects in the formation of understanding, rather than passive recipients of information.

Upon closer examination, this process becomes more effective when accompanied by reflective practice, which involves reviewing each step taken to assess success, identify weaknesses, and formulate strategic improvements. Thus, inquiry focuses on exploration and knowledge discovery, while reflective practice ensures more meaningful understanding through metacognitive awareness and critical evaluation. The combination of the two creates a learning cycle that strengthens critical thinking, problem-solving, and continuous improvement skills for both students and teachers (Muthmainnah et al., 2022). Therefore, integrating inquiry with an emphasis on reflective practice fosters autonomous, critical, and sustainable learning (Feyzioğlu & Demirci, 2021).

Critical learning certainly has an impact on improving students' critical thinking skills, especially in learning that has a high level of difficulty and is suitable for the model used. As seen in Figure 8, learning in science, physics, engineering, and mathematics is highly relevant and correlated with the implementation of the inquiry learning model. For example, physics learning has a complex level of difficulty due to several abstract theories and mathematical solutions that require students to think critically (Maharani & Prahani, 2024; Sari et al., 2022). Inquiry comes with its own syntax that can improve critical thinking skills, making it suitable for implementation in physics material, can see at Figure 10. Meanwhile, reflective practice in inquiry provides support and forms of feedback evaluation that can reduce students' critical thinking skills.

In reflective practice, individuals consciously review experiences, processes, or decisions they have made and then identify factors that influenced their success or failure. This process aligns with critical thinking, which requires one to test assumptions, assess evidence, distinguish fact from opinion, and consider alternative solutions (Lintangesukmanjaya, 2025; Raj et al., 2022; Supena et al., 2021). In other words, reflective practice provides a concrete context for practicing critical thinking, while critical thinking strengthens the quality of reflection, making it more objective, in-depth, and resulting in meaningful improvements. Furthermore, the use of learning technology also has an impact on improving students' critical thinking skills. The use of technology in inquiry-based learning can significantly strengthen critical thinking skills and reflective practice (Lintangesukmanjaya, 2025). In relation to critical thinking, technology provides access to diverse information sources, flexibility, interactivity, and collaboration, enabling students to evaluate evidence, compare perspectives, and test hypotheses more effectively (Karataş et al., 2024; Olsson et al., 2024). Meanwhile, in the context of reflective practice, reflection technology helps students document the learning process, review the steps taken, and record the development of their understanding chronologically (Ariana et al., 2025).

The integration of technology into inquiry learning creates a learning ecosystem that not only facilitates exploration and investigation but also strengthens students' ability to think critically and continuously reflect on their learning processes and outcomes. One of the technologies shown in Figure 9, which has the greatest impact in the 21st century, is Artificial Intelligence (AI). AI can adapt scenarios to students' abilities and responses, presenting them with challenges that trigger evidence-based analysis, evaluation, and problem-solving (Lima et al., 2024; Nikolic et al., 2023; Pryzant et al., 2020). The application of AI, for example, in AR, VR, or interactive simulations, allows students to test hypotheses, predict outcomes, and compare the consequences of various decisions safely and realistically (Crogman et al., 2025). The use of AI-based technology in AR, VR, and interactive simulations in inquiry learning provides significant opportunities to strengthen critical thinking skills and reflective practice (Ramnarain et al., 2024). This integration creates an immersive, adaptive, and sustainable inquiry learning cycle, where technology is not only a medium, but also an intelligent partner in honing critical thinking and self-reflection skills.

Based on the interrelationships between inquiry learning, reflective practice, critical thinking, and the use of technology (including AI in AR, VR, and interactive simulations), future research recommendations can be directed at developing technology-based learning tools that systematically integrate inquiry learning syntax with practical reflective stages. Research can focus on designing immersive learning environments that utilize AI-based adaptive AR/VR to facilitate exploration and investigation (Crogman et al., 2025; Ramnarain et al., 2024), while providing documentation and automated feedback features that support in-depth reflection. Each stage of inquiry, from question formulation and data collection to analysis and conclusion, can be enriched with AI-assisted structured reflection mechanisms, enabling students not only to critically solve problems but also to become aware of their own thinking processes. This recommendation emphasizes the importance of empirical trials to evaluate the effectiveness of such designs in improving critical thinking skills, as well as their adaptability across various learning contexts and educational levels.

4. Conclusion

Based on a bibliometric analysis of 185 Scopus-indexed documents, this study demonstrates that the integration of inquiry learning and technology has evolved as an effort to improve critical thinking skills in the digital era. The increasing number of publications and citations in the past five years demonstrates the growing academic attention to the use of technology to support learner-centered learning. The main findings of this study indicate that the relationship between inquiry learning, reflective activities, and technology forms a mutually reinforcing learning ecosystem. Inquiry learning, reflective practice, and technology form a network that supports knowledge construction and the development of critical thinking. The main contribution of this study to the bibliometric literature is a comprehensive presentation of knowledge structures, development trends, dominant research themes, and the direction of research evolution linking inquiry learning, critical thinking skills, and educational technology. These findings demonstrate a shift in the role of technology from merely a learning medium to a cognitive partner that supports exploration, reflection, and the development of higher-order thinking skills. The implications for 21st-century education demonstrate the need for learning that requires the integration of inquiry, reflective practice, and technology as a foundation for the development of higher-order thinking skills. However, research explicitly integrating these three components remains relatively limited and has yet to establish a well-established conceptual framework. Therefore, future research is needed to develop AI-based learning models that systematically integrate inquiry syntax with stages of reflective practice, including the use of AR, VR, and interactive simulations to support evidence-based investigation, in-depth reflection, and the ongoing development of critical thinking skills.

Author Contributions

Rahmatta Thoriq Lintangesukmanjaya: Conceptualization, Methodology, Formal analysis, Writing - Original draft preparation, Writing - original draft. Binar Kurnia Prahani: Data curation, Funding acquisition, Investigation, Methodology, Writing - original draft. Dwikoranto: Validation; Visualization, Writing - Reviewing and Editing. All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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