

Pedagogical Approaches for Developing Critical Thinking in Science Education (1987-2025): A Bibliometric and Thematic Analysis

Gopi Kupuchitty

`gopi.k@graduate.utm.my`

University of Technology Malaysia

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Abstract

Critical thinking is a central outcome of science education, yet research on its pedagogy remains fragmented across disciplines, educational levels and learning contexts. This study combines bibliometric analysis and abstract-level thematic coding of 198 Scopus-indexed publications from 1987–2025 to examine publication growth, citation influence, contributors, collaboration and conceptual and pedagogical patterns. Research expanded after 2017, with 81.3% of publications appearing in 2019–2025. Technology-enhanced learning was the most frequently identified category, followed by problem-based, inquiry-based and project-based learning; these approaches became more visible after 2016. General or integrated science and physics predominated, while chemistry and biology were less represented. Classroom instruction was the most common reported context, and laboratory or practical settings were rare. No coded abstract explicitly combined chemistry, secondary education and practical activity. These findings identify priorities for discipline-sensitive, context-specific research, particularly secondary chemistry laboratory learning. They describe research visibility within the retrieved corpus rather than comparative pedagogical effectiveness.

Introduction

Critical thinking (CT) is widely recognised as an important competency in science education because it enables students to evaluate evidence, analyse explanations and make reasoned judgements. Recent experimental research has increasingly examined how CT can be developed through active and inquiry-oriented learning. Wang et al. (2026) identified hundreds of educational interventions aimed at developing CT, with a substantial proportion situated within science and STEM contexts. Guided laboratory activities, project investigations and other forms of active learning can provide opportunities for students to analyse phenomena, interpret evidence and justify conclusions. However, the development of critical reasoning cannot be assumed to occur simply through participation in these activities. Effective CT development therefore requires deliberate instructional strategies that make reasoning, evaluation and reflection explicit within the learning process.

Student-centred models offer several routes to critical thinking. Inquiry-based science activities support analysis and evaluation, while problem-based and project-based learning require learners to investigate authentic challenges and justify solutions. Cooperative learning, socio-scientific argumentation and technology-enhanced exploration also show promise (Fitriani et al., 2020; Sugrah et al., 2023). Reviews support active approaches but identify variation across contexts and instructional designs (Arifin et al., 2025; Hasanah & Shimizu, 2020).

Existing reviews often concern higher education or broad educational settings, leaving K–12 science less clearly differentiated. Andreucci-Annunziata et al. (2023) identified rapid growth since 2018, predominantly in university contexts. International differences in creative thinking and scientific problem-solving suggest uneven learning opportunities (OECD, 2024), while school teachers report insufficient preparation for teaching critical-thinking strategies (Murphy et al., 2025).

A science-focused synthesis is therefore needed to identify pedagogical approaches across biology, chemistry and physics, compare educational levels, and locate underexplored combinations such as secondary laboratory inquiry. Combining bibliometric mapping with thematic analysis can connect publication trends and conceptual structures with specific teaching approaches and learning contexts.

Literature Review

Evidence supports several constructivist approaches. Arifin et al. (2025) reported a large effect of inquiry-based learning on science students' critical thinking (mean effect size ≈ 1.27). Fitriani et al. (2020) found that Indonesian high-school biology students receiving problem-based learning with a Predict–Observe–Explain cycle improved critical thinking and scientific attitudes more than traditionally taught peers. Barta et al. (2022) also found benefits of concept mapping for critical-thinking abilities and dispositions. Together, these studies support deliberate instructional design for analytical reasoning.

Flipped and blended approaches extend these designs. Ay and Dağhan (2023) combined flipped learning with a Community of Inquiry framework and reported improved critical-thinking strategies and engagement. Sugrah et al. (2023) found gains in critical thinking and scientific attitudes through socio-scientific issues-based flipped junior-high science. Nevertheless, varied frameworks

and mixed findings limit consensus on explicit instruction (Andreucci-Annunziata et al., 2023). Teachers value hands-on investigations and discourse (Butcher et al., 2023), but large-scale comparisons remain limited.

Disciplinary and contextual gaps also remain. Nearly two-thirds of the K–12 interventions reviewed by Wang et al. (2026) concerned science and STEM, but only 15 of 378 specifically concerned chemistry. Task-based chemistry experiments provide one relevant instructional strand (Zhou et al., 2013). Their integration with flipped learning in secondary laboratories warrants investigation, although the extent of this gap must be established within clearly defined search and coding boundaries.

i. Database Scope

Prior studies used Web of Science (Aktoprak & Hursen, 2022; Dong et al., 2023; Pagán Castaño et al., 2023; Orhan, 2023), Scopus (Misbah et al., 2022; Purnama, 2024; Anggereini et al., 2025; Salido et al., 2025), or multiple databases (Arthi & Gandhimathi, 2025; Zulkarnaen et al., 2025). Database choice affects coverage, citation patterns and disciplinary representation. This study uses Scopus for multidisciplinary coverage and consistent bibliographic metadata, avoiding cross-database duplication and indexing discrepancies (Donthu et al., 2021; Falagas et al., 2008).

ii. Temporal Span

Longer studies trace historical development (Pagán Castaño et al., 2023; Orhan, 2023), whereas shorter windows foreground emerging pedagogies and technologies (Misbah et al., 2022; Zulkarnaen et al., 2025; Anggereini et al., 2025; Salido et al., 2025). Intermediate windows capture growth and recent developments (Aktoprak & Hursen, 2022; Dong et al., 2023; Purnama, 2024). These choices affect observed trends, while recent publications have shorter citation windows. The present 1987–2025 span accommodates historical and contemporary developments.

iii. Thematic Focus on Critical Thinking in Science Education

Previous mappings address primary education (Aktoprak & Hursen, 2022), broad educational contexts (Pagán Castaño et al., 2023; Dong et al., 2023; Orhan, 2023; Purnama, 2024), and science education (Misbah et al., 2022). More specialised studies concern English language teaching (Arthi & Gandhimathi, 2025), project-based learning and STEM (Zulkarnaen et al., 2025), environmental and socio-scientific issues (Anggereini et al., 2025), and AI-supported higher education (Salido et al., 2025). Table 1 compares their scope and analytical attributes.

Table 1
Previous Bibliometric Studies on Critical Thinking in Education

Authors	Objective	Data & Year Coverage	Source	Total Document Entries (TDE)	Bibliometric Attributes Examined
Aktoprak & Hursen (2022)	To map the characteristics and research trends of critical thinking in primary education and identify gaps for future research.	Critical thinking in primary education (1995–2021)	Web of Science	386 publications	Annual publication trends; countries; languages; document types; bibliographic coupling of countries, sources and documents; author-keyword co-occurrence.
Misbah et al. (2022)	To analyse research trends in critical thinking skills within science education and map their global development.	Critical thinking in science education (2017–2022*)	Scopus	191 articles from 1,788 records	Annual publication trends; leading journals; country productivity; keyword clusters; network and overlay visualisation; emerging research topics.
Dong et al. (2023)	To identify the research trends and hotspots of critical thinking research over the previous two decades.	Critical thinking research (2000–2021)	Web of Science	2,043 publications	Annual publications; keyword frequency and co-occurrence; productive countries/regions, institutions and authors; highly cited publications; emerging keyword trends.
Pagán Castaño et al. (2023)	To assess the development and current state of critical thinking research and identify major trends and future research directions.	Critical thinking literature; search window 1969–2019 (results from 1978–2019)	Web of Science Core Collection	1,295 publications	Annual publications and citations; h-index and citation thresholds; influential documents; journals; authors; institutions; countries; co-authorship; co-citation; keyword co-occurrence.
Orhan (2023)	To provide an overall picture of critical thinking research in education and identify productivity, influence and scientific collaboration patterns.	Critical thinking in educational research (1980–2022)	Web of Science	5,064 articles and reviews	Publication and journal trends; citation analysis of journals, countries, authors, institutions and documents; institutional/country co-authorship; author co-citation; co-word analysis.
Purnama (2024)	To map the status and development of critical thinking research and identify major contributors and research trends.	Critical thinking research (1994–2023)	Scopus	16,011 journal articles	Publication trends; author keywords; highly cited authors and documents; active journals; productive institutions; productive countries; citation patterns.
Arthi & Gandhimathi (2025)	To map research trends and networks relating to critical thinking skills in English Language Teaching.	Critical thinking in ELT (2012–2022)	Scopus; Web of Science	238 articles	Annual scientific production and growth; relevant journals and authors; globally cited documents; affiliations; countries; international collaboration; keyword co-occurrence; thematic evolution.
Anggereini et al. (2025)	To map trends, collaboration patterns and conceptual structures connecting eco-design, socio-scientific issues, environmental learning, eco-literacy and critical thinking.	Eco-design, SSI and environmental learning (2013–2024)	Scopus	Not explicitly reported*	Co-authorship; institutional collaboration; keyword co-occurrence; citation and co-citation analysis; network, overlay and density visualisation; thematic clusters and temporal research evolution.
*TDE: Total Documents Examined					

Authors	Objective	Data & Year Coverage	Source	Total Document Entries (TDE)	Bibliometric Attributes Examined
Salido et al. (2025)	To map the research landscape connecting artificial intelligence and critical thinking in higher education and synthesise related skills, challenges and instructional strategies.	AI and critical thinking in higher education (2023–2025)	Scopus	290 bibliometric records	Publication trends; influential authors; key journals; institutions; citation networks; keyword co-occurrence; thematic clusters; emerging themes and research directions.
Zulkarnaen et al. (2025)	To evaluate trends in Project-Based Learning for developing critical thinking in science education, particularly its integration with STEM.	PjBL and critical thinking in science education (2019–2024)	Scopus; Google Scholar	Not explicitly reported*	Publication trends; citation counts; h-index and i10-index; keyword co-occurrence and clusters; temporal evolution; citation and author networks; journals; collaboration networks; overlay, density and network visualisations.
*TDE: Total Documents Examined					

The present study addresses this gap by combining performance analysis and science mapping with abstract-level pedagogical coding. It examines how approaches change over time and intersect with disciplinary, educational and contextual categories. No particular pedagogy or discipline was privileged in the search, allowing underrepresented combinations to emerge from the retrieved evidence.

Research Questions

Accordingly, this study addresses the following research questions:

- RQ1. How has research on developing critical thinking in science education evolved in terms of publication output, citation patterns and conceptual trends from 1987 to 2025?
- RQ2. Which sources, documents, authors, institutions and countries have contributed most prominently to research on critical thinking in science education in terms of publication productivity and citation influence?
- RQ3. Which pedagogical and instructional design approaches and associated research themes are most frequently represented in research on developing critical thinking in science education, and how have the leading approaches changed over time?
- RQ4. How are leading pedagogical and instructional design approaches distributed across science disciplines, educational levels and learning contexts, and which combinations are comparatively underrepresented within the analysed literature?

Methods

Scopus records were retrieved on 15 September 2026. Its structured publication, citation, author, affiliation, country, abstract and keyword metadata supported the analysis. Publications dated 2026 were excluded to avoid partial-year coverage; no language, document-type or subject-area restrictions were applied.

Search Strategy

A PRISMA-informed structure (Page et al., 2021) documented record identification and retention (Fig. 1). The framework was adapted for bibliometric metadata analysis rather than a systematic evaluation of intervention effectiveness.

The title search required both critical-thinking and science-education concepts to be central concerns. Synonyms for critical-thinking skills and the principal science disciplines increased coverage while limiting incidental mentions.

The following search string was applied in Scopus:

TITLE (("critical thinking" OR "critical thinking skill" OR "critical thinking skills" OR "critical thinking ability" OR "critical thinking abilities" OR "critical thinking disposition" OR "critical-thinking") AND ("science education" OR "science teaching" OR "science learning" OR "science instruction" OR "chemistry education" OR "chemistry teaching" OR "chemistry learning" OR "physics education" OR "physics teaching" OR "physics learning" OR "biology education" OR "biology teaching" OR "biology learning")) AND PUBYEAR < 2026

Discipline-specific terms captured studies without 'science education' in their titles. No inquiry-based, problem-based, project-based, flipped or task-based learning terms were required, allowing pedagogical patterns to emerge from the analysis.

Data Identification and Retention

The search yielded 198 publications from 1987–2025 including journals and other Scopus-indexed document types. All records were retained; no exclusions were applied (Fig. 1).

No methodological quality appraisal or effect-size synthesis was undertaken because the objectives concerned publication development, influence, contributors, collaboration, conceptual relationships and pedagogical patterns rather than intervention effectiveness.

Data Cleaning and Harmonisation

The Scopus CSV export was cleaned using BiblioSpy® (Ahmi, 2026). Author names, affiliations, countries, source titles and keywords were inspected and harmonised to reduce fragmented profiles, duplicate institutional entries and distorted keyword networks.

Equivalent keyword meanings, spelling variants, abbreviations, hyphenation and singular or plural forms were reviewed, including 'critical thinking' and 'critical-thinking skills'.

Ambiguous or incomplete entries were checked against available Scopus metadata; supplementary information was added only when reliable evidence was available. The cleaned dataset supported performance analysis, science mapping and thematic coding.

Data Analysis

Bibliometric analysis examined publication and citation trends, source, author, institution and country performance, collaboration, and conceptual organisation. Co-authorship and international collaboration characterised participation; keyword co-occurrence and temporal patterns identified conceptual themes. Full counting was applied to authors, institutions and countries, so attributed totals may exceed the publication count.

All 198 abstracts were coded using a deductive–inductive codebook covering pedagogical approaches, associated themes, science disciplines, educational levels and learning contexts. Pedagogical approaches and associated themes were coded using multiple-response categories because a single study could contain more than one approach or theme. For descriptive classification, each record was also assigned one primary discipline, educational level and learning context based on the most explicit information reported in the abstract, while additional discipline, level or contextual information was retained through supplementary codes where applicable. Consequently, counts based on multiple-response coding, such as records containing any reference to secondary education, may exceed counts reported for mutually exclusive primary-level categories. Information not explicitly stated in the abstract was coded as 'not reported', and no assumptions were made from titles, journal sources or presumed study settings. The coding therefore represents the occurrence and distribution of reported characteristics within the abstracts rather than the effectiveness of particular pedagogical approaches.

Analytical Tools

BiblioSpy® (Ahmi, 2026) was used to support metadata harmonisation, bibliometric performance analysis and science mapping. The analyses included publication trends, citation patterns, source productivity, author contributions, institutional affiliations, country or regional distribution, collaboration patterns and author-keyword co-occurrence. The software was also used to generate the temporal, source, geographical and network visualisations reported in this study. For the author-keyword co-occurrence analysis, a minimum occurrence threshold of two was applied, resulting in 38 keywords being retained for network visualisation and interpretation.

ChatGPT (OpenAI) was used as an AI-assisted analytical tool during the abstract-coding process to support initial classification, category grouping and pattern identification based on the predefined coding framework. The coding was conducted on 16 September 2026 using prompts that specified the coding categories, definitions and decision rules. All AI-generated classifications were subsequently reviewed by the researcher against the original abstracts. Ambiguous, overlapping or inconsistent classifications were manually revised, and the researcher retained full responsibility for the final coding decisions, analysis and interpretation. The AI-assisted process was therefore used to improve coding efficiency rather than to replace researcher judgement. The coding framework and decision rules used to guide the analysis are retained as part of the study documentation.

Results

The 198 publications received 2,216 citations (11.19 per document); 160 were cited (80.8%), averaging 13.85 citations each (Table 2). The h-index was 21 and g-index 40; 1,313 h-core citations represented 59.3% of the total. Despite a 1987 starting point, mean document age was 6.04 years. The corpus comprised 660 author contributions, 554 unique authors, 180 institutions, 29 countries and 320 keywords. Authorship averaged 3.33 per paper: 22 papers were single-authored and 88.9% multi-authored, but international co-authorship was only 9.09%.

Table 2
Bibliometric Summary

Indicator	Value
Timespan	1987:2025
Total Publications (TP)	198
Citable Year Span	39 years
Annual Growth Rate	9.27%
Document Average Age	6.04 years
Total Citations (TC)	2216
Average Citations per Document	11.19
Number of Cited Papers (NCP)	160
Average Citations per Cited Paper	13.85
Average Citations per Year	56.82
Total Contributing Authors	660
Total Unique Authors	554
Total Institutions	180
Total Countries	29
Single-Authored Documents	22
Average Authors per Paper	3.33
International Co-authorship Rate	9.09%
Unique Author Keywords	320
Total References	19301
h-index	21
g-index	40
m-index	0.525
e-index	29.53
Citation Sum within h-Core	1313

Figure 2 shows sporadic early output followed by expansion after 2017: four publications in 2017, nine in 2018 and 28 in 2019. Thereafter, annual output fluctuated between 16 and 29, peaking in 2025. The 161 papers published during 2019–2025 represented 81.3% of the corpus. Citation peaks differed: 2019 contributed 320 citations, the single 2002 paper received 294, and two 2016 papers received 251. Influence therefore extended beyond the most productive years.

Table 3
Yearly Bibliometric Statistics

Year	TP	NCA	NCP	TC	C/P	C/CP	h	g	m	e
2025	29	101	17	184	6.34	10.82	6	13	3	11.18
2024	21	83	14	80	3.81	5.71	5	8	1.667	5.39
2023	26	84	20	138	5.31	6.9	7	11	1.75	7.42
2022	16	56	15	159	9.94	10.6	8	12	1.6	8.31
2021	22	78	19	173	7.86	9.11	7	12	1.167	9.11
2020	19	62	16	166	8.74	10.38	8	12	1.143	8.94
2019	28	73	26	320	11.43	12.31	9	17	1.125	12.92
2018	9	29	8	115	12.78	14.38	5	9	0.556	8.94
2017	4	11	4	37	9.25	9.25	3	4	0.3	5.1
2016	2	3	2	251	125.5	125.5	2	2	0.182	15.72
Note: TP = Total Publications; NCA = Number of Contributing Authors; NCP = Number of Cited Publications; TC = Total Citations; C/P = Citations per Publication; C/CP = Citations per Cited Publication; h = h-index; g = g-index; m = m-Quotient; e = e-index										

The 2016–2025 cohorts contained 176 publications (88.9%; Table 3). Output peaked in 2025 at 29 papers and 101 authors; 17 papers received 184 citations (6.34 per publication). The 2019 cohort combined 28 publications, 26 cited papers and 320 citations with the highest annual h-index (nine). Two 2016 papers produced the highest average, 125.50 citations, illustrating small-cohort effects. Unequal cohort sizes and citation windows limit annual comparisons; citation averages fluctuated independently of output.

Journal of Physics: Conference Series contributed 51 papers (25.8%) and AIP Conference Proceedings 24 (12.1%), together accounting for 37.9% (Fig. 3). Jurnal Pendidikan IPA Indonesia followed with ten, then IOP Conference Series: Earth and Environmental Science with five; other leading sources contributed two to four each. The top ten supplied 109 papers (55.1%). Proceedings were prominent alongside education journals. Source productivity measures dissemination, while citation influence requires separate assessment; source titles do not establish individual studies' disciplines.

Table 4
Source Statistics

Source Title	Publisher	TP	TC	NCA	NCP	C/P	C/CP	h	g	m
Journal of Physics: Conference Series	Institute of Physics Publishing	51	292	155	44	5.725	6.636	10	12	1
AIP Conference Proceedings	American Institute of Physics Inc.	24	39	77	14	1.625	2.786	3	5	0.3
Jurnal Pendidikan IPA Indonesia	Universitas Negeri Semarang	10	166	48	10	16.6	16.6	6	10	0.6
IOP Conference Series: Earth and Environmental Science	IOP Publishing Ltd	5	12	25	3	2.4	4	2	3	0.286
Journal of Turkish Science Education	Ekip Buro Makineleri A.	4	21	21	3	5.25	7	3	4	0.6
International Journal of Instruction	Eskisehir Osmangazi University	4	190	12	4	47.5	47.5	4	4	0.444
Journal of Technology and Science Education	OmniaScience	4	66	16	4	16.5	16.5	4	4	0.5
Thinking Skills and Creativity	Elsevier Ltd	3	113	7	3	37.667	37.667	3	3	0.273
Journal of Chemical Education	American Chemical Society	2	44	8	2	22	22	2	2	0.4
Science and Education	Springer Netherlands	2	360	2	2	180	180	2	2	0.08
Note: TP = Total Publications; TC = Total Citations; NCA = Number of Contributing Authors; NCP = Number of Cited Publications; C/P = Citations per Publication; C/CP = Citations per Cited Publication; h = h-index; g = g-index; m = m-Quotient										

Citation influence differed from output (Table 4). Journal of Physics: Conference Series received 292 citations (5.73 per paper; h = 10), whereas two Science and Education papers received 360 (180 per paper). International Journal of Instruction averaged 47.5 citations across four papers and Thinking Skills and Creativity 37.67 across three. Jurnal Pendidikan IPA Indonesia combined ten papers, 166 citations and h = 6; AIP Conference Proceedings received 39 citations from 24 papers. High averages from small cohorts require caution.

Table 5
Highly-Cited Papers

#	Authors	Title	Source	TC	C/Y	NTC
1	Bailin (2002)	Critical thinking and science education	Science and Education	294	11.76	1
2	Vieira & Tenreiro-Vieira (2016)	Fostering Scientific Literacy and Critical Thinking in Elementary Science Education	International Journal of Science and Mathematics Education	161	14.64	1.28
3	Syawaludin et al. (2019)	Development of augmented reality-based interactive multimedia to improve critical thinking skills in science learning	International Journal of Instruction	96	12	8.4
4	Siegel (1989)	The rationality of science, critical thinking, and science education	Synthese	96	2.53	1
5	Forawi (2016)	Standard-based science education and critical thinking	Thinking Skills and Creativity	90	8.18	0.72
6	García-Carmona (2025)	Scientific Thinking and Critical Thinking in Science Education : Two Distinct but Symbiotically Related Intellectual Processes	Science and Education	66	33	10.4
7	Ramdani et al. (2021)	Analysis of students' critical thinking skills in terms of gender using science teaching materials based on the 5e learning cycle integrated with local wisdom	Jurnal Pendidikan IPA Indonesia	64	10.67	8.14
8	Suardana et al. (2018)	Students' critical thinking skills in chemistry learning using local culture-based 7E learning cycle model	International Journal of Instruction	57	6.33	4.46
9	Arifin et al. (2025)	The effect of inquiry-based learning on students' critical thinking skills in science education: A systematic review and meta-analysis	Eurasia Journal of Mathematics, Science and Technology Education	43	21.5	6.78
10	Wahyuni et al. (2019)	Edmodo-based blended learning model as an alternative of science learning to motivate and improve junior high school students' scientific critical thinking skills	International Journal of Emerging Technologies in Learning	38	4.75	3.32
Note: TC = Total Citations; C/Y = Citations per Year; NTC = Normalised Total Citations						

The ten leading papers received 1,005 citations, approximately 45.4% of all citations (Table 5). Bailin (2002) led with 294, followed by Vieira and Tenreiro-Vieira (2016) with 161; Siegel (1989) and Syawaludin et al. (2019) each received 96. Contributions span conceptual foundations, scientific literacy, augmented reality, standards, cultural learning cycles, inquiry and blended learning. García-Carmona (2025) led annual citations (33) and normalised citations (10.4); Arifin et al. (2025) also showed recent visibility. Citation prominence does not establish pedagogical effectiveness.

Table 6
Author Statistics

Author	Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g	m	e
Jatmiko, Budi	Universitas Pendidikan Ganesha	Indonesia	8	7	85	10.62	12.14	4	8	0.44	7.94
Prahani, Binar Kurnia	Universitas Kaltara	Indonesia	8	7	64	8.00	9.14	3	8	0.33	6.93
Wilujeng, Insih	Universitas Negeri Yogyakarta	Indonesia	7	5	55	7.86	11.00	4	7	0.40	5.92
Jumadi, Jumadi	Universitas Negeri Yogyakarta	Indonesia	6	4	39	6.50	9.75	4	6	0.50	4.80
Wibowo, Firmanul Catur	Universitas Tidar	Indonesia	5	3	9	1.80	3.00	1	3	0.17	2.45
Kuswanto, Heru	Universitas Negeri Yogyakarta	Indonesia	5	5	34	6.80	6.80	4	5	0.50	3.74
Sukarmin, Sukarmin	Universitas Sebelas Maret	Indonesia	4	4	48	12.00	12.00	2	4	0.25	6.48
Rahmawati, Yuli	Universitas Negeri Jakarta	Indonesia	4	4	34	8.50	8.50	3	4	0.43	4.69
Sinaga, P.	Universitas Pendidikan Indonesia	Indonesia	4	3	12	3.00	4.00	1	3	0.13	3.00
Mardiah, Alin	Universitas Negeri Jakarta	Indonesia	3	3	25	8.33	8.33	3	3	0.50	4.00
Note: TP = Total Publications; NCP = Number of Cited Publications; TC = Total Citations; C/P = Citations per Publication; C/CP = Citations per Cited Publication; h = h-index; g = g-index; m = m-Quotient; e = e-index											

All ten leading authors were affiliated with Indonesian institutions (Table 6). Prahani and Jatmiko each contributed eight papers, Wilujeng seven and Jumadi six. Jatmiko led total citations (85; 10.62 per paper), compared with Prahani's 64. Sukarmin had the highest average (12.00 across four papers), and Wibowo the lowest (1.80). Jatmiko, Wilujeng, Jumadi and Kuswanto each attained h = 4. Productivity and citation influence varied within this nationally concentrated group.

Table 7
Institutional Statistics

Institution	Country	TP	NCA	NCP	TC	C/P	C/CP	h	g	m	e
Universitas Negeri Surabaya	Indonesia	17	50	14	118	6.94	8.43	6	10	0.67	8.12
Universitas Negeri Yogyakarta	Indonesia	14	24	10	76	5.43	7.60	5	8	0.50	5.92
Universitas Sebelas Maret	Indonesia	14	32	13	186	13.29	14.31	5	13	0.56	12.00
Universitas Negeri Jakarta	Indonesia	13	28	11	77	5.92	7.00	5	8	0.50	6.24
Universitas Pendidikan Indonesia	Indonesia	9	19	7	49	5.44	7.00	4	7	0.40	5.29
Universitas Negeri Malang	Indonesia	8	19	8	44	5.50	5.50	3	6	0.50	4.90
University of Jember	Indonesia	7	17	4	85	12.14	21.25	4	7	0.50	8.31
Universitas Pendidikan Ganesha	Indonesia	6	15	5	42	7.00	8.40	4	6	0.44	4.69
Universitas Negeri Semarang	Indonesia	5	12	3	14	2.80	4.67	3	3	0.33	2.24
University of Mataram	Indonesia	5	13	3	78	15.60	26.00	2	5	0.29	8.54
Note: TP = Total Publications; NCA = Number of Contributing Authors; NCP = Number of Cited Publications; TC = Total Citations; C/P = Citations per Publication; C/CP = Citations per Cited Publication; h = h-index; g = g-index; m = m-Quotient; e = e-index											

All leading institutions were Indonesian (Table 7). Universitas Negeri Surabaya led output (17), followed by Universitas Negeri Yogyakarta and Universitas Sebelas Maret (14 each), then Universitas Negeri Jakarta (13). Sebelas Maret led citations (186; 13.29 per paper; g = 13), while Surabaya led h-index (six). Mataram achieved the highest citation averages: 78 citations across five papers, or 15.60 per paper and 26.00 per cited paper. Jember received 85 citations from seven papers; Semarang received 14 from five.

Figures 4 and 5 show national concentration under full counting. Indonesia contributed 135 country-attributed papers, followed by the United States (15), Malaysia (eight), Taiwan and Spain (six each), the United Kingdom (five), and Australia and Türkiye (four each). Slovakia, France, Brazil, Colombia, China, Portugal and the Philippines contributed three each; Germany and the United Arab Emirates contributed two. Smaller contributors included Canada, Greece, Fiji, India, Thailand, Russia, Kazakhstan, Mexico and South Africa. Counts reflect author affiliations, not study locations or collaboration, and may exceed 198. Unmapped countries may still produce relevant research.

Figure 6 contains 38 keywords occurring at least twice, arranged in four interconnected clusters. 'Critical thinking' and 'critical thinking skill' connect science education and learning with problem-based learning, inquiry-based learning, argumentation, scientific argumentation, socio-scientific issues, physics education and learning, and STEAM. Pedagogical and disciplinary themes overlap; physics is conspicuous, while chemistry, biology and educational-level terms are less visible. Co-occurrence describes conceptual relationships, not comparative effectiveness.

Problem-based learning has the longest visible keyword period, approximately 2013–2025, with a central marker around 2024 (Fig. 7). Argumentation spans approximately 2019–2022; science learning, 2020–2023; critical thinking, 2021–2025; and critical thinking skill, 2022–2024. Science education spans approximately 2020–2024, centred around 2023. These distributions show recent thematic visibility rather than causal development or effectiveness.

Table 8
Most frequently identified pedagogical approaches and instructional design approaches

Pedagogical approach and instructional design approach	n	%
Technology-enhanced learning	25	12.6%
Problem-based learning	19	9.6%
Inquiry-based learning	13	6.6%
Project-based learning	12	6.1%
Context-based and culturally responsive learning	9	4.5%
Other named active-learning model	7	3.5%
Socio-scientific issues	7	3.5%
Discovery learning	6	3.0%
Metacognitive and self-regulated learning	6	3.0%
Blended learning	5	2.5%
Constructivist and integrated learning	5	2.5%
Explicit critical-thinking and HOTS instruction	5	2.5%
Collaborative and cooperative learning	4	2.0%
Learning cycle and POE models	4	2.0%
Reading writing and literacy strategies	4	2.0%

Of 198 abstracts, 116 (58.6%) named at least one approach and 82 (41.4%) did not (Table 8). Multi-coding makes frequencies non-exclusive. Technology-enhanced learning led (25; 12.6%), encompassing digital, mobile, virtual, multimedia, simulation and AI-supported designs. Problem-based (19; 9.6%), inquiry-based (13; 6.6%) and project-based learning (12; 6.1%) followed. Context-based or culturally responsive learning occurred nine times; socio-scientific issues and other named active-learning models seven each; discovery and metacognitive or self-regulated learning six each. Frequencies indicate abstract visibility, not outcome superiority.

Table 9
Evolution of leading pedagogical approaches across time periods

Approach	1987 to 2005	2006 to 2010	2011 to 2015	2016 to 2020	2021 to 2025	Total
Technology-enhanced learning	0	0	0	9	16	25
Problem-based learning	0	0	1	6	12	19
Inquiry-based learning	0	0	0	1	12	13
Project-based learning	0	0	0	3	9	12
Context-based and culturally responsive learning	0	0	0	2	7	9
Other named active-learning model	0	0	0	4	3	7
Socio-scientific issues	0	0	0	0	7	7
Discovery learning	0	0	0	3	3	6
Metacognitive and self-regulated learning	1	0	0	1	4	6
Blended learning	0	0	0	2	3	5
Constructivist and integrated learning	1	0	0	2	2	5
Explicit critical-thinking and HOTS instruction	0	0	0	3	2	5

Of 198 records, 114 appeared in 2021–2025 and 62 in 2016–2020 (Table 9). Between these periods, technology-enhanced learning increased from nine to 16 occurrences, problem-based learning from six to 12, inquiry from one to 12, projects from three to nine, and context-based or culturally responsive learning from two to seven. All seven socio-scientific-issue records appeared in 2021–2025; few approaches were named before 2016. These raw counts partly reflect corpus growth and do not establish causal change or effectiveness.

Table 10
Associated themes identified in the abstracts

Associated theme	n	%
Curriculum materials and instructional design	47	23.7%
Assessment measurement and learner profiles	43	21.7%
Societal environmental and cultural relevance	43	21.7%
Problem solving and authentic application	32	16.2%
Inquiry investigation and evidence	30	15.2%
Technology-mediated learning	29	14.6%
Collaboration communication and discourse	26	13.1%
Argumentation reasoning and decision making	24	12.1%
Metacognition reflection and learner autonomy	22	11.1%
Critical-thinking concepts dispositions and literacy	17	8.6%
Teacher knowledge and professional practice	7	3.5%

Curriculum materials and instructional design led the associated themes (47; 23.7%; Table 10). Assessment and learner profiles and societal, environmental and cultural relevance each appeared in 43 records (21.7%). Problem solving followed (32; 16.2%), then inquiry and evidence (30; 15.2%), technology (29; 14.6%), collaboration and discourse (26; 13.1%), argumentation and

decisions (24; 12.1%), metacognition and autonomy (22; 11.1%), and critical-thinking concepts, dispositions and literacy (17; 8.6%). Teacher knowledge and practice was least represented (seven; 3.5%). Themes were non-exclusive.

Table 11
Overall distribution by science discipline, educational level and learning context

Dimension	Category	n	%
Science discipline	General or integrated science	66	33.3%
Science discipline	Physics	52	26.3%
Science discipline	Discipline not reported	32	16.2%
Science discipline	Chemistry	22	11.1%
Science discipline	Biology and life sciences	11	5.6%
Science discipline	Integrated STEM or STEAM	10	5.1%
Science discipline	Multiple science disciplines	5	2.5%
Educational level	Educational level not reported	107	54.0%
Educational level	Upper secondary	36	18.2%
Educational level	Mixed educational levels	21	10.6%
Educational level	Primary	14	7.1%
Educational level	Higher education	6	3.0%
Educational level	Secondary unspecified	6	3.0%
Educational level	Lower secondary	5	2.5%
Educational level	Pre-service teacher education	2	1.0%
Educational level	In-service teachers or educators	1	0.5%
Learning context	Classroom instruction	86	43.4%
Learning context	Learning context not reported	81	40.9%
Learning context	Conceptual or theoretical	13	6.6%
Learning context	Blended or flipped learning	6	3.0%
Learning context	Laboratory or practical activity	6	3.0%
Learning context	Online or digital environment	5	2.5%
Learning context	Informal or non-formal setting	1	0.5%
Note. Percentages are based on the 198 records eligible for thematic analysis. Each record contributes to one primary category within each dimension.			

General or integrated science (66; 33.3%) and physics (52; 26.3%) predominated over chemistry (22; 11.1%) and biology (11; 5.6%; Table 11). Educational level was absent in 107 abstracts (54.0%); reported levels were led by upper secondary (36; 18.2%), mixed levels (21; 10.6%) and primary (14; 7.1%). Classroom instruction predominated (86; 43.4%), but 81 abstracts omitted context (40.9%). Laboratory/practical and blended/flipped contexts each contained six records (3.0%). Tables 12–14 cross-tabulate approaches against these primary categories.

Table 12
Distribution of leading pedagogical approaches by science discipline

Approach	General science	Physics	Discipline NR	Chemistry	Biology	STEM or STEAM	Multiple	Total
Technology-enhanced learning	9	10	3	2	0	0	1	25
Problem-based learning	6	5	1	2	2	1	2	19
Inquiry-based learning	4	1	5	1	1	1	0	13
Project-based learning	5	4	0	3	0	0	0	12
Context-based and culturally responsive learning	3	3	1	2	0	0	0	9
Other named active-learning model	3	3	1	0	0	0	0	7
Socio-scientific issues	3	1	1	2	0	0	0	7
Discovery learning	4	1	0	1	0	0	0	6
Metacognitive and self-regulated learning	2	1	2	0	0	1	0	6
Explicit critical-thinking and HOTS instruction	1	2	1	1	0	0	0	5
Blended learning	2	1	0	2	0	0	0	5
Constructivist and integrated learning	2	1	2	0	0	0	0	5
Note. NR = not reported. Pedagogical approaches were multi-coded; science discipline was single-coded. Row totals should not be summed to estimate unique publications								

Technology-enhanced learning concentrated in physics (ten) and general science (nine), with two chemistry occurrences (Table 12). Problem-based learning was broader: general science (six), physics (five), and chemistry and biology (two each). Projects concerned general science (five), physics (four) and chemistry (three), with none in biology. Context-based or culturally responsive learning and socio-scientific issues each contributed two chemistry occurrences. Five of 13 inquiry records lacked an identifiable discipline. General science and physics therefore represented the widest range of leading approaches.

Table 13
Distribution of leading pedagogical approaches by educational level

Approach	Level NR	Upper secondary	Mixed	Primary	Higher ed	Secondary unspecified	Lower secondary	Pre-service	In-service	Total
Technology-enhanced learning	9	7	4	4	1	0	0	0	0	25
Problem-based learning	9	3	1	2	0	1	2	0	1	19
Inquiry-based learning	9	2	1	1	0	0	0	0	0	13
Project-based learning	7	4	0	0	0	1	0	0	0	12
Context-based and culturally responsive learning	6	2	0	0	0	0	1	0	0	9
Other named active-learning model	2	2	2	0	1	0	0	0	0	7
Socio-scientific issues	6	0	0	1	0	0	0	0	0	7
Discovery learning	2	2	0	1	0	0	1	0	0	6
Metacognitive and self-regulated learning	2	0	0	1	2	0	0	1	0	6
Explicit critical-thinking and HOTS instruction	3	1	0	0	0	0	0	1	0	5
Blended learning	1	3	1	0	0	0	0	0	0	5
Constructivist and integrated learning	3	0	0	2	0	0	0	0	0	5
Note. NR = not reported. Pedagogical approaches were multi-coded; educational level was single-coded. Row totals should not be summed to estimate unique publications										

Non-reporting constrained level comparisons (Table 13): levels were missing in nine of 13 inquiry records, nine of 19 problem-based records, seven of 12 project-based records, six of nine context-based records and six of seven socio-scientific-issue records. Upper secondary led reported levels for technology (seven), projects (four), problems and blended learning (three each); three of five blended records concerned this level. Primary education featured technology (four), problems and constructivist/integrated learning (two each). Missing information prevents firm claims about level-specific dominance.

Table 14
Distribution of leading pedagogical approaches by learning context

Approach	Classroom	Context NR	Conceptual	Laboratory or practical	Blended or flipped	Online or digital	Informal	Total
Technology-enhanced learning	10	7	1	1	2	4	0	25
Problem-based learning	9	8	0	1	1	0	0	19
Inquiry-based learning	5	4	1	2	0	1	0	13
Project-based learning	7	4	0	0	1	0	0	12
Context-based and culturally responsive learning	4	4	0	0	0	1	0	9
Other named active-learning model	4	3	0	0	0	0	0	7
Socio-scientific issues	2	3	1	0	0	0	1	7
Discovery learning	3	3	0	0	0	0	0	6
Metacognitive and self-regulated learning	2	3	0	1	0	0	0	6
Explicit critical-thinking and HOTS instruction	1	4	0	0	0	0	0	5
Blended learning	0	0	0	0	5	0	0	5
Constructivist and integrated learning	4	1	0	0	0	0	0	5
Note. NR = not reported. Pedagogical approaches were multi-coded; learning context was single-coded. Row totals should not be summed to estimate unique publications								

Classrooms were the most frequent identified context for technology (ten), problems (nine), projects (seven) and inquiry (five; Table 14). Digital environments mainly involved technology-enhanced learning (four); all five blended-learning occurrences had blended/flipped contexts. Laboratories appeared with inquiry twice and technology, problems and metacognition/self-regulation once each. No project-based, socio-scientific-issue, discovery, blended, constructivist or explicit critical-thinking approach had a primary laboratory context. Practical applications therefore formed a small strand within predominantly classroom-focused research.

Table 15
Underrepresented science disciplinary, educational level and learning context combinations

Combination	n	Interpretation
Chemistry and secondary education	9	Limited representation relative to the broader chemistry and secondary-literature totals
Chemistry and laboratory/practical	1	Rarely represented in the coded abstracts
Secondary education and laboratory/practical	2	Limited representation of practical science at secondary level
Chemistry and secondary and laboratory/practical	0	No complete three-dimensional occurrence identified in the coded abstracts
Inquiry-based learning and laboratory/practical	2	Few abstracts linked inquiry explicitly with practical settings
Problem-based learning and laboratory/practical	1	Very limited representation
Technology-enhanced learning and laboratory/practical	1	Very limited representation
Project-based learning and laboratory/practical	0	No occurrence identified in the coded abstracts
Note. A zero means that no eligible abstract explicitly reported the complete combination; it does not prove that no such study exists outside the search strategy or in information omitted from the abstract.		

Multi-value coding identified 23 chemistry records and 67 including secondary education, but only nine combining both (Table 15). The 23 include chemistry mentions beyond the 22 primary-chemistry records in Tables 11–12. Of six laboratory/practical records, one concerned chemistry and two secondary education. None explicitly combined chemistry, secondary education and practical activity. This intersection was underrepresented within the retrieved, abstract-coded corpus; zero occurrences do not establish absence from the wider literature.

Discussion

The findings suggest increasing attention to interventions. Earlier scholarship linked critical thinking with rational scientific judgement (Bailin, 2002; Siegel, 1989; Halpern, 1998), while synthesis supports explicit instruction (Abrami et al., 2008, 2015; Niu et al., 2013). Evidence that active learning improves science achievement (Freeman et al., 2014; Prince, 2004; Michael, 2006) provides context, but the present mapping establishes research emphasis rather than pedagogical superiority.

Technology-enhanced learning was most visible, although it describes an instructional environment rather than one coherent pedagogy. Learning effects depend on integration (Tamim et al., 2011; Schmid et al., 2014; Sung et al., 2016), and digital tools require purposeful inquiry and design (de Jong et al., 2013; Zacharia et al., 2015; Brinson, 2015). Research should examine how technologies support evidence evaluation, reflection and decisions.

Problem-based, inquiry-based and project-based approaches form the principal active-learning strand. Problems require knowledge-gap identification and justified solutions (Hmelo-Silver, 2004; Dochy et al., 2003; Strobel & van Barneveld, 2009); inquiry links questions, investigation and evidence-based conclusions (Pedaste et al., 2015; Minner et al., 2010; Furtak et al., 2012). Guidance and scaffolding remain necessary (Lazonder & Harmsen, 2016; Hmelo-Silver et al., 2007; Alfieri et al., 2011), so frequency alone cannot predict outcomes.

Approaches became more visible after 2016, especially in 2021–2025, alongside corpus expansion. Inquiry showed particularly strong recent concentration, consistent with emphasis on investigation and evidence. Flipped learning remained marginal despite reported design-dependent benefits (van Alten et al., 2019; Strelan et al., 2020; O’Flaherty & Phillips, 2015). This diversification does not establish convergence on an optimal design.

Associated themes link pedagogy with authentic problems, societal relevance and discourse. Socio-scientific issues involve evidence, values and consequences (Sadler & Zeidler, 2005; Zeidler et al., 2005; Sadler, 2004). Argumentation requires constructing and critiquing claims (Driver et al., 2000; Osborne et al., 2004; Erduran et al., 2004), connecting knowledge with judgement (Zohar & Nemet, 2002; Osborne, 2010; Duschl, 2008). Limited attention to teacher practice identifies an implementation concern.

The predominance of general science and physics limits disciplinary balance. Critical reasoning depends on subject knowledge, epistemic standards and evidence (Bailin, 2002; Duschl, 2008; Osborne, 2010). Scientific literacy likewise integrates reasoning and disciplinary understanding (Vieira & Tenreiro-Vieira, 2016; Norris & Phillips, 2003; Roberts, 2007). Chemistry laboratories can connect observations with explanations (Hofstein & Lunetta, 2004; Reid & Shah, 2007; de Jong et al., 2013), but cross-disciplinary transfer requires testing.

Missing educational-level information prevents conclusions about genuine upper-secondary dominance. Deliberately scaffolded tasks can develop higher-order thinking across achievement groups (Zohar & Dori, 2003; Abrami et al., 2015; Niu et al., 2013), and reasoning can develop progressively (Kuhn, 1999; Halpern, 1998; Kuhn & Pease, 2008). Clear participant-level reporting is therefore essential for comparative synthesis.

Only six abstracts explicitly identified practical contexts. Laboratories connect concepts with observation and evidential reasoning (Hofstein & Lunetta, 2004; Reid & Shah, 2007; Hofstein et al., 2004). Physical and virtual laboratories support inquiry when pedagogically structured (de Jong et al., 2013; Zacharia et al., 2015; Brinson, 2015); activity requires guidance, questioning and reflection to support reasoning (Lazonder & Harmsen, 2016; Pedaste et al., 2015; Abrahams & Millar, 2008).

The cross-dimensional results sharpen this concern: nine abstracts combined chemistry and secondary education, one chemistry and practical work, and two secondary education and practical work. None reported all three, identifying an intersection for full-text investigation rather than establishing a universal research absence.

Implications for Theory, Practice and Policy

Theoretically, critical-thinking development should be examined through interactions among pedagogy, disciplinary knowledge and context. Models should explain how technology, problems, inquiry and projects support domain-specific evidence evaluation and judgement across disciplines and educational levels.

For practice, structured student-centred designs should make evidence evaluation, reflection and decisions explicit. Inquiry, argumentation, technology and contextualised tasks require purposeful scaffolding. Limited laboratory representation, particularly in secondary chemistry, warrants deliberate critical-thinking tasks in practical work; frequency of study alone should not determine instructional choices.

Policy priorities include explicit disciplinary reasoning in curricula, teacher development for practical learning design, and clearer reporting of participants and contexts. Limited international co-authorship supports cross-national partnerships. Funding for underrepresented disciplines and settings, teacher capacity, digital infrastructure and equitable active-learning resources could strengthen transferability and classroom relevance.

Limitations

Scopus-only coverage omits relevant work indexed elsewhere, including Web of Science, ERIC and Dimensions. Title restrictions improve precision but may exclude studies addressing critical thinking without naming both concepts. Findings therefore describe the retrieved corpus, not the entire literature.

Abstract-only coding limits detail on pedagogy, discipline, level and context. Educational level was unreported in 54.0% of records and context in 40.9%. An absent combination, including secondary chemistry practical work, may reflect incomplete reporting or search coverage. Full-text investigation is required before concluding that an intersection lacks research.

Multi-coded approaches and themes yield non-exclusive frequencies that cannot be summed as independent proportions. Frequencies indicate visibility, not effectiveness or quality; neither quality appraisal nor effect-size synthesis was conducted. Citation indicators also vary with publication age, source type and citation lag. Multi-database searches, full-text coding, longitudinal analysis and systematic reviews could test the robustness and transferability of these patterns.

Conclusion

Research on critical-thinking pedagogy in science education expanded during 1987–2025, with uneven productivity, influence and international participation. Technology-enhanced, problem-based, inquiry-based and project-based learning were most visible, alongside instructional design, authentic problems, evidence and societal relevance. General science and physics predominated over chemistry and biology; classrooms predominated over laboratories. Missing contextual information constrained comparisons, while secondary chemistry practical work was underrepresented. These results describe visibility, not comparative effectiveness. Future studies should test how designs support evidence evaluation, reasoning, reflection and decisions across disciplines and settings, supported by explicit instruction, laboratory research, fuller reporting and international collaboration.

Declarations

Author Contribution

Corresponding author has conducted the study and prepared the full manuscript, including the abstract, introduction, literature review, methodology, findings, discussion, and conclusion.

Data Availability

The bibliographic records analysed in this study were retrieved from the Scopus database. The analytical dataset is publicly available: kupuchitty, gopi (2026), "Pedagogical Approaches for Developing Critical Thinking in Science Education (1987-2025): A Bibliometric and Thematic Analysis ", Mendeley Data, V2, doi: 10.17632/p9rjkv3df5.2

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Figures

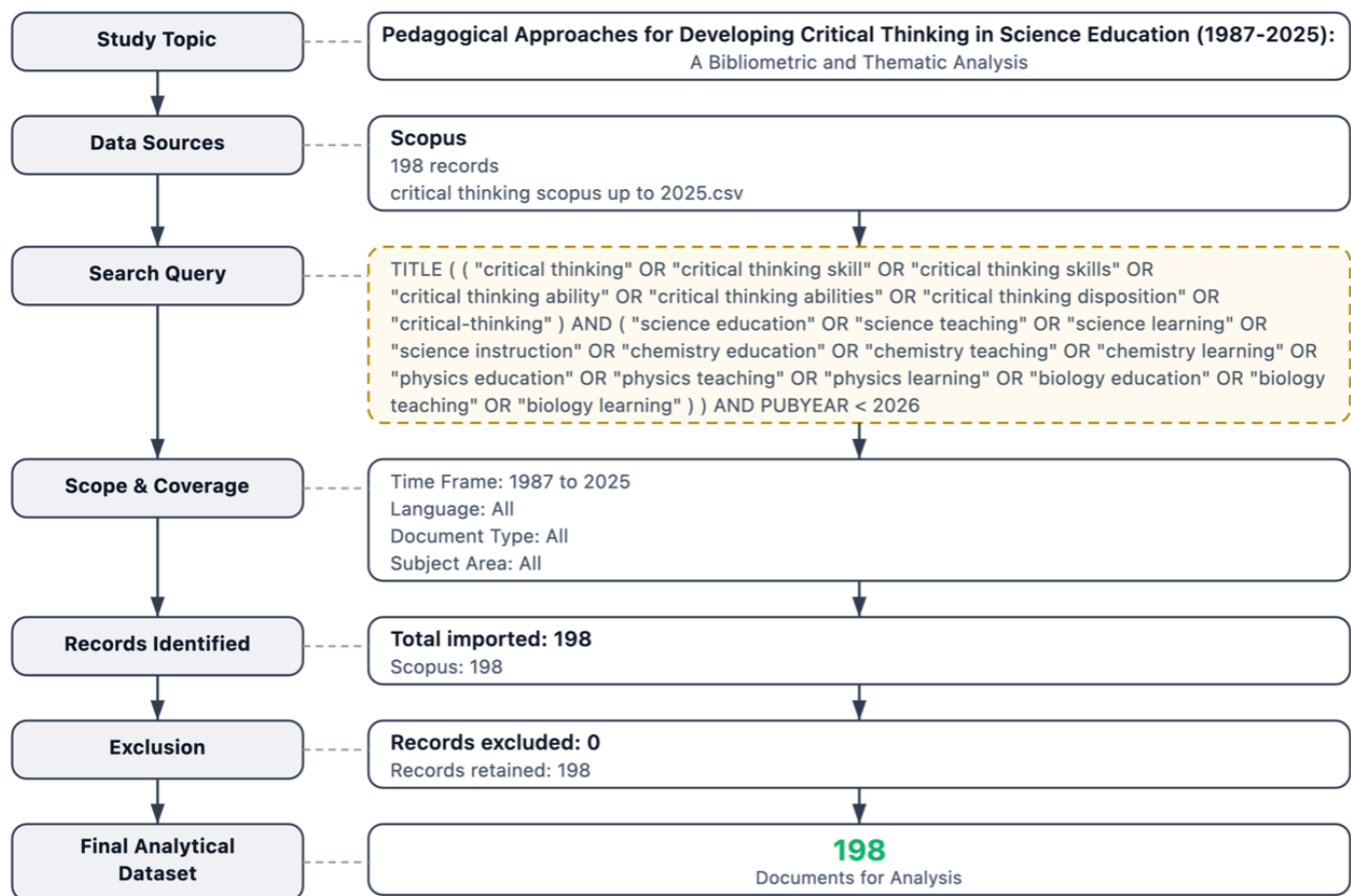


Figure 1

Data identification and retention workflow, adapted from the reporting principles of Page et al. (2021).

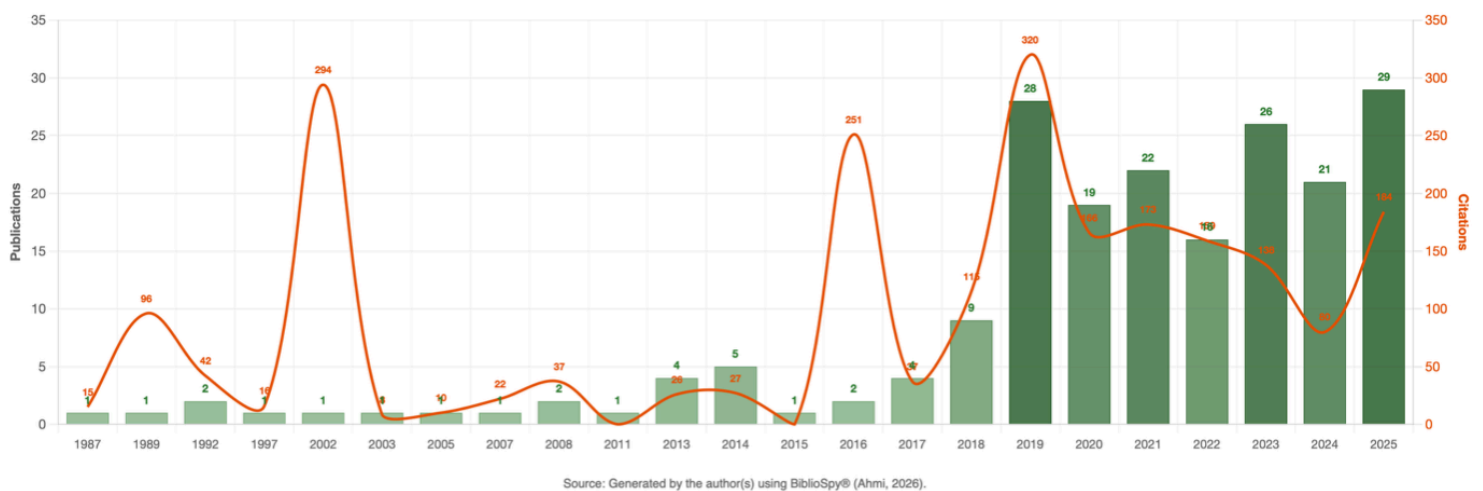


Figure 2

Annual Publications & Citations

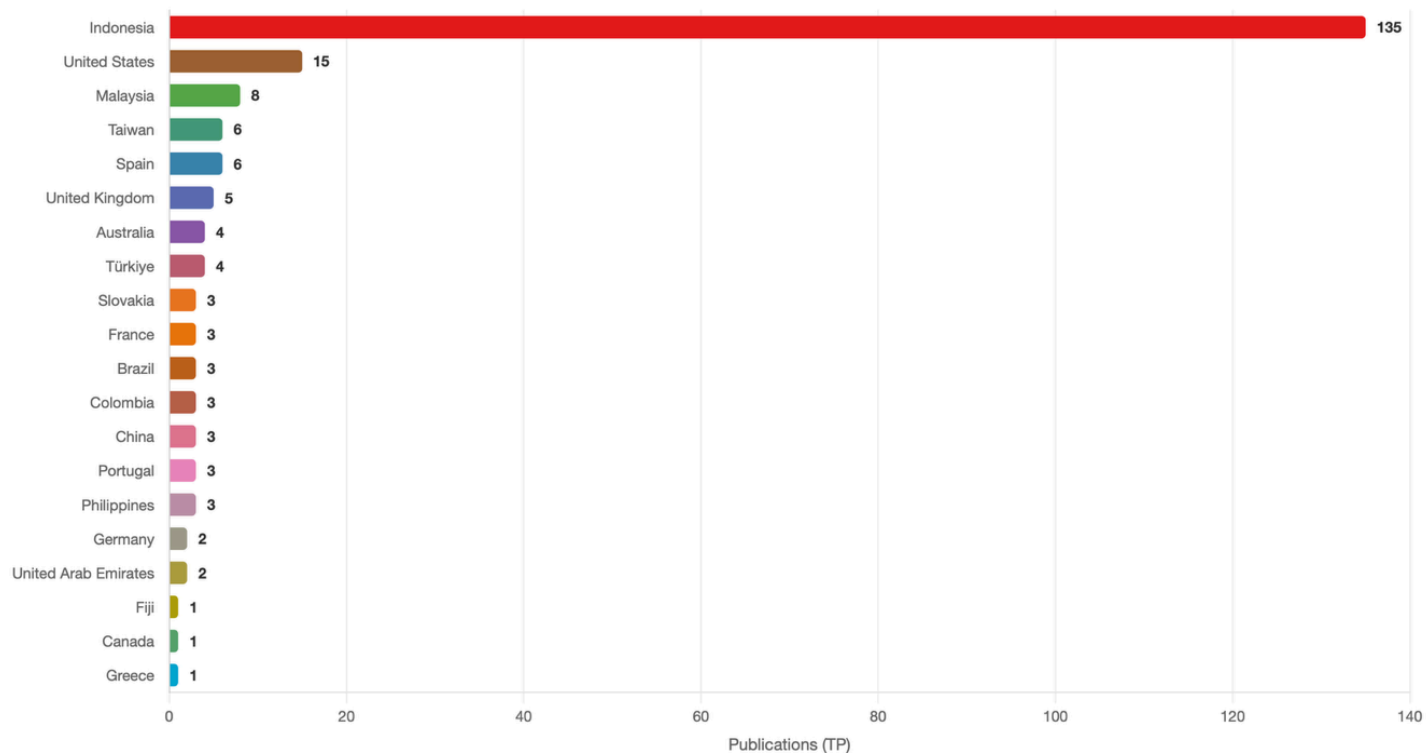


Figure 5

Top Countries in Publication

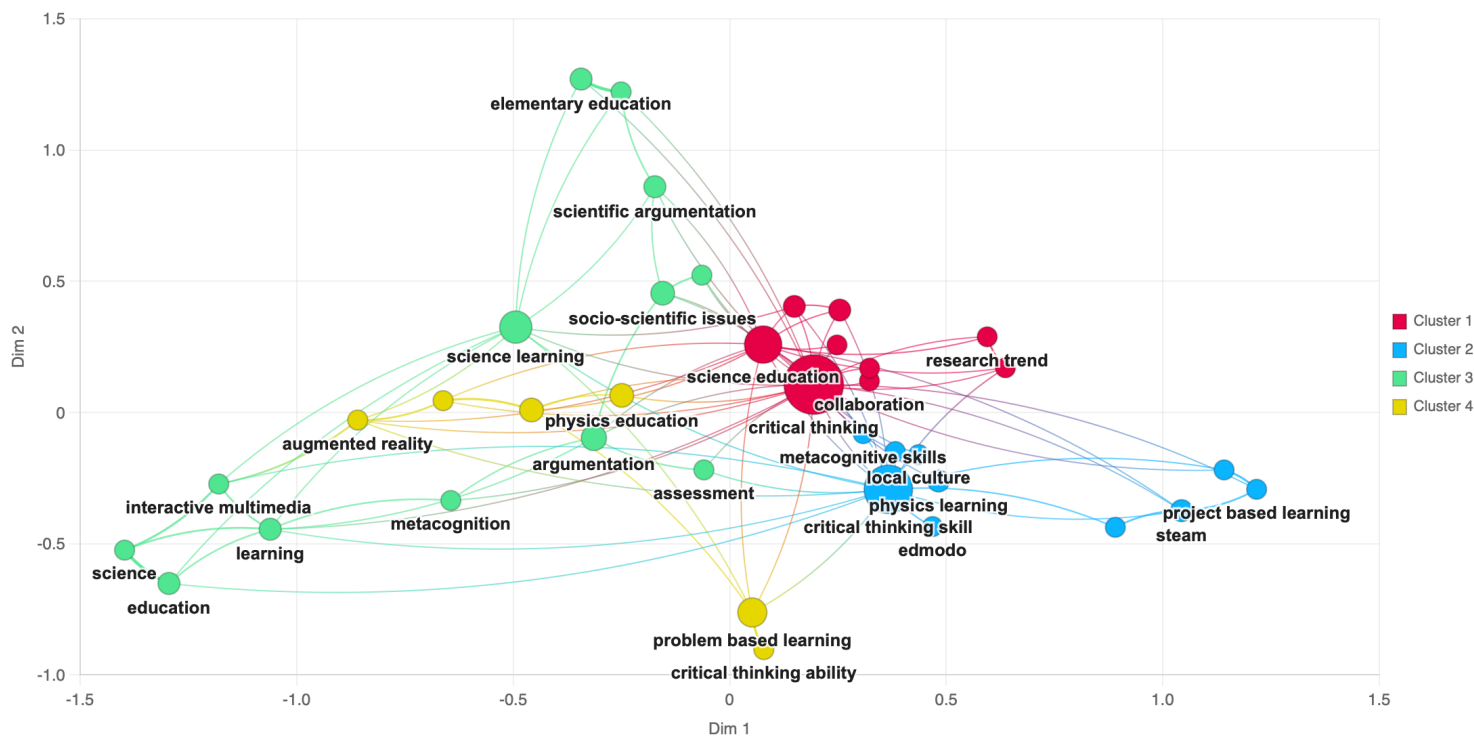


Figure 6

Network visualisation of author keywords

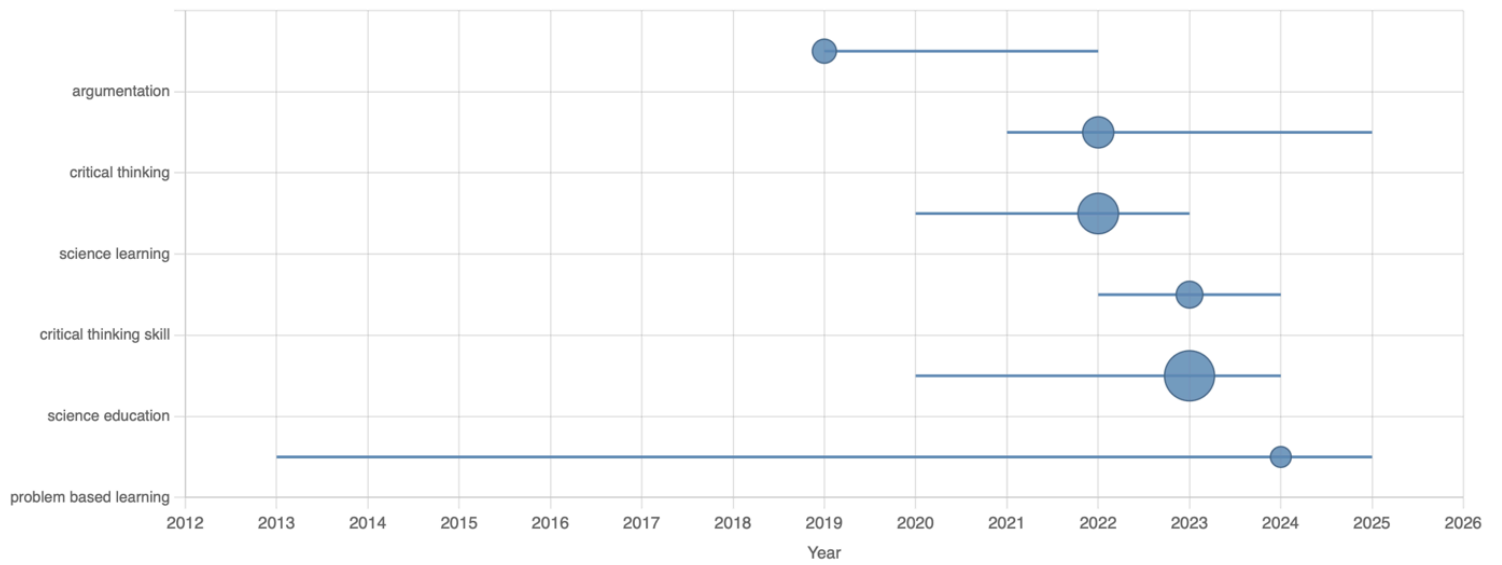


Figure 7

Keyword Trend Topics