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Mapping Constructive Alignment Research In Science Education: A Bibliometric and Network Analysis (2000–2025)

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Constructive alignment (CA) has become a central pedagogical framework aligning intended learning outcomes, teaching strategies, and assessments to promote meaningful learning. Despite the rising number of studies applying CA across educational contexts, no bibliometric research has systematically mapped its development within science education, creating a gap in understanding the field's intellectual structure and evolution. This study presents a bibliometric analysis of CA research in science education from 2000 to 2025, based on 20 Scopus-indexed publications. Using Bibliometrix®, OpenRefine, and VOSviewer, the analysis examines publication trends, leading authors and institutions, citation patterns, and thematic structures. The results show increased scholarly attention after 2015, with prominent contributions from Malaysia, Australia, and the United Kingdom. Keyword co-occurrence networks reveal dominant themes such as curriculum alignment, assessment design, higher-order thinking skills, and teacher professional development. Earlier studies were mostly theoretical, while more recent research demonstrates a shift toward empirical classroom applications. This study uniquely contributes a comprehensive synthesis of CA scholarship in science education, offering insights that guide future research, policy development, and instructional practices.

Keywords: constructive alignment, science education, bibliometric analysis, curriculum design, assessment practices, higher-order thinking skills, empirical research

INTRODUCTION

The accelerating demands of the Fourth Industrial Revolution have intensified the need for pedagogical approaches that integrate intended learning outcomes, instructional activities, and assessment practices in a coherent and purposeful manner (Lipuma et al., 2024; Sajidan et al., 2024). Constructive alignment, rooted in Biggs and Tang's (2011)

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foundational work, provides a structured curriculum framework in which meaningful learning emerges when teaching strategies and assessment tasks are designed to elicit the outcomes they intend to measure. According to Biggs and Tang (2011), deep learning is achieved only when curriculum components operate in concert, a principle particularly critical in science education where inquiry, conceptual reasoning, and cognitive complexity require tightly coordinated learning experiences. Recent implementations of constructive alignment across STEM disciplines have shown its capacity to enhance higher-order thinking, scientific literacy, and student engagement (Costabile et al., 2025; Morris, 2025). Empirical studies further highlight that tasks oriented toward critical reasoning significantly strengthen students' analytical capacities (Artika et al., 2023), while teachers' expertise in designing aligned learning activities is essential for maintaining curricular coherence (Hien et al., 2025). Likewise, research demonstrates that students' progression from foundational understanding to more advanced problem-solving hinges on well-sequenced instructional tasks that closely mirror intended outcomes (Žakelj et al., 2025).

The rapid expansion of digital learning during the COVID-19 pandemic added a new dimension to the relevance of constructive alignment in science education. As instruction shifted toward online and hybrid formats, educators were required to redesign outcomes, activities, and assessments to ensure alignment within technology-mediated environments (Ambusaidi et al., 2021; McBain et al., 2020). Studies show that virtual laboratories, simulations, and multimodal assessments were adopted not merely as temporary adaptations but as deliberate mechanisms for sustaining coherence and ensuring measurable learning outcomes during periods of reduced face-to-face interaction (Blatti et al., 2019; Schmidt et al., 2015). These structural changes catalyzed broader global engagement with constructive alignment, resulting in diverse and context-specific lines of inquiry spanning multiple disciplines and educational levels.

With this widening interest, countries such as Indonesia, Malaysia, United States and Germany have contributed notable research within secondary and tertiary science education (Othman et al., 2022; Lampropoulos et al., 2023). Studies in chemistry, biology, and environmental science highlight how alignment supports collaborative learning, inquiry-driven instruction, and formative assessment practices (Lundstedt & Sinander, 2020; Cousins et al., 2012). Despite this expanded scope, the literature remains fragmented, marked by inconsistent operational definitions, variable methodological approaches, and limited cross-contextual comparison. Critical gaps persist regarding how constructive alignment influences domain-specific outcomes such as scientific argumentation, critical thinking, and self-directed learning (Bockholt et al., 2003; Rembach & Dison, 2016).

Given this dispersed and unevenly documented field, a systematic bibliometric analysis is necessary to clarify how constructive alignment research in science education has developed over the last 25 years. Bibliometric techniques make it possible to identify publication patterns, influential scholars and institutions, conceptual structures, and emergent thematic clusters dimensions that cannot be fully captured through narrative reviews. Therefore, this study analyzes Scopus-indexed literature from 2000 to 2025 using Bibliometrix®, VOSviewer, and OpenRefine to examine citation patterns,

collaboration networks, and keyword co-occurrences. The findings provide a comprehensive and evidence-based overview of how constructive alignment has shaped science education scholarship and practice, offering valuable direction for future research and informing the design of coherent, aligned instructional models that support 21st-century science learning.

LITERATURE REVIEW

Constructive alignment (CA) offers a robust theoretical and practical foundation for designing coherent curricula by ensuring congruence among intended learning outcomes (ILOs), teaching and learning activities (TLAs), and assessment tasks (ATs). Biggs and Tang (2011) argue that learning improves when students engage in activities purposefully structured to elicit targeted outcomes; conversely, misalignment results in superficial processing and fragmented understanding. In science education, CA has been extensively applied to promote active knowledge construction, deeper conceptual integration, and enhanced motivation (Ambusaidi et al., 2021; McBain et al., 2020; Othman et al., 2022). Instructional approaches such as guided inquiry, collaborative problem-solving, and reflective assessment have been shown to strengthen students' cognitive engagement and facilitate connections between prior knowledge and new learning (Blatti et al., 2019).

Successful implementation of CA depends on careful alignment between curricular objectives and classroom practices. Inquiry-based, problem-based, and project-based learning approaches are frequently employed to reflect the cognitive expectations embedded within ILOs and foster scientific reasoning (Schmidt et al., 2015; Palmer & Sarju, 2022). Assessment frameworks guided by the SOLO taxonomy and Bloom's hierarchy help scaffold progressive knowledge development by enabling learners to demonstrate increasingly complex understanding (Rembach & Dison, 2016). Moreover, CA has been found to support learner autonomy by clarifying performance expectations and enhancing the perceived relevance of learning tasks (Tian & Wahid, 2024). Despite its benefits, persistent challenges including inadequate curriculum documentation, inconsistencies between evaluation and instruction, and insufficient teacher preparation continue to impede its effective application (Ramaraj & Nagammal, 2019; van Altena et al., 2020).

The heightened demand for quality assurance and accountability in education has intensified interest in synthesizing CA research through bibliometric approaches. Bibliometric analysis offers a systematic means of identifying influential researchers, leading institutions, collaboration networks, and conceptual trends within a research field (Zhao & Chen, 2023). Recent analyses reveal a noticeable increase in CA-related publications following 2018, coinciding with global curriculum reforms and the expansion of outcome-based science education (Ambusaidi et al., 2021; Othman et al., 2022). Emerging themes include curriculum alignment, authentic assessment, inquiry-based instruction, and technology-enhanced learning (Palmer & Sarju, 2022; Lundstedt & Sinander, 2020). However, despite an expanding literature base, gaps remain regarding demographic variations, fidelity of implementation, and inclusive pedagogical strategies tailored to diverse learner needs (McBain et al., 2020; Blatti et al., 2019).

Previous Studies on Bibliometric Analysis

Although constructive alignment has been a prominent topic in science education, research in this area remains conceptually and geographically dispersed, limiting understanding of how the field has evolved and where scholarly contributions are concentrated. While bibliometric methods have been applied to map related domains such as STEM integration (Othman et al., 2022), cognitive engagement (McBain et al., 2020), and inclusive pedagogy (Palmer & Sarju, 2022), no Scopus-indexed bibliometric study has specifically examined constructive alignment. This absence represents a substantial gap, given the increasing reliance on CA as a framework for improving instructional coherence and strengthening learning outcomes. A targeted keyword search ("constructive alignment" OR "curriculum design" OR "learning outcomes") AND ("higher-order thinking" OR "critical thinking" OR "cognitive skills" OR "problem solving") AND ("biology education" OR "life sciences") confirmed the lack of comprehensive analytic work in this domain, particularly within biology-related research.

This gap is scientifically urgent because fragmented evidence constrains the ability of researchers, policymakers, and curriculum designers to make data-driven decisions regarding CA implementation. Through bibliometric and network analysis techniques, this study systematically maps publication trends, intellectual structures, and thematic developments to illuminate conceptual blind spots, emerging priorities, and underexplored contexts. Rather than serving as a traditional narrative review, this study provides the first foundational mapping of constructive alignment scholarship in science education, establishing an evidence base that supports future research and promotes more coherent and impactful instructional practices.of more coherent and impactful instructional practices.

RESEARCH QUESTIONS

This paper presents a bibliometric analysis of constructive alignment in science education by focusing on six main research questions (RQs):

RQ 1: What is the current landscape of research on constructive alignment in science education?

RQ 2: What emerging trends are observable in publications related to constructive alignment in science education?

RQ 3: Which journals and publications serve as epicentres for groundbreaking studies on constructive alignment in science education?

RQ 4: What landmark papers have shaped the discourse and direction of constructive alignment in science education research?

RQ 5: Which key authors, institutions, and countries are driving advancements in constructive alignment in science education?

RQ 6: What pivotal research themes underpin the development and growth of constructive alignment in the science education field?

METHOD

This study employed data sourced from the Scopus database as of August 4, 2025. The collected data encompassed a range of variables, such as document types, source types, subject areas, publication trends, average authorship per document, institutional contributions, publication distribution by country, and prominent keywords, among other aspects. Many prior studies on constructive alignment and higher-order thinking skills (HOTS) have relied on single-database sources, such as Scopus, potentially narrowing the scope of analysis. This study, therefore, acknowledges the value of integrating multiple databases such as Web of Science and Google Scholar in future research to achieve a more comprehensive analysis.

Search Strategy

The review adopted the modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for conducting systematic reviews (Moher et al., 2009). The search string *(TITLE-ABS-KEY("constructivism" OR "constructivist teaching" OR "student-centered learning" OR "constructive alignment" OR "curriculum alignment") AND TITLE-ABS-KEY("higher order thinking" OR "HOTS" OR "thinking skills" OR "critical thinking" OR "cognitive skills" OR "reasoning skills" OR "students thinking skill") AND TITLE-ABS-KEY("science education" OR "science" OR "STEM education" OR "school science" OR "secondary education" OR "biology education")) AND PUBYEAR > 1999 AND PUBYEAR < 2026* was entered into the Scopus search engine. Then, subject filters were applied. The scope and coverage in this study were based on search field, time frame, source type, and document type to exclude irrelevant papers. This search yielded 176 documents (see Figure 1). After scanning the abstracts of all documents in the list, further exclusions were made based on topical relevance. After the screening of documents had been completed, 20 documents on constructive alignment and higher order thinking in science education remained in the final database.

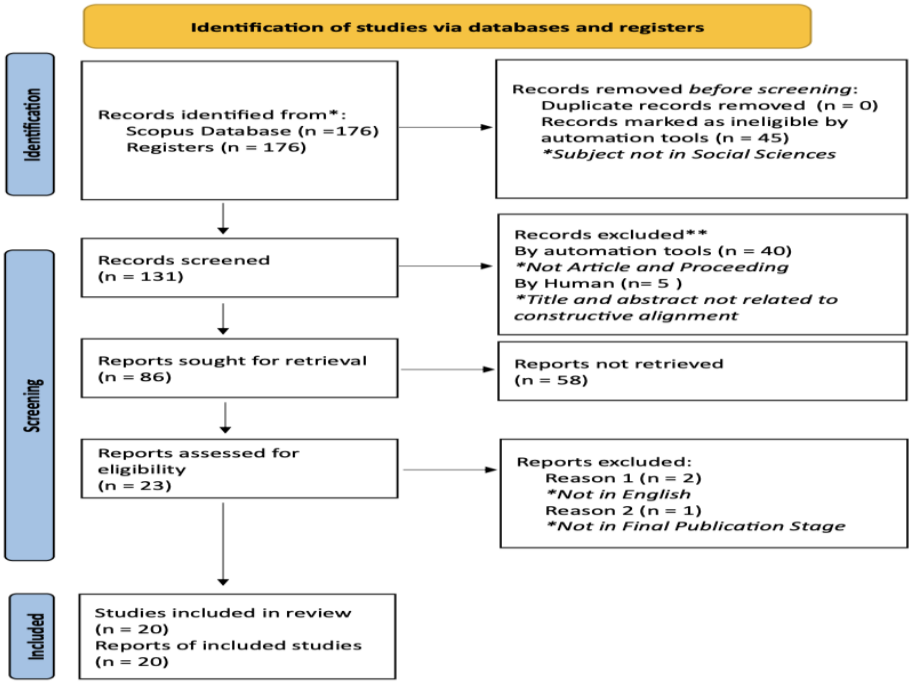

Figure 1
Flow diagram of the search strategy

Data Cleaning

Data cleaning and harmonisation are essential for ensuring accuracy and reliability in bibliometric analysis. In this study, OpenRefine and biblioMagika® (Ahmi, 2024) were used to standardise author names, affiliations, keywords, and other bibliographic fields, resolving inconsistencies commonly found in Scopus exports. These tools supported the removal of duplicates, correction of variant spellings, and completion of missing information, resulting in a coherent and well-structured dataset suitable for robust analysis. biblioMagika® also facilitated the generation of core bibliometric indicators including publication counts, citation metrics, and collaboration patterns while keeping the focus on the broader analytical aims rather than technical procedures.

To ensure the validity and reliability of the bibliometric results, data were cross-checked for completeness, consistency, and accuracy after the cleaning process. Harmonisation steps were conducted iteratively to minimise errors, reduce noise in the dataset, and prevent distortions in citation or authorship metrics. The use of established cleaning protocols and verified bibliometric indicators strengthens the credibility of the findings, ensuring that the resulting analyses accurately reflect the intellectual structure and thematic development of constructive alignment research in science education. Through systematic refinement, the dataset established a dependable foundation for subsequent mapping and interpretation.

Data Analysis

The data analysis was systematically designed to address the research objectives by mapping the bibliometric landscape of constructive alignment in science education. Key analytical parameters included document types, source titles, publication languages, subject areas, and citation metrics. Descriptive indicators such as annual publication trends, leading authors, productive institutions, contributing countries, and high-impact journals were employed to reveal publication patterns and research dynamics. To evaluate academic impact, metrics such as total publications, citation counts, average citations per publication, h-index, g-index, and m-index were utilized. Furthermore, advanced bibliometric techniques, including co-occurrence network analysis, thematic mapping, and factorial analysis, were applied to authors' keywords to identify thematic clusters and conceptual structures. These visualizations enabled the exploration of interconnections across subfields, highlighting emerging research themes in constructive alignment, curriculum alignment, and science pedagogy.

FINDINGS

In the upcoming results section, the authors will present an in-depth examination of the research landscape for constructive alignment in science education. This detailed analysis will address the research questions (RQs), yielding a deep understanding of the field. Through this focused analysis, the authors are committed to delivering a detailed and insightful overview of constructive alignment in the science education domain, contributing valuable knowledge for scholars, practitioners, and decision-makers.

RQ1: Current Landscape of Constructive Alignment in Science Education Research

To explore the current landscape of constructive alignment research in science education, this study analyzed publication types, source categories, languages, subject areas, and citation metrics across a dataset of 20 Scopus-indexed publications from 2003 to 2025. Although the overall volume of publications is modest, the research trajectory reveals a marked increase after 2018, coinciding with global curriculum reforms that promoted outcome-based education and higher-order thinking skills as core priorities. As educational systems increasingly emphasized competencies such as critical thinking, scientific reasoning, and inquiry-based learning, constructive alignment gained renewed relevance as a framework capable of supporting these goalscontributing to the rise in scholarly output during this period. Of the 20 publications, 18 have been cited, generating a total of 278 citations, with an average of 13.90 citations per paper and 15.44 citations per cited paper, indicating steady academic influence.

Across these publications, 71 authors contributed to the field, reflecting growing interdisciplinary engagement. Authorship patterns show an average of 3.55 authors per article and a citation-per-author rate of 3.92. Bibliometric indices including an h-index of 6, a g-index of 16, and an m-index of 0.261 suggest consistent scholarly impact, while the total citation count within the h-core (275 citations) underscores the sustained relevance of research on constructive alignment. Collectively, these metrics illustrate

the expanding visibility of constructive alignment in science education and its alignment with global pedagogical shifts toward curriculum coherence, assessment alignment, and deeper cognitive engagement. The findings also provide a strong foundation for subsequent analyses of author networks, thematic clusters, and the evolution of knowledge within the field.

Table 1
Citation metric

Main Information	Data
Publication Years	2003 - 2025
Total Publications	20
Citable Year	23
Number of Contributing Authors	71
Number of Cited Papers	18
Total Citations	278
Citation per Paper	13.90
Citation per Cited Paper	15.44
Citation per Year	12.64
Citation per Author	3.92
Author per Paper	3.55
Citation sum within h-Core	275
h-index	6
g-index	16
m-index	0.261

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

RQ2: Publication Trends of Constructive Alignment in Science Education Research

To examine publication trends, this study traced the trajectory of research on constructive alignment in science education from its initial emergence in 2003 through to 2025. A notable surge in scholarly output occurred in 2023, which marked the peak with 20 publications and 275 citations, reflecting intensified interest and increased academic engagement. The cumulative rise in total publications and citations over time, as visualized through bibliometric indicators, suggests growing recognition of constructive alignment as a critical component of science education reform. These patterns align with broader educational shifts emphasizing higher-order thinking skills, curriculum coherence, and outcome-based pedagogies.

The number of contributing authors (71 by 2025) further demonstrates the expanding and collaborative nature of the field, drawing from interdisciplinary expertise in pedagogy, curriculum studies, and cognitive science. The h-index (6), g-index (16), and m-index (0.261) indicate a steady growth in scholarly impact, with cited works becoming increasingly influential. Spikes in citations observed in 2011, 2016, and 2023 suggest moments of conceptual refinement, possibly aligned with national education reforms or global pedagogical initiatives. Overall, these findings highlight the accelerating relevance of constructive alignment research in shaping effective science education practices and underscore its potential as a foundation for future curriculum innovation.

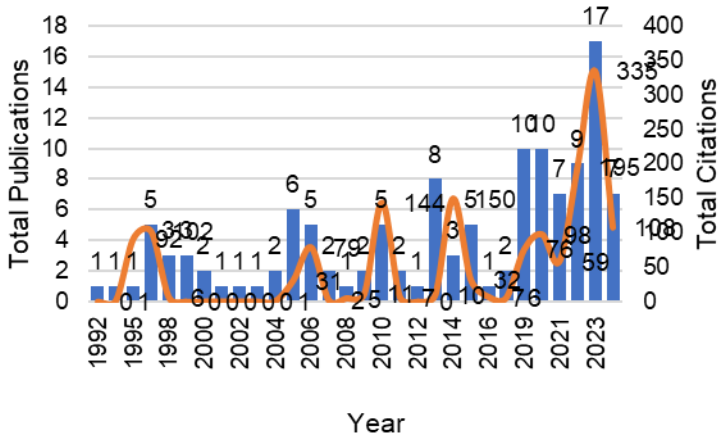

Figure 2
Total publications and citations by year (Excluding the year 2025 as data is only available up to 4 August 2025)

Table 2
Publication by year

Year	TP	NCA	NCP	TC	C/P	C/CP	*h*	*g*	*m*
2003	1	1	0	0	0.00	0.00	0	0	0.000
2004	2	2	1	1	0.50	1.00	1	1	0.045
2005	6	6	6	31	5.17	5.17	3	5	0.143
2006	5	5	3	79	15.80	26.33	3	5	0.150
2007	2	2	2	2	1.00	1.00	1	1	0.053
2008	1	1	1	5	5.00	5.00	1	1	0.056
2009	2	2	2	11	5.50	5.50	1	2	0.059
2010	5	5	4	144	28.80	36.00	2	5	0.125
2011	2	2	1	7	3.50	7.00	1	2	0.067
2012	1	1	0	0	0.00	0.00	0	0	0.000
2013	8	8	2	10	1.25	5.00	2	3	0.154
2014	3	3	3	150	50.00	50.00	3	3	0.250
2015	5	5	3	32	6.40	10.67	3	5	0.273
2016	1	1	1	7	7.00	7.00	1	1	0.100
2018	2	2	2	6	3.00	3.00	2	2	0.250
2019	10	10	8	76	7.60	9.50	5	8	0.714
2020	10	10	9	98	9.80	10.89	4	9	0.667
2021	7	7	6	59	8.43	9.83	4	7	0.800
2022	9	9	8	195	21.67	24.38	5	9	1.250
2023	17	17	15	335	19.71	22.33	9	17	3.000
2024	7	7	7	108	15.43	15.43	7	7	3.500
Total	124	124	89	1557	12.56	17.49	6	16	0.261

Notes: TP = total number of publications; NCA = number of contributing authors; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index.
* Publication data for the year 2024 is only up until 4 August 2025.

RQ3: Source Title of Constructive Alignment in Science Education Research

To explore the publication platforms advancing research on constructive alignment in science education, this study identified key source titles contributing significantly to the discourse. Among these, Education Sciences stood out with the highest publication frequency (TP = 3), accumulating 45 citations and an h-index of 2, indicating steady influence and scholarly engagement. Likewise, the Journal of Chemical Education contributed three articles and achieved the highest citation-per-paper (C/P) rate of 25.67, with an h-index of 3, signaling consistent quality and impact across its contributions. Notably, Health Professions Education recorded the single most-cited paper (TC = 115), underscoring the high impact individual articles can have, even from journals with limited frequency. Other journals, such as Jurnal Pendidikan IPA Indonesia, Bioscience Education, and the International Journal of Innovation in Science and Mathematics Education, added international breadth to the literature, each contributing one publication with moderate citation metrics. Furthermore, high-performing journals like the European Journal of Educational Research and International Journal of Science Education demonstrated strong citation ratios and index scores (e.g., g-index, m-index), reinforcing their role in disseminating high-quality, influential research. Collectively, these journals reflect both the diversity of publication venues and the increasing scholarly attention toward constructive alignment within science education, spanning disciplines and educational contexts.

Table 3
Most active source titles that published two (2) or more documents

Source Title	TP	NCA	NCP	TC	C/P	C/CP	*h*	*g*	*m*
Education Sciences	3	7	2	45	15.00	22.50	2	3	0.667
Journal of Chemical Education	3	14	3	77	25.67	25.67	3	3	0.429
Jurnal Pendidikan IPA Indonesia	1	6	1	1	1.00	1.00	1	1	0.500
Bioscience Education	1	5	1	2	2.00	2.00	1	1	0.071
International Journal of Innovation in Science and Mathematics Education	1	10	1	3	3.00	3.00	1	1	0.167

Note: TP=total number of publications; NCA=number of contributing authors; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h = h-index; g = g-index; m = m-index

RQ4: Highly Cited Documents of Constructive Alignment in Science Education Research

To determine the most influential contributions in constructive alignment (CA) research within science education, Table 4 presents the top ten most highly cited documents. Leading the list is Schmidt et al. (2015), whose critique of traditional lecture-based pedagogy in Health Professions Education has amassed 115 citations, averaging 10.45 citations per year. This foundational work helped shift pedagogical focus toward student-centered and aligned instructional strategies. Blatti et al. (2019), with 54 citations, emphasized systems thinking and sustainability in the Journal of Chemical Education, reinforcing CA's relevance in addressing complex, real-world challenges. Notably, Lampropoulos et al. (2023) made rapid impact with 42 citations in one year

through their exploration of augmented reality and gamification in education, signaling growing interest in technologically enhanced alignment approaches.

Other highly cited works include López-Fernández et al. (2022) on socioscientific issues, Othman et al. (2022) on STEM modules and student perception, and Rembach & Dison (2016) on applying SOLO taxonomy to social science instruction. Earlier contributions like Bockholt et al. (2003) examined constructivist learning via multimedia in biology education, while Palmer & Sarju (2022) addressed persistent misconceptions in chemistry through aligned teaching. Khurma & El Zein (2024) and Acut (2024) offered recent insights on inquiry skills and real-world STEM immersion, respectively. Collectively, these works reflect a trajectory from foundational theory to innovative, applied strategies in CA, establishing its role in enhancing science education through integrated curriculum, teaching, and assessment practices.

Table 4
Top five (5) highly cited articles

No.	Author(s)	Title	TC	C/Y
1	Schmidt et al. (2015)	On the use and misuse of lectures in higher education	115	10.45
2	Blatti et al. (2019)	Systems Thinking in Science Education and Outreach toward a Sustainable Future	54	7.71
3	Lampropoulos et al. (2023)	Integrating Augmented Reality, Gamification, and Serious Games in Computer Science Education	42	14
4	López-Fernández et al. (2022)	How Can Socio-scientific Issues Help Develop Critical Thinking in Chemistry Education? A Reflection on the Problem of Plastics	19	4.75
5	Othman et al. (2022)	Creative Teaching STEM Module: High School Students' Perception	12	3

RQ 5: Which key authors, institutions, and countries are driving advancements in constructive alignment in science education?

To determine the leading contributors in constructive alignment (CA) within science education, Table 5 presents the most productive authors and their associated institutions. The analysis highlights a globally distributed authorship network, with notable contributions from Universiti Kebangsaan Malaysia, the University of California system, and Erasmus University Rotterdam. Yasin Ruhizan Mohamad from Malaysia leads in regional scholarly influence with 12 citations and a steady m-index of 0.250. In contrast, Blatti Jillian L. from the United States demonstrates substantial global impact through a co-authored paper that achieved 54 citations (C/P = 54.00), alongside collaborators Juarez, Portillo, and Cuccinello, all affiliated with prominent U.S. institutions. Other high-impact contributors include Franco-Mariscal (Spain), Wagener (Netherlands), and Palmer (UK), reflecting strong engagement from Europe, while Yardy (Australia) and Dison (South Africa) extend the geographical reach further. Although each author contributed a single paper, their high citation-per-publication ratios and index scores signal a meaningful impact in advancing CA discourse. These findings suggest that while the field remains emergent, it is driven by a globally dispersed and interdisciplinary cohort, emphasizing CA's growing relevance across diverse educational systems.

Table 5
Most productive authors that published more than three (3) documents

Full Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	*h*	*g*	*m*
Yasin, Ruhizan Mohammad	Universiti Kebangsaan Malaysia	Malaysia	1	1	12	12.00	12.00	1	1	0.250
Dison, Laura	University of the Witwatersrand	South Africa	1	1	6	6.00	6.00	1	1	0.100
Blatti, Jillian L.	Pasadena City College	United States	1	1	54	54.00	54.00	1	1	0.143
Yardy, Andrew	The University of Newcastle	Australia	1	1	3	3.00	3.00	1	1	0.167
Barker, Martin	University of Aberdeen	United Kingdom	1	1	2	2.00	2.00	1	1	0.071
Cuccinello, Anthony	University of Southern California	United States	1	1	54	54.00	54.00	1	1	0.143
Palmer, Alex L.	University of York	United Kingdom	1	1	4	4.00	4.00	1	1	0.250

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index

To identify the most influential institutions advancing research in constructive alignment (CA) within science education, Table 6 highlights those with a minimum of four publications. The University of Newcastle (Australia) leads in productivity, contributing nine publications and achieving 27 citations, supported by a moderate h-index of 3 and a g-index of 5. Although its citation-per-publication (C/P) average is 3.00, the institution's consistent output underscores its ongoing engagement with CA scholarship. Erasmus University Rotterdam (Netherlands), despite having only five publications, stands out with an exceptional total of 575 citations, yielding a remarkable 115.00 C/P ratio and a perfect C/CP. This performance reflects a high-impact publication portfolio, solidified by h- and g-index values of 5. Notably, Universiti Kebangsaan Malaysia (UKM) also demonstrates strong scholarly impact with an average of 9.25 citations across four publications and the highest m-index (0.750) among all listed institutions. Institutions from the United States and Indonesia, such as Pasadena City College, the University of California network, and Universitas Sebelas Maret, also contribute meaningfully, highlighting the global diffusion and institutional commitment toward research on constructive alignment in science education.

Table 6
Most productive institutions with a minimum of four (4) publications

Institution Name	Country	TP	NCP	TC	C/P	C/CP	*h*	*g*	*m*
The University of Newcastle	Australia	9	9	27	3.00	3.00	3	5	0.500
Erasmus University Rotterdam	Netherlands	5	5	575	115.00	115.00	5	5	0.455
Universitas Sebelas Maret	Indonesia	4	4	4	1.00	1.00	1	2	0.500
Universiti Kebangsaan Malaysia	Malaysia	4	4	37	9.25	9.25	3	4	0.750
University of Aberdeen	United Kingdom	4	4	8	2.00	2.00	2	2	0.143

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index

The global distribution of research on constructive alignment (CA) in science education reveals a growing and geographically diverse scholarly engagement. The United States leads with the highest research output, totaling 19 publications and 506 citations, supported by an h-index of 9 and g-index of 19. These figures indicate sustained productivity and scholarly influence, with an average of 26.63 citations per publication and a strong citation-per-cited-publication (C/CP) rate of 33.73. Australia follows in productivity with 13 publications and 36 citations, supported by a moderate m-index of 0.500, reflecting steady research contributions. The Netherlands, although contributing only five papers, demonstrates exceptional impact with 575 total citations and a remarkable citation-per-publication average of 115.00, highlighting a focused yet influential body of work.

Asia and Europe are also key players in this evolving field. Malaysia, with four publications and an average of 9.25 citations per article, reflects an emerging hub of CA research in Southeast Asia, supported by a relatively high m-index of 0.750. Other contributors such as Indonesia, the United Kingdom, Spain, and South Africa also reflect the internationalization of CA discourse. As visualized in Figure 3, this global diffusion underscores the cross-continental relevance of constructive alignment in reforming science education, demonstrating both the breadth and depth of scholarly commitment to aligning curriculum, pedagogy, and assessment across diverse educational contexts.

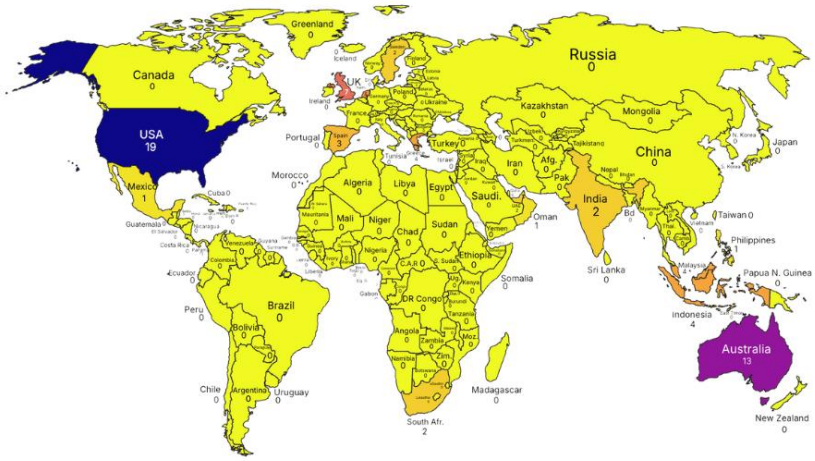

Figure 3
Visualisation of global distribution of constructive alignment in science education.

Table 7
Countries that contributed four (4) or more publications

Country	TP	NCP	TC	C/P	C/CP	*h*	*g*	*m*
United States	19	15	506	26.63	33.73	9	19	0.391
Australia	13	13	36	2.77	2.77	3	6	0.500
United Kingdom	7	7	18	2.57	2.57	2	4	0.143
Netherlands	5	5	575	115.00	115.00	5	5	0.455
Malaysia	4	4	37	9.25	9.25	3	4	0.750
Greece	4	4	168	42.00	42.00	4	4	1.333
Indonesia	4	4	4	1.00	1.00	1	2	0.500

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index

RQ6: Co-occurrence Analysis of Constructive Alignment in Science Education Research

The co-occurrence network in Figure 4 provides a comprehensive visualization of the thematic structure underlying research on constructive alignment (CA) in science education. Central to the network are high-frequency keywords such as constructivism, science education, and inquiry-based learning, underscoring their foundational role in shaping the discourse. The central positioning and strong linkages of these terms reveal the theoretical backbone of CA, rooted in constructivist epistemology and its application in science pedagogy. These nodes not only reflect the frequency of use but also their conceptual centrality, highlighting the enduring influence of constructivist principles in informing curriculum alignment and instructional design across educational levels.

A prominent cluster emerging around constructivism connects closely with terms like active learning, student-centered learning, and collaborative learning, emphasizing the pedagogical reorientation towards learner agency and engagement. This cluster reflects a paradigm shift from teacher-directed instruction to more participatory, inquiry-driven learning environments, aligning with CA's emphasis on aligning learning outcomes, teaching methods, and assessments to promote deep understanding.

Another cluster features keywords such as science education, STEM education, critical thinking, and inquiry-based learning, which collectively foreground CA's role in fostering cognitive development, particularly Higher Order Thinking Skills (HOTS). This cognitive-emphasis cluster illustrates how CA contributes to scientific reasoning and problem-solving capabilities, key competencies in 21st-century education.

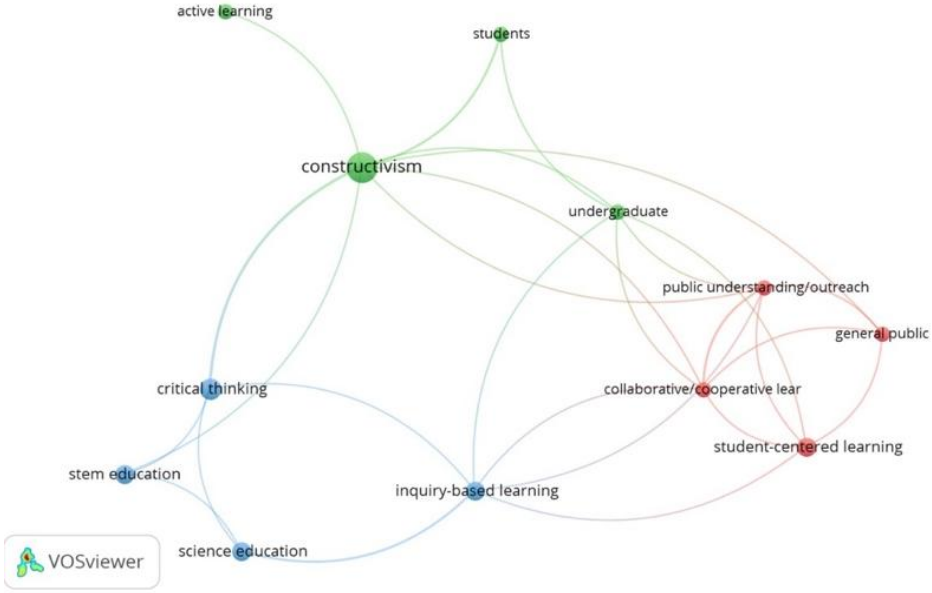

Figure 4
Co-occurrence network of the author's keywords with at least 10 Occurrences

DISCUSSION

This study provides a comprehensive bibliometric mapping of constructive alignment (CA) in science education from 2000 to 2025, revealing how the field has developed in response to shifting pedagogical priorities and global educational reforms. A notable increase in publications especially after 2018 and during 2020–2023 corresponds with intensified demands for higher-order thinking, competency-based learning, and curriculum coherence across science disciplines. The COVID-19 pandemic further accelerated this trajectory as educators sought structured frameworks to maintain instructional alignment in digital, hybrid, and remote learning contexts. CA gained prominence as it offered a coherent blueprint for designing learning outcomes,

activities, and assessments in ways that supported continuity, cognitive engagement, and measurable learning outcomes in rapidly changing instructional environments. These findings affirm CA's expanding relevance for cultivating 21st-century competencies such as problem-solving, critical thinking, scientific literacy, and adaptability.

Country-level patterns (RQ1) demonstrate strong contributions from the United States, Australia, and the United Kingdom, reflecting established research cultures centered on outcomes-based assessment and inquiry-oriented pedagogy. Malaysia's emerging influence supported by strong citation metrics highlights Southeast Asia's growing commitment to integrating CA into curriculum reforms that prioritize higher-order thinking. Institutional analyses (RQ2) further indicate that research impact is shaped not only by publication volume but also by thematic specialization, as illustrated by institutions like Erasmus University Rotterdam producing fewer yet highly influential works.

At the author level (RQ3), the field is shaped by both established and emerging researchers whose citation profiles indicate sustained engagement with CA across diverse science education contexts. International collaboration networks spanning Malaysia, Greece, the Netherlands, and the United States suggest increasing interdisciplinary integration of CA principles in curriculum design, inquiry-based instruction, and assessment practices. Seminal contributions by scholars such as Schmidt et al. (2015) and Blatti et al. (2019) continue to inform the theoretical and practical evolution of CA by foregrounding the need to move beyond didactic teaching toward more student-centered, cognitively aligned learning environments.

Keyword and thematic analyses (RQ4–RQ5) reveal that CA research has evolved from foundational conceptual work toward more applied, context-specific investigations. Early studies emphasized constructivism, alignment theory, and student-centered learning, while more recent themes highlight the integration of digital learning tools, STEM pedagogies, formative assessment, and the explicit cultivation of critical thinking skills. These shifts indicate that CA is increasingly used to guide instructional coherence within models emphasizing inquiry, authentic assessment, and cognitive development. The prominence of technology-enhanced learning as an emerging cluster reflects the ongoing influence of post-pandemic digital transformation, suggesting that future studies will continue to interrogate how CA functions within virtual laboratories, simulations, and hybrid teaching models.

The co-occurrence network (RQ6) further demonstrates that CA functions as a multidimensional framework. Pedagogical clusters emphasize active learning and student agency; cognitive clusters highlight inquiry-based learning, reasoning, and higher-order thinking; and societal clusters draw attention to scientific literacy, community engagement, and inclusive education. This multifaceted structure illustrates how CA not only aligns curriculum components but also supports broader educational goals related to equity, scientific citizenship, and meaningful engagement in science.

Limitations and Future Research

While this study provides important insights into the development and intellectual structure of constructive alignment (CA) research in science education, several limitations should be acknowledged. First, the exclusive use of the Scopus database may have excluded relevant studies indexed in other repositories, limiting the comprehensiveness and global representativeness of the dataset. Second, although the keyword strategy was systematically developed, variations in terminology (e.g., instructional alignment, learning coherence) may have resulted in the omission of studies conceptually related to CA. Third, restricting the search to English-language publications introduces language bias and may underrepresent scholarship from regions where science education research is published in local languages. Additionally, bibliometric indicators such as citation counts and indices measure scholarly visibility rather than pedagogical quality or classroom impact, and they may disadvantage newer publications that have had less time to accumulate citations. These limitations should be taken into account when interpreting the trends and patterns reported in this study.

Future research should broaden database coverage, incorporate multilingual sources, and refine search strategies to capture a wider conceptual range of alignment-related terminology. Comparative studies across regions, disciplines, or educational levels would also enrich understanding of how CA functions within diverse curricular ecosystems. Finally, emerging areas such as AI-assisted assessment, virtual laboratories, and hybrid learning environments present promising avenues for exploring how CA principles adapt to rapidly evolving forms of science instruction.

CONCLUSION

Alignment (CA) research in science education from 2000 to 2025, offering new theoretical, methodological, and practical contributions to the field. The findings reveal how CA has grown in prominence particularly in the context of global curriculum reforms and post-pandemic digital transformation highlighting its critical role in supporting higher-order thinking, scientific literacy, and coherent instructional design.

Methodologically, the study advances CA scholarship by providing an evidence-based mapping of influential authors, institutions, and thematic trajectories, offering a clearer understanding of the field's intellectual development. Practically, the identified research trends such as formative assessment, inquiry-based pedagogy, and technology-enhanced learning underscore the relevance of CA for strengthening curriculum alignment and assessment validity in modern science classrooms.

Overall, this study contributes a foundational evidence base that can inform policy decisions, guide teacher professional development, and support future innovation in curriculum and assessment design. By illuminating both the progress and gaps in CA research, the study lays the groundwork for more strategic, coherent, and impactful applications of constructive alignment within science education systems worldwide.

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