

Constructive Alignment as a Framework for Enhancing Motivation and Higher-Order Thinking in Science Classrooms: A Systematic Synthesis

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ABSTRACT

Constructive alignment (CA) offers a coherent approach to linking intended learning outcomes, pedagogy and assessment in science education, with potential to strengthen students' higher-order thinking skills (HOTS), motivation and achievement. This systematic literature review synthesizes research published between 2000 and 2025 in Scopus and Web of Science. Following PRISMA procedures, 42 articles met inclusion criteria and were analysed thematically to map trends in CA application across science education, with particular attention to secondary contexts. Three core themes emerged: (1) pedagogical strategies that align inquiry-based, student-centred and collaborative learning with explicit outcomes; (2) curriculum frameworks that embed HOTS and scientific literacy to ensure outcome–activity coherence; and (3) authentic assessment practices (formative, performance-based and context-rich) that reinforce motivation and meaningful learning. Evidence indicates that CA can reliably bridge curriculum intentions with classroom practices, improving the validity of tasks and the depth of student learning. However, persistent challenges include limited teacher readiness, misalignment between curriculum standards and assessment demands, and a shortage of validated instruments to evaluate alignment quality and its effects. The review recommends sustained professional development in CA design, development and validation of multi-dimensional measurement tools, and integration of CA principles into policy and curriculum reforms. Overall, adopting CA as a guiding framework particularly in secondary science can enhance HOTS, motivation and learning quality within and beyond Malaysia.

Keywords: constructive alignment; science education; higher-order thinking skills; motivation; pedagogy; curriculum; assessment.

INTRODUCTION

The global shift towards competency-based education, particularly under the influence of the Fourth Industrial Revolution, has highlighted the importance of pedagogical frameworks that ensure coherence between intended learning outcomes, teaching strategies, and assessment practices [6], [10],[19]. Within this context, constructive alignment (CA), first introduced by Biggs, has become a pivotal framework in science education. CA promotes consistency between curriculum goals, instructional methods, and assessment strategies to support meaningful and student-centered learning [1],[3]. Over the last two decades, CA has been increasingly adopted in STEM education as a means of fostering higher-order thinking skills (HOTS), scientific literacy, and student motivation—three essential elements of 21st-century education [5],[14].

LITERATURE REVIEW

Scholarly interest in CA has grown substantially, especially with the integration of inquiry-based, gamified, and project-based learning approaches that encourage active participation and deeper understanding [7],[16]. These strategies demonstrate how CA strengthens the alignment between curriculum design and classroom practice, while also enhancing the validity of assessment tasks and ensuring that learning activities are outcome-driven. Furthermore, the COVID-19 pandemic accelerated the adoption of CA-based approaches, as educators sought to realign curriculum delivery with digital tools, simulations, and virtual laboratories [13],[21]. This adaptation underscored the flexibility of CA in supporting blended and online learning while maintaining engagement and measurable learning outcomes [3], [21].

Internationally, countries such as Indonesia, the United States, and Germany have contributed significantly to CA research, with applications spanning both secondary and higher education [9], [15]. Studies have also expanded across diverse science domains including biology, chemistry, and environmental science emphasizing collaborative learning, critical thinking, and formative assessment as integral components of aligned instruction [6], [12]. These developments suggest that CA is not only a theoretical framework but also a practical tool for improving instructional coherence and equity in science education.

Despite these advances, several gaps remain. Existing literature has yet to fully examine how CA impacts specific outcomes such as scientific argumentation, critical reasoning, and self-directed learning across varied contexts [4],[18]. Moreover, research often lacks validated instruments, comprehensive demographic analyses, and cross-regional perspectives, particularly in Southeast Asia. Given these limitations, analysis provides a systematic means of mapping the evolution of CA scholarship, identifying influential publications, leading authors, and emerging research themes from 2000 to 2025. Accordingly, this study employs bibliometric and network analysis techniques using tools such as Bibliometrix®, VOSviewer, and OpenRefine to analyze Scopus-indexed publications.

The objective is to synthesize empirical evidence on how constructive alignment functions as a pedagogical framework that enhances student motivation and higher-order thinking in science classrooms.

METHODOLOGY

This analysis was conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The review focused on publications addressing constructive alignment (CA) in science education between 2000 and 2025. This analysis was selected as the methodological approach because it allows for the systematic identification, selection, and evaluation of research outputs, thereby providing a transparent and replicable overview of the intellectual structure of the field.

Database Selection

The Scopus database was used as the primary data source for this study, as it is widely recognized for its comprehensive coverage of international, peer-reviewed academic publications [7]. A targeted search strategy was applied using the following 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. This strategy ensured the inclusion of studies that explicitly linked constructive alignment with higher-order thinking skills, science education, or related domains.

Inclusion and Exclusion Criteria

The research selection process was iterative and multi-staged. Initially, 176 documents were retrieved. the following inclusion and exclusion criteria were established to select studies relevant to answering the research questions. After applying these criteria, 20 documents remained for final analysis (see Table 1).

Table 1 Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed full-text research papers indexed in Scopus.	Non-empirical papers such as editorials, reviews, and conference abstracts.
Published between 2000 and 2025.	Publications outside the specified time range.
Focused on constructive alignment, curriculum alignment, or student-centred learning in science or biology education.	Studies focusing exclusively on primary education or unrelated educational fields.
Written in English.	Written in other language
Empirical studies	Literature review, meta – analysis paper

Data Cleaning and Quality Assurance

To ensure the reliability and validity of the selected studies, a systematic quality assessment procedure was employed. Each article was evaluated against ten predefined quality criteria (Table 2), adapted from [22]. These criteria assessed whether the study was relevant to constructive alignment, had clearly defined objectives and research questions, described instruments and samples appropriately, reported results and conclusions consistently, acknowledged limitations, and provided implications and directions for future research.

Table 2 Quality assessment criteria

Questions of quality assessment criteria
1. Is the research topic related to constructive alignment in science/biology education?
2. Are the research objectives clearly defined?
3. Are the research questions or hypotheses specified?
4. Is the instrument or framework clearly described and based on the study design?
5. Is the study sample (e.g., teachers, students, institutions) clearly described?
6. Are the research results adequately addressed in the study?
7. Are the conclusions clearly presented and consistent with the results?
8. Do the authors discuss the limitations of the study?
9. Are practical or theoretical implications for constructive alignment provided (e.g., for pedagogy, curriculum, or assessment)?
10. Are future research directions in constructive alignment suggested?

Source: Zhao, Llorente, Gomez (2021)

Articles were scored using a three-point scale: Yes (1 point), Partially (0.5 points), and No (0 points). Each study was independently reviewed by three assessors, and the final score was averaged. Following quality review standards, only articles scoring 7.5 or higher out of 10 were included in the final dataset. The initial search identified 176 records from Scopus. After removing 45 articles that were unrelated to the field (e.g., outside social sciences), 131 records proceeded to screening. Of these, 45 records were excluded due to irrelevance (40 through automation tools and 5 through manual checks of titles and abstracts). The remaining 86 articles were retrieved for full-text assessment, but 63 were excluded due to language (non-English), publication status (not yet finalized), or lack of relevance to constructive alignment. A total of 23 articles were assessed for eligibility, of which 20 met the quality threshold and were included in the final analysis. This process is illustrated in Figure 1 (PRISMA flow diagram). The final dataset of 20 articles forms the basis of this bibliometric analysis, providing a robust foundation for mapping research trends and thematic developments in constructive alignment within science education.

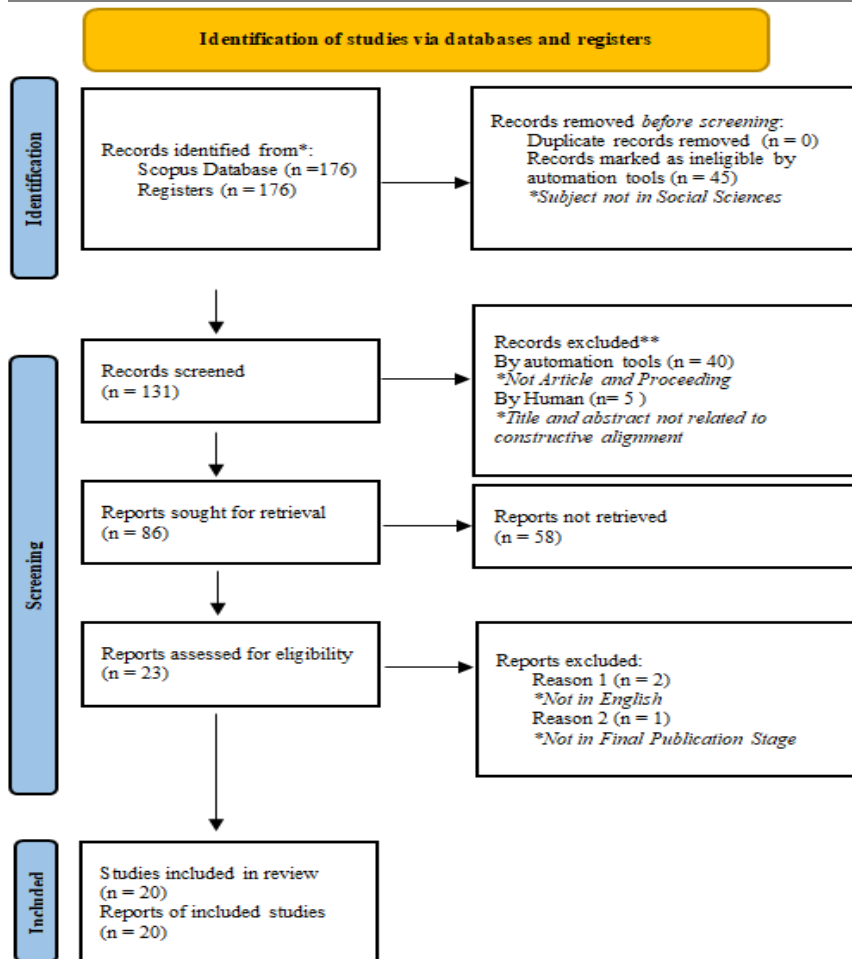


Figure 1. PRISMA flow of data extraction procedure

RESULTS

Research Themes on Constructive Alignment in Science Education

In the 20 selected articles, a clear trend emerges toward increasing depth and diversification of research themes on constructive alignment (CA) in science education. Based on thematic mapping and keyword co-occurrence analysis, the articles can be categorised into four primary themes: curriculum alignment, assessment practices, pedagogical strategies, and learner outcomes (Figure 2).

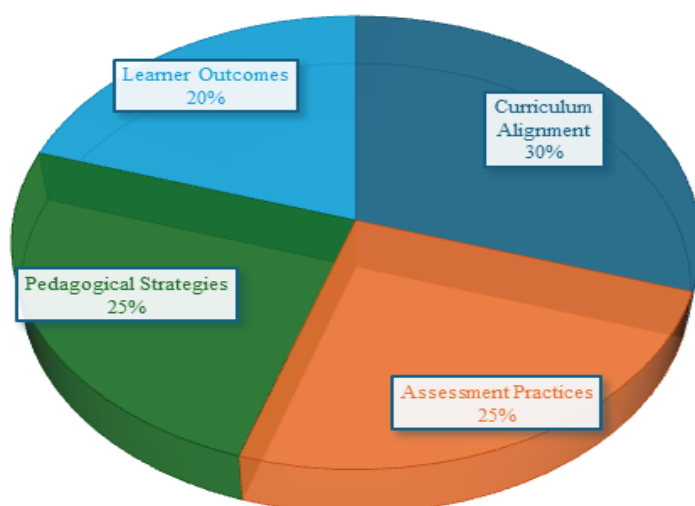


Figure 2. Different Research Themes on Constructive Alignment in Science Education

Articles focusing on curriculum alignment represent the largest segment, accounting for 30% of the dataset. These studies highlight the importance of aligning intended learning outcomes with teaching strategies and assessment to enhance higher order thinking skills in science education. The second major cluster is assessment practices, comprising 25% of the studies. These articles examine authentic, performance-based, and formative assessments that reinforce higher-order thinking skills (HOTS) and provide reliable measures of student learning. The third theme, pedagogical strategies, accounts for 25% of the reviewed studies. This cluster includes inquiry-based learning, project-based tasks, and collaborative learning approaches that operationalise CA principles in classroom practice. Finally, learner outcomes constitute 20% of the studies, with a strong emphasis on higher-order thinking skills, scientific literacy, and student motivation.

The analysis of 20 selected articles revealed four major research themes on constructive alignment (CA) in science and Biology education: evaluating CA, relationship studies, comparative studies, and improving CA, with several studies addressing other specialised issues (Figure 2; Table 3). These themes highlight how CA has been applied, evaluated, and adapted across diverse educational contexts, reflecting both its theoretical grounding and practical implementation to increase higher order thinking skills and motivation among students.

Table 3 Different themes about constructive alignment

Theme	Sub-themes	References
Pedagogical Approaches and Teaching Methods	Constructivist Learning	Costabile et al. (2025); Bockholt et al. (2003); Ramaraj & Nagammal (2019)
	Inquiry-Based Learning	Morris (2025); Khurma & El Zein (2024)
	Active Learning Strategies	Sajidan et al. (2024); Cousins et al. (2012)
	Simulation-Based Teaching	Costabile et al. (2025)
	Collaborative Learning	Sajidan et al. (2024)
Critical Thinking and Higher-Order Skills	Critical Thinking Development	Khurma & El Zein (2024); López-Fernández et al. (2022); McBain et al. (2020); Lundstedt & Sinander (2020)
	Problem-Solving Skills	López-Fernández et al. (2022); McBain et al. (2020)
	Systems Thinking	Blatti et al. (2019)
Technology Integration in STEM Education	Augmented Reality and Gamification	Lampropoulos et al. (2023)
	Multimedia Learning	Bockholt et al. (2003)
	Digital Tools and Platforms	Lampropoulos et al. (2023)
Assessment and Evaluation	Constructive Alignment	Lipuma et al. (2024)
	Rubric Development	Rembach & Dison (2016)
	Skills Assessment	Cousins et al. (2012)
Inclusive and Diverse Learning	Supporting Diverse Learners	Kim & Kim (2024); Palmer & Sarju (2022)
	Inclusive Education Practices	Palmer & Sarju (2022); Rembach & Dison (2016)
	Writing-to-Learn Strategies	Kim & Kim (2024)
Real-World Application and Experiential Learning	Field Trips and Work Immersion	Acut (2024)
	Outreach Activities	Palmer & Sarju (2022); Blatti et al. (2019)
	Authentic Learning Experiences	Acut (2024)
Teacher Professional Development	Teacher Beliefs and Practices	Ambusaidi et al. (2021)
	Curriculum Implementation	Ambusaidi et al. (2021)
	Self-Directedness	Sajidan et al. (2024)

Communication and Presentation Skills	Oral Presentations	Lipuma et al. (2024)
	Scientific Communication	Blatti et al. (2019)
Curriculum Design and Structure	Module Development	Othman et al. (2022); Bockholt et al. (2003)
	Course Structure	Costabile et al. (2025); Schmidt et al. (2015)
	Reform-Oriented Curriculum	Ambusaidi et al. (2021)
Subject-Specific Approaches	Chemistry Education	López-Fernández et al. (2022); Palmer & Sarju (2022)
	Biology Education	Ambusaidi et al. (2021); Bockholt et al. (2003); Cousins et al. (2012)
	Computer Science Education	Lampropoulos et al. (2023)
	Design Education	Ramaraj & Nagammal (2019)

The evaluation of CA emerged as one of the most prevalent themes, represented by seven articles. These studies assessed CA across various pedagogical approaches, including constructivist learning [2], [4],[17], inquiry-based learning [4], [14], and active learning strategies such as collaboration, simulation, and project work [6],[19]. Collectively, these evaluations confirmed the effectiveness of CA in enhancing curriculum coherence, fostering deep learning, and strengthening assessment validity. Importantly, more recent studies have shifted from conceptual discussion to empirical evaluation, demonstrating a growing interest in measuring CA's impact in authentic classroom contexts.

DISCUSSION

This systematic review provides a comprehensive overview of the evolution of Constructive Alignment (CA) research in science education over the past 25 years. The findings reveal a progression from foundational theoretical work to sophisticated, technology-integrated applications, illustrating how CA has matured into both a pedagogical framework and an institutional strategy. The discussion highlights shifts in research themes, instrument sophistication, and strategies for enhancing CA implementation.

The Onion Framework of Constructive Alignment

Building on prior uses of layered competence models in digital education [20], this review adapts the onion framework to constructive alignment in STEM education (Figure 4). The framework illustrates how CA has evolved from a narrow focus on core competences learning outcomes and curriculum objectives toward extended competences involving pedagogy and assessment practices, and ultimately into special competences encompassing teacher beliefs, professional development, and institutional policies. This layered representation highlights the progression of CA research from classroom level enactments to systemic educational integration, underscoring its potential as both a pedagogical and institutional strategy.

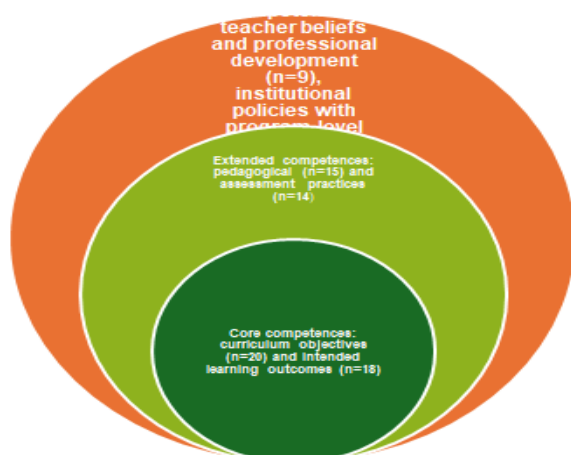


Figure 4. Onion framework of constructive alignment

(Source: Adapted from Saunders et al., 2019)

The framework conceptualizes CA across three interconnected layers. Core competences represent the foundation of CA, focusing on curriculum objectives and intended learning outcomes ($n=20$; $n=18$). Extended competences capture the pedagogical and assessment practices ($n=15$; $n=14$) that operationalize alignment in classroom instruction. Special competences represent broader systemic and contextual dimensions, including teacher beliefs, professional development ($n=9$), and institutional policies with program-level integration ($n=7$). This layered structure illustrates the progression of CA research from narrow classroom applications to holistic educational systems, highlighting its role in fostering coherence across teaching, learning, and institutional practice.

The review underscores that constructive alignment (CA) has evolved beyond Biggs' original conception into a comprehensive pedagogical framework that systematically enhances motivation and higher-order thinking in science classrooms. The adapted onion model of CA illustrates how core competencies such as learning outcomes and curriculum objectives are connected with extended competencies, including assessment design and pedagogical strategies, and further supported by special competencies related to teacher professional development and institutional coherence. This multilayered reconceptualization positions CA not merely as a classroom-level instructional design model but as a systemic driver of educational alignment that bridges curriculum, pedagogy, and assessment across contexts. Moreover, by integrating constructivist learning theory, socio-scientific inquiry, and technology-enhanced pedagogy, CA demonstrates its versatility in fostering student engagement, critical reasoning, and motivation in dynamic science learning environments.

Strategies for Improving Constructive Alignment

The review identifies several effective strategies for strengthening CA implementation. Technology-mediated approaches align digital platforms and immersive tools with learning outcomes and assessment criteria [2], [9]. Collaborative learning frameworks such as the Think-Pair-Project-Share model emphasize structured peer learning and reflection, reinforcing the alignment of outcomes, pedagogy, and assessment [19]. Authentic assessment approaches, including field immersion and socio-scientific issues enhance transfer and relevance by embedding CA principles in real world contexts [1], [16].

The onion framework underscores that CA should not be limited to classroom-level practices but extended to institutional and systemic integration. Theoretically, it positions CA as both a pedagogical design principle and a systemic alignment logic for curriculum policy. In practice, it highlights the importance of continuous faculty development, coherent program level design, and context-sensitive adaptation. For policy, the framework signals that systemic coherence in CA including curriculum standards, assessment consistency, and institutional support is critical to achieving lasting impact on science education outcomes. This holistic view provides a roadmap for future research and practice, emphasizing the need for longitudinal, cross-cultural, and technology-integrated studies to advance CA's impact.

The implications of these findings are significant. First, CA has proven effective in enhancing higher-order thinking, motivation, and authentic skill development across science education, but its success depends on institutional support, teacher readiness, and context-specific adaptation. Faculty development, resource allocation, and systemic integration remain crucial levers for sustainable implementation [2], [20]. Finally, future research should prioritize longitudinal studies, cross-cultural validation, and the development of standardized CA instruments. Such directions will ensure that CA continues to evolve as a robust framework for 21st-century education, capable of bridging theory and practice while preparing learners for increasingly complex and technology-rich environments.

CONCLUSION

This systematic review has provided a comprehensive analysis of 25 years of research on Constructive Alignment (CA) in science education, tracing its trajectory from early conceptual validation to technology enhanced, system-wide applications. The findings reveal how CA has evolved into a mature pedagogical framework that not only integrates outcomes, pedagogy, and assessment but also extends into teacher beliefs, institutional policies, and program-level coherence. By synthesizing evidence from 20 key studies, this review underscores the significance of CA in promoting higher-order thinking skills, motivation, and authentic learning experiences.

While this review provides a broad overview, several limitations should be acknowledged. First, the study was restricted to 20 selected articles, which may not capture all global perspectives on CA, particularly from underrepresented regions. Second, although the review emphasizes science education, much of the evidence is still concentrated in higher education, with relatively fewer studies in secondary school contexts where CA implementation faces unique challenges. Third, many of the instruments reviewed remain researcher-developed and context-specific, which limits their transferability across settings and weakens cross-study comparisons. Finally, the review does not fully explore the intersection of CA with non-STEM disciplines, which could offer valuable insights into its broader applicability.

Future research should address these gaps by pursuing three key directions. First, there is a need for longitudinal and cross-cultural studies that examine the sustained impact of CA across diverse contexts, including secondary and vocational education. Such studies could clarify how systemic alignment influences long-term learning outcomes and career readiness. Second, researchers should prioritize the development and validation of standardized CA instruments that capture multi-dimensional outcomes, enabling comparability across studies and contexts. Third, more work is required on strategies to enhance CA implementation, particularly in technology-rich and resource-constrained environments. This includes investigating the integration of CA with emerging technologies (e.g., AI, AR/VR, gamification), professional development frameworks for teachers, and policy-level initiatives that promote systemic coherence. By advancing research in these areas, scholars and practitioners can ensure that CA continues to evolve as a robust, scalable framework for transforming science education and preparing learners for the demands of the 21st century.

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