HYDROGEN
JURNAL KEPENDIDIKAN KIMIA
https://e-journal.undikma.ac.id/index.php/hydrogen/index

February 2026. 14(1)
e-ISSN: 2656-3061
p-ISSN: 2338-6487
pp. 125-140

Ethno-STEAM/STEM in Chemistry Education: A Literature Review of Instructional Models, Digital Learning Resources, and Their Effects on Chemical Literacy and Critical Thinking

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Article History
Received: 21-01-2026
Revised: 12-02-2026
Published: 28-02-2026

Keywords: Ethno-STEAM/STEM; Chemistry Education; Chemical literacy; Critical Thingking.

Abstract
This study presents a literature review of Ethno-STEAM/Ethno-STEM in chemistry education, focusing on instructional models, digital learning resources, and reported effects on chemical literacy and critical thinking from 2021 to 2025. The review employed a systematic search, screening, and selection procedure aligned with the PRISMA 2020 guideline, followed by a qualitative synthesis using thematic analysis and narrative comparative synthesis. Searches were conducted in Scopus (n = 10), Web of Science (n = 10), and SINTA (n = 30). Following PRISMA 2020, 50 records were identified, 12 duplicates were removed, 38 records were screened by title and abstract, 22 full texts were assessed for eligibility, and 15 studies were included in the qualitative synthesis. The findings indicate that the corpus is dominated by development-oriented (R&D) studies emphasizing the design of digitally supported learning resources, most commonly e-modules and e-worksheets/e-LKPD, alongside a smaller number of empirical studies and review evidence (SLR/meta-analysis). Ethno-STEAM/Ethno-STEM is opera-tionalized through multiple pedagogical pathways, primarily inquiry-based approaches (guided/blended inquiry), project/problem-based learning (PjBL/PBL), practicum-oriented learning (including e-lab designs), and culturally responsive teaching. Local wisdom and cultural practices are typically positioned as a contextual foundation for mapping cultural phenomena onto chemistry concepts and for structuring investigation, design, and communication tasks aligned with STEAM practices. Outcome synthesis suggests more consistent support for critical thinking improvement, whereas direct evidence for chemical literacy remains comparatively limited and constrained by variability in outcome measure-ment and reporting. The review highlights the need for more robust empirical evaluations with clearer reporting of instructional syntax and implementation fidelity, as well as more standardized measurement of chemical literacy and critical thinking.

How to Cite: Munawwarah, & Side, S. (2026). Ethno-STEAM/STEM in Chemistry Education: A Literature Review of Instructional Models, Digital Learning Resources, and Their Effects on Chemical Literacy and Critical Thinking. *Hydrogen: Jurnal Kependidikan Kimia*, *14*(1), 125-140. https://doi.org/10.33394/hjkk.v14i1.19392

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INTRODUCTION

Chemistry learning in the twenty-first century necessitates a shift beyond mere conceptual understanding, demanding an integrative application of chemical knowledge in real-life contexts. This transition is often hampered by the abstract nature of chemistry, where many students struggle to coordinate the macroscopic, submicroscopic, and symbolic representations of chemical phenomena effectively. Research has shown that employing systems thinking in chemistry education can address these challenges, emphasizing the interconnectedness of chemical concepts and real-world applications (Aubrecht et al., 2019; York & Orgill, 2020).

For instance, Sinaga et al. (2019) demonstrated that innovative learning materials significantly enhance student engagement and competence in chemistry, thereby fostering a more profound understanding of the subject. Moreover, utilizing inquiry-based models has been shown to improve critical thinking and problem-solving skills among chemistry students, further bridging the gap between abstract knowledge and practical application (Purwandari et al., 2022). Furthermore, the incorporation of collaborative learning, such as peer support during laboratory experiences, has been indicated as a critical factor contributing to students' overall satisfaction and success in chemistry courses (Huangfu et al., 2025). Ultimately, modern chemistry education must embrace these strategic pedagogical innovations to cultivate not only a comprehensive understanding of chemical principles but also the ability to employ this knowledge wisely in everyday situations (Flynn et al., 2019).

In response to these demands, STEAM (Science, Technology, Engineering, Arts, Mathematics) has gained prominence because it promotes interdisciplinary integration, creativity, problem solving, and the production of tangible artifacts. In chemistry education, STEAM can support more contextualized learning through design tasks, experimentation, modeling, and project work. A study conducted Ridwan et al. (2021) demonstrates that integrating STEAM through project-based learning can foster students' knowledge and skills by allowing them to investigate authentic, complex questions and challenges, ultimately leading to improved motivation and engagement in chemistry topics. Furthermore, Dios et al. discuss the need for flexibility in curricular structure to better connect classroom learning with students' environments, thereby enriching the educational experience (Queiruga et al. (2021). However, the effective implementation of STEAM does not occur automatically; educators must be mindful that such contexts resonate with students' cultural backgrounds. This is supported by Szozda et al. (2022) who emphasize that context-based learning can significantly enhance understanding in chemistry education. Moreover, research by Akatyev (2024) highlights the importance of making connections to students' daily lives to ensure that learning is relevant and engaging, which is critical for achieving the goals of STEAM education. Thus, while STEAM offers innovative avenues for chemistry learning, its success largely depends on the intentional inclusion of students' realities and experiences within the educational framework.

Within this context, Ethno-STEAM has emerged as an approach that integrates STEAM with local knowledge, cultural practices, and community-based wisdom as learning resources. The "ethno" dimension enables chemistry learning to become more relevant and socially grounded, while contributing to the recognition and preservation of culturally embedded scientific practices. Such integration can be enacted by selecting locally situated phenomena, such as traditional production processes, food practices, natural dyes, material processing, or community health practices, and connecting them explicitly to chemistry concepts. Advances in educational technology further expand the possibilities for implementing Ethno-STEAM.

For instance, research by Sumarni et al. (2023) demonstrates that blended inquiry learning combined with an Ethno-STEM approach enhances first-semester students' chemical literacy by contextualizing chemistry learning. Similarly, the research illustrate how incorporating ethnoscience into digital learning platforms promotes critical thinking among future science educators by allowing them to reflect on the intersection of scientific norms and local knowledge (Prayogi et al., 2023).

Furthermore, a study emphasizes that chemistry teachers' understanding of ethnoscience is vital for effectively integrating STEM and enhancing student engagement in chemistry (Fitriyana et al., 2021). Over the past five years, studies have increasingly employed digital learning resources such as e-modules, e-worksheets (e-LKPD), e-laboratory environments, microblog-based learn-ing media, and augmented reality to package cultural contexts and STEAM activities in more interactive formats. Digital resources are considered promising as they can support visualization of chemical processes, provide multimodal learning stimuli, facilitate indepen-dent and blended learning, and enhance engage-ment through structured inquiry and project tasks.

Nevertheless, the existing literature suggests that research on Ethno-STEAM in chemistry learning remains dispersed across multiple emphases, ranging from instructional material development and the selection of learning models (e.g., inquiry, guided inquiry, project-based learning) to the measurement of outcomes such as chemical literacy, critical thinking, scientific attitudes, or character. Many publications prioritize development outputs (e.g., validity and practicality) or report learning gains, yet they do not consistently provide a comprehensive account of learning processes, how Ethno-STEAM is operationalized through instructional syntax, how STEAM activities are integrated with cultural content, and how digital media function pedagogically to strengthen learning experiences.

For instance, Irnawati & Rahmawan (2024) emphasized the importance of integrating local cultures into instructional materials to make chemistry concepts more relatable, proposing the development of Weebly-based learning media for Ethnochemical acid-base content, thus enhancing student engagement with local traditions and practices. Additionally, the study highlighted that digital instructional tools can significantly improve students' understanding of redox reactions, demonstrating that local cultural contexts can help concretize abstract scientific concepts and improve learning outcomes (Redhana et al., 2024).

Eka et al. (2023) explored how teachers perceive the integration of 21st-century skills in chemistry and advocated for the use of digital learning media to facilitate concrete understanding in a subject known for its abstract nature. Furthermore, Widiana et al. (2021) illustrated the effectiveness of project-based learning in fostering nationalism and learning achievements among students, reinforcing the need for active engagement in learning processes that connect scientific concepts with students' cultural backgrounds. This demonstrates the pressing need for a more structured approach that not only develops instructional materials but also clearly articulates the pedagogical strategies employed within Ethno-STEAM initiatives.

Addressing these gaps, the novelty of the present review lies in its more focused and integrated synthesis. Rather than summarizing Ethno-STEAM studies broadly, this review examines (a) the range of instructional models employed, (b) the characteristics of digital learning resources developed and implemented, and (c) the evidence of their effects on chemical literacy and critical thinking in chemistry learning. This approach is expected to clarify what is most frequently used, how it is implemented, and what outcome patterns emerge in the 2021–2025 evidence base.

Accordingly, this study aims to conduct a literature review of Ethno-STEAM in chemistry education from 2021 to 2025 by analyzing: (1) the dominant instructional models (e.g., inquiry, guided inquiry, PjBL, blended learning) and how they are operationalized; (2) the types and pedagogical features of digital learning resources employed (e.g., e-modules, e-worksheets/e-LKPD, e-labs, AR) and their roles in learning; and (3) empirical findings on the effects of Ethno-STEAM on chemical literacy and critical thinking. The findings are expected to inform researchers and practitioners in designing more purposeful, effective, and culturally relevant Ethno-STEAM-based chemistry instruction.

METHOD

This study employed a literature review design using a systematic search and screening procedure followed by narrative–thematic synthesis. The study selection and reporting were aligned with the PRISMA 2020 guideline to ensure transparency and reproducibility in identifying, screening, assessing eligibility, and including studies. The review focused on the implementation of Ethno-STEAM/Ethno-STEM in chemistry education, with particular attention to instructional models, digital learning resources, and their reported effects on chemical literacy and critical thinking within the period 2021–2025.

The literature search was conducted across three principal databases to capture both internationally reputable and nationally accredited publications in chemistry education. International coverage was obtained through Scopus and Web of Science (WoS), while Indonesian nationally accredited journal publications were identified through SINTA. The search was restricted to studies published between 2021 and 2025 to reflect the most recent five-year evidence base on Ethno-STEAM/Ethno-STEM in chemistry learning and to ensure that the included studies had traceable publication records.

Studies were eligible for inclusion if they were published between 2021 and 2025, focused explicitly on chemistry learning/chemistry education at the secondary or higher-education level, and used the terms ethno-STEAM/ethno-STEM/etno-STEAM/etno-STEM in the title, abstract, or keywords with clear evidence that the approach was operationalized within the instructional design.

Eligible studies also needed to report at least one of the review's focal dimensions: an instructional model or learning syntax (e.g., inquiry, guided inquiry, PjBL, blended learning, or laboratory/practicum learning), a form of digital learning resource (e.g., e-modules, e-worksheets/e-LKPD, e-laboratory, microblog, or augmented reality), and/or outcomes directly linked to chemical literacy and/or critical thinking. In addition, each study had to be accessible in full text and provide a verifiable DOI and/or an official journal/publisher link to support traceability.

Studies were excluded if they addressed STEAM/STEM in a general sense without a clear chemistry learning focus, if they were non-empirical publications without instructional implementation (such as popular commentaries) or conference abstracts lacking full text, if they mentioned "ethno" and "STEM/STEAM" without demonstrating their integration in the learning process, or if they could not be verified due to invalid DOI/link or inaccessible full text that prevented assessment of methods and results. Study selection followed PRISMA 2020 stages that is shown in Figure 1.

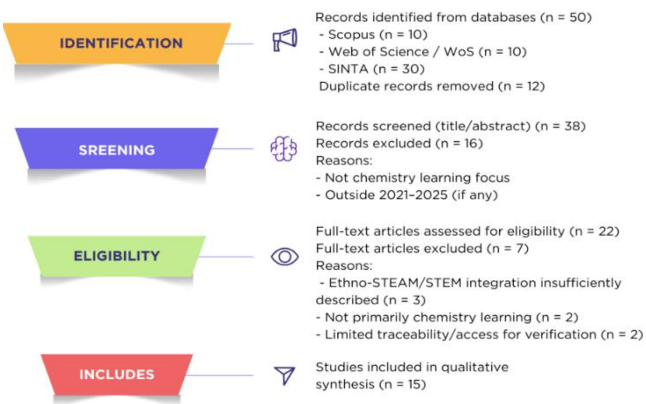

Figure 1. PRISMA 2020 Flowchart for Study Selection in The Review of Ethno-STEAM/Ethno-STEM in Chemistry Education

Data extraction was conducted using a structured extraction form to ensure consistency across studies, as commonly recommended in systematic and narrative reviews to enhance transparency and replicability (Peters et al., 2015). For each article, bibliographic information (author, year, title, journal, and DOI/link) and indexing category (nationally accredited vs internationally reputable) were recorded, followed by methodological characteristics such as study type (R&D, experimental/quasi-experimental, mixed methods, SLR/meta-analysis), research design, educational level, sample size, and the chemistry topic or content focus.

To support methodological transparency, the extraction also included a basic consideration of study characteristics relevant to the strength of evidence, acknowledging differences in inferential capacity among study types (Gough et al., 2017). In particular, R&D studies were interpreted as providing evidence of feasibility and instructional potential, whereas quasi-experimental and meta-analytical studies offer stronger support for effectiveness claims (Creswell & Plano Clark, 2018). The extraction emphasized the review's analytical focus by documenting the instructional model and its syntax, the type and features of digital learning resources, and the manner in which the ethno dimension was integrated. Outcome measures related to chemical literacy and critical thinking were captured in terms of operational definitions, indicator sets, and assessment formats, while explicitly noting variations in conceptual frameworks and measurement approaches across studies (Facione, 2015; OEC, 2019).

Findings were synthesized using thematic analysis to identify recurring patterns across studies (Braun & Clarke, 2006), followed by a narrative comparative synthesis to examine relationships among instructional models, digital resources, ethno integration modes, and targeted outcomes. Cross-study comparisons were conducted by educational level, chemistry topic, and implementation characteristics such as duration, task or product requirements, and assessment approaches. The synthesis also considered methodological limitations of the evidence base, including variability in study designs, sample sizes, outcome definitions, and reporting completeness, consistent with recommendations for narrative evidence synthesis (Gough et al., 2017). This review used secondary data from publicly available scholarly publications and did not involve direct human participant research; therefore, ethical approval wasn't required (Resnik, 2018). Academic integrity was maintained through accurate reporting and appropriate citation of original studies.

RESULTS AND DISCUSSION

Profile of Research Designs, Instructional Models, and Digital Resources

This section provides an overview of the study characteristics within the evidence base on Ethno-STEAM/Ethno-STEM in chemistry education published between 2021 and 2025. At this stage, the review aims to map the landscape of the included literature by identifying prevailing research designs, the range of instructional approaches adopted to operationalize

Ethno-STEAM/Ethno-STEM, and the extent to which digital learning resources are incorporated to support chemistry learning. Establishing these study characteristics is essential before examining implementation patterns and learning effects, because it situates subsequent interpretations within the structure and scope of the available evidence. By clarifying which study designs and pedagogical models dominate the corpus, the review can more appropriately weigh the strength and comparability of findings, while also revealing underexplored areas, particularly those related to the consistency of instructional process reporting and the alignment among instructional strategies, digital resources, and outcomes such as chemical literacy and critical thinking.

Table 1 summarizes the characteristics of the 15 studies included in this review on Ethno-STEAM/Ethno-STEM in chemistry education published between 2021 and 2025. Overall, the corpus consists of a mixture of empirical studies, development-oriented research (R&D), and review-based evidence (SLR/meta-analysis), reflecting both implementation-focused inquiries and synthesis efforts within the recent literature.

Across the included studies, Ethno-STEAM/Ethno-STEM has been investigated in diverse chemistry topics, with frequent attention to core secondary and introductory university content (e.g., acid–base, reaction rate, redox, organic chemistry, and green chemistry). In addition, most studies explicitly linked Ethno-STEAM/Ethno-STEM to student competencies that extend beyond conceptual understanding, including chemical literacy, critical thinking, HOTS, metacognition, and character-related outcomes.

Tabel 1. Characteristics of the Included Studies (n = 15)

Year	Short Title	Study Type	Chemistry Topic	Instructional Model	Digital Learning Resource	Key Outcome(s) Reported	DOI / Official Link
2021	Ethno-STEM Integrated PjBL	Empirical	Chemistry learning (NR)	Project-based learning	None/ NR	Critical & creative thinking	10.21580/jec.2021.3.1.6574 (Ariyatun, 2021)
2023	Blended Inquiry + Ethno-STEM for Chemical Literacy	Empirical	General chemistry (first semester)	Blended inquiry	None/ NR	Chemical literacy	10.15294/jpii.v12i3.45879 (Prayogi et al., 2023)
2023	Ethnoscience + PBL (Buffer Solution)	Empirical	Buffer solution	Problem-based learning	None/ NR	Scientific reading (as reported)	10.29303/jppipa.v9i7.1612 (Siti Nur Ni'mah & Faiq Makhdum Noor, 2023)
2023	PjBL Chemistry + (secondary metabolites)	Empirical	Secondary metabolites	Project-based learning	None/ NR	Conservation & entrepreneurial character	10.3926/jotse.1792 (Sudarmin et al., 2023)

Year	Short Title	Study Type	Chemistry Topic	Instructional Model	Digital Learning Resource	Key Outcome(s) Reported	DOI / Official Link
2023	SLR: Ethno-STEM & Chemistry Literacy	Review (SLR)	Chemistry literacy	Review synthesis	None	Mapping/profile of chemical literacy	10.29303/jppipa.v9i2.2559 (Primadianningsih et al., 2023)
2023	Etno-STEAM e-Module (Batik context)	R&D	Solution-related topic (NR)	NR	E-module	Learning outcomes (NR)	10.15294/chemined.v12i1.59507
2023	Ethno-STEAM Electronic Worksheet	R&D	NR	Project-oriented learning (NR)	E-worksheet / e-LKPD	Numeracy literacy; conservation character	10.30870/educhemia.v8i2.21554 (Apriliani et al., 2023)
2024	PBL Worksheet + Ethnoscience (Acid–Base)	R&D / trial (NR)	Acid–base	Problem-based learning	Worksheet / e-LKPD (NR)	Learning outcomes (NR)	10.29303/jppipa.v10i7.7930 (Marthin et al., 2024)
2024	Local Wisdom in Chemistry Learning (Ethnoscience)	Review	Chemistry learning	Review synthesis	None	Implementation patterns & challenges	10.30605/jsgp.7.3.2024.4801 (Cahyani & Fadly, 2024)
2024	Green Chemistry e-Module (Ethno-STEM)	R&D	Green chemistry	Guided inquiry	E-module	Critical thinking (primary)	10.15294/jipk.v18i1.46536 (Karpudewan, 2024)
2024	Ethno-STEM Acid–Base Practicum e-Laboratory	R&D	Acid–base practicum	Practicum/lab learning	E-laboratory instruction	Practicality/feasibility; learning support	10.26740/jppipa.v9n2.p55-64
2024	Meta-analysis: Ethno-STEM & Critical Thinking	Review (Meta)	Chemistry learning	Review synthesis	None	Critical thinking (effectiveness)	10.29303/jppipa.v9iSpecialIssue.6422
2025	Ethno-STEM e-Module (Reaction	R&D	Reaction rate	NR	E-module	HOTS; scientific attitude	10.23887/jpki.v9i1.103020

Year	Short Title	Study Type	Chemistry Topic	Instructional Model	Digital Learning Resource	Key Outcome(s) Reported	DOI / Official Link
	Rate; Toraja context)						
2025	CRTT e-LKPD for Redox	R&D	Redox	CRTT (culturally responsive transformative teaching)	e-LKPD	Learning outcomes (NR)	10.21831/jpms.v13i2.86707
2025	Smart Ethno-STEM Mobile AR (Organic Chemistry)	R&D / trial (NR)	Organic chemistry	AR-supported Ethno-STEM learning (NR)	Mobile AR	Metacognition; literacy (NR)	10.29303/jppipa.v11i12.12998

In terms of instructional design, Table 1 indicates that Ethno-STEAM/Ethno-STEM is operationalized through multiple pedagogical pathways, most commonly inquiry-oriented approaches (including blended inquiry and guided inquiry) and problem/project-based learning, alongside culturally responsive models and technology-supported practicum designs. A notable pattern is the recurring use of digital learning resources—particularly e-modules, e-worksheets/e-LKPD, e-laboratory instructions, and mobile AR—suggesting that recent research frequently positions digital tools as scaffolds for integrating cultural contexts with STEM/STEAM learning activities. To further clarify how these instructional approaches are distributed across the evidence base and how they relate to study types, the following section visualizes the distribution of included studies by instructional model category and study type (Figure 2). Figure 2 illustrates the distribution of the 15 included studies by instructional model category and study type (R&D/development, empirical, and review).

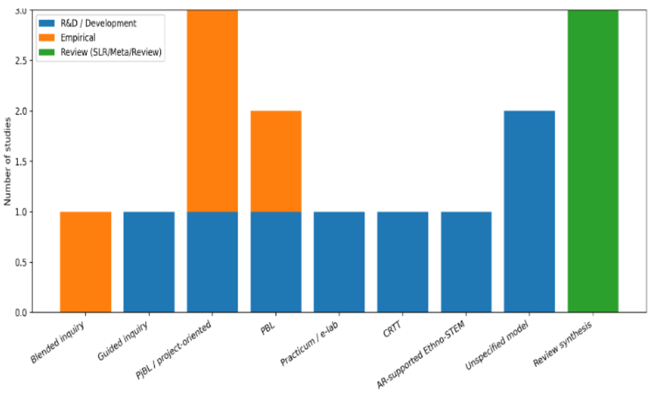

Figure 2. Distribution of Includes Studies by Instructional Model and Study Type (n = 15)

The overall pattern shows a clear dominance of development-oriented research across most model categories, with empirical studies appearing in fewer categories and review studies concentrated in the "review synthesis" category. Project-oriented approaches (particularly project-based learning) appear more frequently than several other single categories, while technology-supported and culturally responsive approaches (e.g., AR-supported Ethno-STEM, practicum/e-lab learning, and CRTT) are represented by a smaller number of studies, indicating emerging but still limited evidence in these areas.

Taken together, Table 1 and Figure 1 suggest that the Ethno-STEAM/Ethno-STEM literature in chemistry education during 2021–2025 is largely shaped by a developmental trajectory. The predominance of research and development

(R&D) studies indicates that researchers have prioritized designing and validating learning resources, such as e-modules, e-worksheets/e-LKPD, and technology-enhanced materials, often alongside limited-scale trials. While this contributes valuable instructional prototypes and demonstrates feasibility, it also implies that the evidence base may be less mature regarding robust effectiveness testing across varied classrooms and broader populations.

Consequently, interpretations of impact should be made cautiously, particularly when outcomes are reported from small-scale implementations or short-term trials. Additionally, a systematic literature review by Leavy et al. (2023) highlights the emerging trend of integrating digital technologies within STEAM education, emphasizing the need for comprehensive studies that go beyond simple efficacy claims to explore the contextual implementation of these tools in diverse educational settings.

Moreover, the research indicates that STEAM activities not only motivate students but also enhance their overall learning experiences, thereby underscoring the importance of longitudinal studies to ascertain the lasting effects of Ethno-STEAM interventions on student outcomes (Hsiao & Su, 2021). Furthermore, another study supports the assertion that engaging instructional designs focusing on Ethno-STEAM can increase students' creative thinking, thus calling for detailed accounts of pedagogical practices to evaluate their effectiveness (Ahmad et al., 2021).

A second implication concerns the diversity of instructional models used to operationalise Ethno-STEAM/Ethno-STEM in chemistry learning. Inquiry-oriented approaches (including guided and blended inquiry), PBL/PjBL frameworks, and practicum-based designs repre-sent different pedagogical routes for integrating cultural contexts with scientific practices. This diversity is promising because it suggests conceptual flexibility: ethno contexts can be embedded into investigation cycles, problem-solving scenarios, or design-and-produce projects.

However, Table 1 also indicates that not all studies report instructional syntax with comparable detail (several are marked NR), which limits cross-study comparability. In practice, the strength of Ethno-STEAM/Ethno-STEM does not merely depend on the presence of local context, but on how that context is systematically translated into learning tasks, representations, and assessment opportunities within the instructional sequence.

Finally, Table 1 indicates that digital learning resources are frequently positioned as scaffolds for implementing Ethno-STEAM/Ethno-STEM, while Figure 1 shows that technology-supported categories are still represented by relatively few studies. This suggests a dual pattern: digital tools are widely adopted (e-modules and e-worksheets are common), but evidence for more specialized technologies (e.g., mobile AR and structured e-lab designs) remains limited and unevenly distributed across models.

Moreover, although outcomes such as chemical literacy and critical thinking align well with the goals of Ethno-STEAM/Ethno-STEM, the studies vary in the extent to which outcome measurement is clearly operationalized and anchored to established indicator frameworks. This variation points to an important research need future work should expand empirical evaluations (beyond R&D feasibility) and standardize reporting of instructional implementation and outcome instruments, so that the field can move toward more cumulative and comparable evidence.

Notably, Gale et al. (2020) emphasize the importance of curriculum implementation frameworks to foster the effective integration of STEM education, which can enhance the potential of digital tools in Ethno-STEAM contexts. Yulkifli et al. (2022) further demonstrate that utilizing Ethno-STEM approaches in e-modules significantly boosts student engagement and learning outcomes, highlighting an area needing deeper investigation. Additionally, research by Sumarni & Kadarwati (2020) indicates that project-based learning rooted in Ethno-STEM not only improves critical thinking skills but also emphasizes the necessity for well-defined outcome measures to assess effectiveness accurately. These studies collectively call for a more standardized approach in employing digital technologies and measuring their impacts in Ethno-STEAM settings.

Operationalization of Ethno-STEAM/Ethno-STEM in Chemistry Learning

Building on the study-characteristics overview, the next step is to examine not only which instructional approaches and digital resources were used, but also how Ethno-STEAM/Ethno-STEM was concretely enacted in chemistry learning activities. Given the diversity of designs identified in the included corpus, understanding operationalization is essential to interpret outcomes more meaningfully—because the impact of Ethno-STEAM/Ethno-STEM depends on how cultural contexts are selected, how they are mapped to chemistry concepts, and how they are translated into inquiry, project/design, or practicum tasks supported by digital scaffolds.

Accordingly, Table 2 synthesizes the implementation patterns across the 15 studies by detailing the cultural/ethno anchors employed, the targeted chemistry topics, the dominant learning activity structures, the resulting learning artifacts or products, and the forms of digital support used to facilitate the Ethno-STEAM/ Ethno-STEM learning process.

Table 2. Operationalization of Ethno-STEAM/Ethno-STEM in Chemistry Learning

Year	Ethno source / cultural context	Chemistry concept(s)/topic	Instructional activity pattern (STEAM tasks)	Learning artifact / product	Digital support
2021	NR (ethno context not specified in available metadata).	Chemistry learning	Ethno-STEM integrated Project-Based Learning (PjBL) (implementation details not fully reported in accessible metadata).	Project/product outputs	NR
2023	Community ethno-practices as contextual triggers (e.g., fermentation/food preservation, composting, traditional industries such as batik) integrated into General Chemistry learning contexts.	General Chemistry (first-semester teacher education; multiple topics across the semester, including chemical reactions and related foundational concepts).	Blended Inquiry Learning integrated with Ethno-STEM (BIL–Ethno-STEM) using WSU-Ethno-STEM stages: lecturers introduce a community phenomenon; students orient to culturally contextual problems; formulate hypotheses; plan and conduct observation/experimentation linked to local wisdom; reconstruct and analyze findings; and communicate results through reports/presentations in a blended (online–offline) inquiry cycle.	Inquiry products (written reports, oral presentations) and documented solutions/argumentation addressing the culturally contextualized chemistry problems.	Synchronous and asynchronous platforms (e.g., video conference/online chatrooms; blogs; WhatsApp groups) to support discussion, reporting, and collaboration.
2023	Local batik-making practices and traditional essential-oil production as ethnoscience sources (e.g., field observation at a local batik industry and a traditional essential-oil industry).	Secondary metabolites course (essential oils and terpenes) with community knowledge reconstruction into scientific	Ethno-STEM integrated Project-Based Learning (PjBL): explore local wisdom (industry observation); reconstruct community knowledge into scientific concepts (e.g., via FGD); design and	Chemical batik products (motifs representing chemical structures of secondary metabolites) produced on canvas/cloth; project reports and presentations.	Learning media/tool support includes tutorial video(s) and project documentation; other digital platforms not explicitly foregrounded.

Year	Ethno source / cultural context	Chemistry concept(s)/topic	Instructional activity pattern (STEAM tasks)	Learning artifact / product	Digital support
		chemistry content.	plan a chemistry project; develop and iteratively refine a product; monitor progress and reflect; present and evaluate both process and product.		
2023	Systematic literature review (no single ethnocultural source).	Chemistry literacy (review focus).	PRISMA-guided SLR synthesis (no classroom implementation).	Review synthesis outputs.	NR
2023	Batik-based local wisdom as an Ethno-STEAM context (batik culture used as a contextual anchor).	Solution-related chemistry topic (as reported in study metadata).	Ethno-STEAM e-module learning sequence (module-guided exploration, contextual problem tasks, and STEAM-linked activities embedded in the e-module).	Ethno-STEAM e-module and completed in-module tasks.	E-module (digital module).
2023	Ethno-STEAM context integrating local culture into learning tasks (specific cultural artifact not detailed in available metadata).	NR (chemistry topic not specified in available metadata).	Ethno-STEAM electronic worksheet activities (project-oriented tasks embedded in an e-worksheet to support literacy/character outcomes).	Electronic worksheet (e-LKPD) outputs.	E-worksheet / e-LKPD (digital worksheet).
2023	Ethnoscience framing grounded in local cultural values (Jambi context; specific cultural artifact not detailed in the accessible text sections).	Buffer solution.	Ethnoscience approach through Problem-Based Learning (PBL): students work with real-world/contextual problems linked to local culture, discuss and solve problems collaboratively, and apply buffer-solution concepts to interpret phenomena.	Problem solutions, student activity outputs, and written responses on scientific literacy (essay-based assessment).	NR (digital support not specified).
2024	Ethno-STEM framing within green chemistry learning (specific local-wisdom source not detailed in accessible metadata).	Green chemistry.	Guided inquiry sequence embedded in an Ethno-STEM e-module.	In-module inquiry tasks/worksheets.	E-module
2024	Community use of natural materials (plants/pigments) as acid–base indicators;	Acid–base (indicator/practicum focus).	Ethno-STEM-loaded practicum supported by an e-laboratory instruction: students	E-laboratory instruction (digital practicum guide)	Microsoft Sway-based e-laboratory instruction

Year	Ethno source / cultural context	Chemistry concept(s)/topic	Instructional activity pattern (STEAM tasks)	Learning artifact / product	Digital support
	local culture observation is used to frame the practicum context.		observe local cultural practices/materials; select and justify natural indicator sources; conduct acid–base testing; interpret results; and communicate findings, aligned with STEM reasoning (selection/engineering of indicators and data handling).	and student-produced natural indicator outputs/documentation.	(cloud-accessible; usable on smartphones/laptops) to deliver interactive practicum guidance.
2024	Meta-analysis (no single ethnocultural source).	Chemistry (ethno-STEM effects; review focus).	Meta-analytic synthesis of Ethno-STEM impacts on critical thinking.	Meta-analysis outputs.	NR
2024	Minangkabau cultural context (Batusangkar, West Sumatra) used to contextualize acid–base concepts via ethnoscience integration.	Acid–base.	Problem-Based Learning (PBL) worksheet integrated with ethnoscience (R&D/4D): students are oriented to contextual problems, organized for inquiry, investigate and propose solutions, develop/present products/solutions, and evaluate/refine understanding.	Student worksheet (LKPD) integrating PBL tasks with ethnoscience contexts for acid–base.	NR / primarily worksheet-based implementation (digital delivery not foregrounded).
2024	Local wisdom/ethnoscience in chemistry learning (review focus).	Chemistry learning (varied topics; review focus).	Literature review synthesis of local-wisdom integration patterns.	Review synthesis outputs.	NR
2025	NR (full-text access limited via publisher restrictions in this review); Ethno-STEM framing implied by the study title.	Organic chemistry.	Smart Ethno-STEM learning supported by mobile Augmented Reality (AR): students interact with AR content to explore concepts and complete structured learning tasks.	Mobile AR learning system/product (Smart Ethno-STEM) used as the primary learning artifact.	Mobile Augmented Reality (AR) technology.
2025	Toraja local wisdom (Pa'piong—traditional cooking practice) as an ethnochemistry/ethnoscience context for reaction-rate discussions.	Reaction rate.	Ethno-STEM e-module implementation: students engage with culturally contextual problems, connect observed/traditional practice to scientific explanations, and	Ethno-STEM e-module learning tasks and student work products embedded in the module.	Digital flipbook platform (Heyzine) for the e-module delivery and access.

Year	Ethno source / cultural context	Chemistry concept(s)/topic	Instructional activity pattern (STEAM tasks)	Learning artifact / product	Digital support
			complete structured learning tasks aligned with STEAM reasoning.		
2025	NR (ethno context not specified in title/metadata).	Redox.	CRTT-based e-LKPD learning sequence (critical reading/thinking tasks integrated into worksheet activities).	CRTT e-LKPD.	E-LKPD

NR = not reported

Beyond describing implementation patterns, Table 2 also suggests meaningful differences in how inquiry-oriented approaches and project/problem-based learning (PjBL/PBL) may function within Ethno-STEAM/Ethno-STEM contexts. Inquiry-based implementations, particularly guided or blended inquiry, tend to position local cultural phenomena as investigable cases that require evidence gathering, interpretation, and justification through chemistry concepts. This structure aligns closely with analytical reasoning processes and may help explain why studies employing inquiry-oriented designs more frequently report outcomes related to critical thinking and argumentation.

In contrast, PjBL/PBL implementations typically frame ethnocultural contexts as design constraints or problem scenarios that culminate in tangible products or solutions, thereby emphasizing integration, creativity, and application of knowledge across STEAM domains. While both approaches support contextualized learning, these differences suggest that inquiry-oriented pathways may be more directly associated with reasoning-focused outcomes, whereas project-based pathways may prioritize synthesis, design thinking, and the production of culturally grounded artefacts. Consequently, variations in reported learning outcomes across Ethno-STEAM/Ethno-STEM studies may partly reflect differences in the underlying pedagogical logic rather than the presence or absence of cultural integration alone.

A key pattern emerging from Table 2 is that cultural contexts are often positioned as authentic problem triggers or contextual anchors that make chemistry content more meaningful and locally situated. Several studies draw on community practices and local industries such as batik-related processes, traditional cooking practices, or community use of natural materials to frame the learning problem and motivate investigation.

In operational terms, the "ethno" component is not merely background information. It functions as the entry point for asking questions, defining constraints, and selecting phenomena that can be examined through chemistry concepts (e.g., acid–base indicators from natural materials, reaction processes embedded in traditional practices, or organic chemistry/natural-product contexts). This suggests that operationalization in the reviewed literature tends to prioritize contextual relevance and cultural resonance as mechanisms to increase engagement and interpretive depth when students encounter abstract chemical ideas.

Research by Munawwarah & Alqadri (2025) and Yusaerah et al. (2023) highlights the integration of ethnochemistry into learning processes, demonstrating how cultural insights can enrich students' understanding and application of chemical concepts. However, the focus on chemical principles in their study is limited to specific practices rather than a comprehensive approach to chemistry education that encompasses a range of chemical concepts. Therefore, while it supports the notion of cultural relevance in education, it does not fully confirm the broad claims made in this statement.

Similarly, the study by Andayani et al. (2021) emphasizes the importance of understanding the chemical content in local traditional practices, specifically in the context of traditional rituals, which may not directly address the broader curriculum implications discussed. While it underlines cultural practices, it does not robustly support claims about fostering a deeper connection across the chemistry curriculum. Given these considerations, it may be more accurate to assert that while these studies highlight significant themes related to culture and education, they do not collectively affirm that embedding cultural elements in the chemistry curriculum is vital for enhancing student engagement and comprehension in a comprehensive manner, as claimed.

A second pattern is that Ethno-STEAM/Ethno-STEM is most commonly enacted through activity structures that naturally accommodate knowledge construction and product-oriented work, particularly inquiry-oriented sequences and PBL/PjBL frameworks. Guided or blended inquiry designs typically translate cultural contexts into investigable questions and evidence-based reasoning tasks, culminating in artifacts such as written reports or presentations.

By contrast, PjBL/PBL operationalizations tend to emphasize design, making, or problem solving with tangible outputs such as culturally grounded products or project documentation thereby strengthening the engineering/design and arts/communication dimensions of STEAM. From a learning-outcome perspective, these structures provide plausible pathways to chemical literacy and critical thinking because they require students to interpret culturally situated phenomena using chemical representations, justify claims with evidence, and communicate solutions or products; however, the extent to which these mechanisms are explicitly described varies across studies, which can limit cross-study comparability.

Finally, Table 2 shows that digital resources are frequently used as scaffolds for implementation, but the forms of digital support are uneven and sometimes underreported. E-modules and e-worksheets/e-LKPD appear as the most common tools for structuring inquiry steps, guiding projects, and embedding tasks and assessments, while more specialized supports such as e-laboratory instructions (e.g., interactive practicum guidance) and mobile AR appear less frequently.

The pattern indicates that many studies operationalize Ethno-STEAM/Ethno-STEM through digitally mediated scaffolding of learning sequences rather than through high-end technology, which may enhance feasibility and adoption. At the same time, the presence of entries highlights an important methodological implication : future research would benefit from more consistent reporting of (a) how cultural anchors are translated into specific learning tasks, (b) what artifacts are produced and how they are assessed, and (c) how digital features function pedagogically (e.g., visualization, formative assessment, collaboration), so that evidence can accumulate more coherently across different instructional models.

CONCLUSION

This literature review synthesised evidence from 15 studies (2021–2025) on Ethno-STEAM/Ethno-STEM in chemistry education, focusing on instructional models, digital learning resources, and reported outcomes related to chemical literacy and critical thinking. Overall, the reviewed literature indicates that Ethno-STEAM/Ethno-STEM is predominantly implemented through inquiry-oriented approaches (including blended and guided inquiry), project/problem-based learning, practicum-oriented activities, and culturally responsive teaching, often supported by digital resources such as e-modules, e-worksheets/e-LKPD, e-laboratory instructions, and mobile AR.

Across these implementations, cultural or local-wisdom contexts are commonly used as authentic anchors to contextualise chemistry concepts and to structure learning tasks that integrate investigation, design, and communication components aligned with STEAM practices. In terms of outcomes, the evidence base more consistently supports improvements in critical thinking, especially when Ethno-STEAM/Ethno-STEM is enacted through inquiry and project-based pathways, and when learning sequences provide opportunities for evidence-based reasoning and problem solving. Evidence directly targeting chemical literacy is present but comparatively less extensive within the included corpus, and cross-study comparison is constrained by variability and incomplete reporting of measurement frameworks and instruments. Importantly, many studies emphasise adjacent competencies (e.g., HOTS, metacognition, numeracy literacy, character, feasibility/practicality), reflecting a research landscape that is still largely development-oriented.

These findings imply that future research should move beyond resource development by increasing the number of robust empirical evaluations that (i) clearly operationalise Ethno-

STEAM/Ethno-STEM learning processes, (ii) report implementation fidelity and the pedagogical function of digital scaffolds, and (iii) apply more standardised and transparent measurement of chemical literacy and critical thinking. Strengthening methodological consistency and expanding classroom-scale effectiveness studies will enable the field to build more cumulative evidence on when, how, and for whom Ethno-STEAM/Ethno-STEM most effectively supports meaningful chemistry learning.

RECOMMENDATION

Future research on Ethno-STEAM/Ethno-STEM in chemistry education should extend beyond predominantly development-oriented work by conducting more robust classroom-based evaluations that explicitly test effects on chemical literacy and critical thinking using stronger empirical designs (e.g., quasi-experimental and mixed-method approaches) with adequate samples and clear comparison conditions. Researchers are encouraged to report implementation more transparently, detailing instructional syntax, duration, teacher facilitation, student tasks, and implementation fidelity, while also standardizing outcome measurement through well-referenced indicator frameworks and validated instruments to improve cross-study comparability.

At the same time, studies should broaden cultural contexts and chemistry topics (e.g., electrochemistry, equilibrium, thermochemistry, environmental chemistry) and clarify the pedagogical function of digital supports (e-modules, e-worksheets/e-LKPD, e-labs, AR) as scaffolds for inquiry, design thinking, and multi-representational understanding. Key obstacles that may affect results include limited instructional time and curriculum constraints, uneven access to devices and internet connectivity, teachers' readiness to integrate culturally grounded content, and risks of superficial or inaccurate cultural representation; therefore, future work should incorporate teacher professional development, provide offline/low-tech alternatives, and involve local communities in selecting and validating cultural materials to ensure feasibility and cultural integrity.

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