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Emotional intelligence in chemistry education: a systematic review of theoretical foundations, pedagogical applications, and research trends

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Emotional Intelligence (EI) has gained increasing attention across education research; however, its role within chemistry education remains conceptually diffuse and methodologically fragmented. This systematic review examines how EI and related affective constructs have been conceptualised, enacted, and investigated within chemistry education research between 2015 and 2025. Following PRISMA 2020 guidelines, an initial search of the Scopus database yielded 292 records, which were reduced through screening and eligibility procedures to 32 articles. Studies were included if they examined emotional or affective processes within chemistry or closely related STEM learning contexts, while studies lacking disciplinary relevance or affective constructs were excluded. To reduce potential bias, screening and coding decisions were independently reviewed by a second researcher. Findings were analysed using a narrative thematic synthesis aligned with the review questions. Because EI-related research spans heterogeneous disciplinary contexts, a second-level disciplinary relevance appraisal was conducted, resulting in a final analytic dataset of 17 studies comprising 8 core chemistry–affective investigations and 9 conceptually relevant studies. A narrative thematic synthesis revealed four interrelated patterns: (1) EI is rarely adopted as an explicit theoretical framework in chemistry education, yet emotional competencies aligned with EI are structurally embedded in disciplinary learning practices; (2) affective demands emerge prominently in laboratory inquiry, representational reasoning, and socio-scientific instructional contexts; (3) existing research is shaped by methodological patterns that privilege self-report measures over process-oriented analyses of emotional dynamics; and (4) persistent conceptual gaps constrain the field's capacity to theorise emotions as constitutive of chemical meaning-making. By synthesising chemistry-specific and conceptually adjacent literature, this review advances an epistemic–affective perspective on EI in chemistry education and articulates an integrative agenda for future research. The findings highlight the need for explicit theorisation of EI grounded in disciplinary practices, methodological innovation capable of capturing situated emotional processes, and culturally responsive research that extends beyond predominantly Western contexts.

Introduction

Chemistry learning is intrinsically demanding, not only cognitively but also affectively. Students are routinely required to interpret ambiguous experimental data, coordinate multiple chemical representations, and engage in inquiry processes in which uncertainty, error, and revision are central features of disciplinary practice. These demands situate chemistry classrooms, particularly laboratory and inquiry-oriented contexts, as affectively charged learning environments in which emotions shape how students persist, reason, and participate (Galloway and Bretz, 2015b; Cooper and Oliver-Hoyo, 2016; Bellocchi, 2019). Yet, despite growing recognition that emotions influence science learning, the affective dimensions of chemistry education have historically received less systematic attention than cognitive and representational aspects.

In broader education research, emotional intelligence has been proposed as a construct capturing individuals' capacities to recognize, regulate, and utilize emotions in adaptive ways. Frameworks of emotional intelligence have been linked to motivation, resilience, collaboration, and self-regulated learning

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across diverse educational context (Goleman, 2004; Mayer *et al.*, 2008; Brackett *et al.*, 2011) s. However, within science and chemistry education, emotional intelligence has not been adopted in a uniform or theoretically coherent manner. Instead, emotional phenomena that are central to chemistry learning, including anxiety during laboratory work, confusion during transitions between representations, and frustration in problem solving, are commonly examined as isolated constructs rather than being explicitly connected to emotional intelligence as a disciplinary framework (M. Cooper and Klymkowsky, 2013; Galloway *et al.*, 2016). This fragmentation raises questions about how emotions are conceptualized in chemistry education and whether emotional intelligence can meaningfully inform disciplinary learning rather than functioning as an external psychological lens.

Recent chemistry education research has begun to foreground affective dimensions more explicitly, particularly in studies of laboratory inquiry, socio-scientific issues, and representational reasoning. These studies suggest that students' emotional responses are not merely epiphenomenal but are intertwined with epistemic activity: emotions signal uncertainty, orient attention, and mediate decisions about whether to persist, revise strategies, or disengage (Pekrun and Linnenbrink-Garcia, 2014; Muis *et al.*, 2018). Such findings resonate with research on epistemic emotions, which positions emotions such as curiosity, confusion, and doubt as integral to knowledge construction (D'Mello and Graesser, 2012; Sinatra *et al.*, 2014). Nevertheless, the extent to which these affective processes are theorized as part of emotional intelligence, or how emotional intelligence might be reconceptualized to align with chemistry specific practices, remains unclear.

This lack of theoretical coherence has practical consequences for chemistry education research. Without a unifying EI-informed lens, affective findings remain difficult to compare across studies, instructional contexts, and methodological traditions. As a result, emotions in chemistry learning are often positioned as contextual modifiers rather than as integral components of disciplinary participation. Addressing this fragmentation requires a synthesis that is sensitive not only to affective theory, but also to the epistemic structure of chemistry as a discipline.

While existing research on Emotional Intelligence in science education has been conducted predominantly in Western contexts, chemistry classrooms in collectivist educational systems such as Indonesia operate under markedly different sociocultural norms. Emotional restraint, relational harmony, and respect for authority are often foregrounded, shaping how students express uncertainty, seek assistance, and regulate frustration during inquiry and laboratory work. These contextual characteristics challenge implicit assumptions embedded within prevailing EI frameworks, which frequently privilege individual emotional expression and self-directed regulation. Consequently, Indonesia represents not merely a local educational setting, but a critical epistemic context for interrogating the cultural boundaries and transferability of EI constructs within chemistry education.

Existing reviews on affect in science education have provided valuable insights into motivation, attitudes, and emotions broadly construed (Osborne *et al.*, 2004; Treagust *et al.*, 2017); however, none have systematically examined EI as it appears within chemistry education as a distinct disciplinary field. Moreover, prior syntheses have frequently aggregated studies across STEM or science domains, potentially obscuring the unique epistemic, representational, and experimental features that characterize chemistry learning. This absence of a discipline-sensitive synthesis limits the field's capacity to articulate how EI-related competencies operate within chemistry classrooms and how they might be intentionally cultivated through pedagogy, curriculum design, and assessment.

To address this gap, the present study undertakes a systematic literature review of EI-related research in chemistry education published between 2015 and 2025. Rather than assuming EI as a predefined theoretical lens, this review adopts an epistemic–affective perspective that examines how emotional competencies aligned with EI are conceptualized, enacted, and investigated within chemistry learning contexts. By integrating chemistry-specific studies with conceptually relevant affective scholarship, the review aims to clarify the current state of the field, identify methodological and theoretical limitations, and articulate future directions for EI research grounded in disciplinary practice.

Guided by this aim, the review addresses the following research questions:

1. How is Emotional Intelligence theoretically conceptualized and positioned within the field of chemistry education?
2. How has Emotional Intelligence been integrated into instructional approaches, learning environments, and assessment practices in chemistry classrooms?
3. What research patterns, methodological characteristics, and learning outcomes have emerged from empirical studies globally and in Indonesia between 2015 and 2025?
4. What conceptual gaps, pedagogical challenges, and future research directions arise from the existing literature?

By integrating chemistry specific findings with broader research on affect in education, this review seeks to advance an epistemic and affective account of chemistry learning. This account recognizes emotions not as peripheral variables but as consequential elements of how learners engage in the work of chemistry. From this perspective, emotions shape learners' engagement with uncertainty, representation, and inquiry, thereby influencing how chemical knowledge is constructed, negotiated, and sustained within disciplinary practice.

Theoretical framework

Understanding Emotional Intelligence (EI) in chemistry education requires a theoretical framing that moves beyond generic affective skills to account for the epistemic and sociocultural demands of disciplinary learning. Chemistry learning is not merely a cognitive endeavor but is inseparable from affective dimensions such as interest, motivation, values, and emotional engagement, which shape how learners interpret, respond to, and make meaning of chemical phenomena (Rahayu, 2015). Attention to the affective domain is therefore essential for understanding how students engage with uncertainty, abstraction, and inquiry in chemistry classrooms. Chemistry is a discipline characterized by abstract representational work, uncertainty-laden laboratory practices, and socio-scientific contexts that evoke both moral and emotional responses (Duit and Treagust, 2012; Cooper *et al.*, 2017). As such, a framework for EI in chemistry must extend beyond generic emotional skills to encompass the affective competencies that support disciplinary reasoning, inquiry, and participation.

Rather than privileging a single theoretical tradition, this review adopts an integrative epistemic–affective lens that brings together four complementary theoretical strands: (1) psychological models of EI; (2) epistemic affect in scientific inquiry; (3) emotion regulation within self-regulated learning; and (4) sociocultural perspectives on classroom emotion. Together, these strands provide the conceptual foundation for interpreting how EI-related competencies are implicitly embedded in chemistry learning practices and for guiding the synthesis of findings across the reviewed studies, even when EI is not explicitly theorized.

Psychological models of emotional intelligence

EI is most commonly theorized through two dominant paradigms: ability-based and mixed-model approaches. Ability-based models conceptualize EI as a set of cognitive abilities used to perceive, understand, manage, and utilize emotions in goal-directed activity (Mayer, 2004; Mayer *et al.*, 2008). These abilities function analogously to other forms of cognition, enabling individuals to interpret affective cues and regulate emotional responses in ways that support reasoning and problem solving.

In contrast, mixed-model approaches conceptualize EI as a constellation of emotional and social competencies, integrating emotion-related skills with dispositions such as motivation, empathy, persistence, and interpersonal communication (Goleman, 2013). From this perspective, EI shapes how individuals navigate intrapersonal and interpersonal demands in complex learning environments.

Both paradigms offer insight into chemistry learning. Ability-based EI is relevant when students must recognize confusion as part of model-based reasoning or regulate anxiety during laboratory troubleshooting. Mixed model emotional intelligence captures broader dispositions, including persistence, empathy, and collaborative communication, that underpin productive engagement in group problem solving and laboratory teamwork. Despite this relevance, EI models have rarely been adopted explicitly within chemistry education research. Instead, affective constructs tend to appear in fragmented forms, such as laboratory anxiety, attitudes toward chemistry, motivation, engagement, or resilience (Galloway and Bretz, 2015a). An EI perspective provides a unifying lens through which these constructs can be understood as components of the emotional competencies that support disciplinary learning.

Epistemic affect and the affective architecture of inquiry

Chemistry learning frequently unfolds through inquiry-based practices that involve questioning phenomena, designing investigations, interpreting ambiguous data, and revising explanatory claims. These practices are accompanied by epistemic emotions including curiosity, confusion, frustration, doubt, anticipation, and satisfaction which arise in relation to knowledge construction rather than to evaluative success or failure alone (Pekrun and Linnenbrink-Garcia, 2014; Pekrun *et al.*, 2017; Muis *et al.*, 2018; Chevrier *et al.*, 2019).

While epistemic emotions such as confusion, frustration, and doubt often arise during moments of cognitive conflict or conceptual uncertainty, positive emotions also play an important role in sustaining engagement during complex learning processes. Emotions such as curiosity, enthusiasm, determination, pride, and satisfaction may emerge when learners make conceptual progress, resolve experimental challenges, or recognize the value of their investigative efforts. These positive emotional experiences support persistence, reinforce self-regulated learning processes, and contribute to the development of disciplinary identity in chemistry learning contexts (Pekrun and Linnenbrink-Garcia, 2014; Muis *et al.*, 2018).

Epistemic emotions play a constitutive role in disciplinary sense-making. Curiosity motivates exploration of particulate explanations; confusion signals conceptual tension and can catalyze reorganization of understanding; frustration emerges when predictions fail or symbolic manipulations break down, and when regulated, can drive hypothesis revision (D'Mello and Graesser, 2012). In laboratory contexts, epistemic affect is particularly pronounced as students encounter uncertainty related to procedures, data validity, or unexpected reaction outcomes (Hofstein and Lunetta, 2004; Carmel *et al.*, 2019). Research in science education suggests that when learners recognize and regulate these emotions, they engage more deeply in troubleshooting, metacognitive reflection, and collaborative reasoning (Carmel *et al.*, 2019; Gao *et al.*, 2021). From this perspective, epistemic affect represents a discipline-specific layer of EI, emotional competencies that support the epistemic work of doing chemistry.

Within chemistry, one of the most persistent sites where epistemic emotions are activated is representational work (Ainsworth, 2006; Tytler *et al.*, 2013; Treagust *et al.*, 2017). Difficulties in coordinating macroscopic, submicroscopic, and symbolic representations have long been identified as central challenges in chemistry learning. Systematic analyses of chemistry instruction highlight that representational transition demand sustained cognitive effort and strategic reasoning, often requiring learners to revisit assumptions and re-evaluate explanatory models (Permatasari *et al.*, 2022). From an epistemic–affective perspective, such representational work is inherently emotionally charged, frequently eliciting confusion, frustration, and uncertainty that must be regulated for productive learning to occur. These findings underscore that representational competence in chemistry is not purely cognitive, but is supported by affective regulation processes aligned with Emotional Intelligence.

Emotion regulation and self-regulated learning in chemistry

Chemistry tasks impose substantial cognitive and representational demands, often requiring sustained engagement with multistep problem solving and abstract reasoning. Within theories of self-regulated learning (SRL), emotion regulation is recognized as a core process enabling learners to maintain engagement, allocate attention, and manage cognitive frustration (Zimmerman, 2002; Efklides, 2011). Strategies such as reappraisal, persistence, help-seeking, and reflective monitoring support learners during challenging chemistry tasks, including stoichiometric reasoning, equilibrium analysis, and extended inquiry cycles.

In chemistry classrooms and laboratories, EI and SRL intersect closely as students navigate cognitively demanding tasks, collaborative inquiry, and laboratory problem-solving processes that require sustained engagement (Naibert and Barbera, 2022; Reid *et al.*, 2022). Effective learners anticipate difficulty, monitor their emotional responses to setbacks, and deploy regulatory strategies, including pausing to reassess evidence or consulting peers, to sustain productive engagement. EI provides the affective scaffolding that enables these SRL processes by allowing learners to interpret emotional states as informational cues rather than as obstacles to learning. Thus, EI and SRL operate as mutually reinforcing mechanisms within the cognitive–affective landscape of chemistry education (Pintrich, 2004; Cooper and Oliver-Hoyo, 2016).

Sociocultural perspectives on emotion in chemistry learning

Context-based and socio-scientific chemistry instruction has been shown to influence not only students' conceptual understanding but also their affective engagement and values (Rahayu, 2019; Fadly *et al.*, 2022). These affective dimensions are closely related to students' ability to regulate emotions during complex socioscientific reasoning, which plays an important role in supporting chemical literacy (Pekrun and Linnenbrink-Garcia, 2014; Muis *et al.*, 2018). Emotions in learning are not solely individual phenomena but are shaped by sociocultural norms, institutional expectations, and classroom interactional practices. In Indonesian chemistry classrooms, for example, learning environments are often characterized by relational harmony, respect for authority, and collective responsibility. Classroom norms and participation structures influence how students' express confusion, seek assistance, take intellectual risks, and tolerate uncertainty during chemistry learning. Such behaviors are closely associated with emotional intelligence related competencies and with students' productive engagement in scientific inquiry (States *et al.*, 2023; Urbanek *et al.*, 2023; Alzen *et al.*, 2025).

From a sociocultural perspective, EI encompasses relational awareness, empathy, and sensitivity to social expectations. In chemistry learning, these competencies become visible in collaborative laboratory work, peer discussions of socio-scientific issues, and the negotiation of shared interpretations of data and models. Students may regulate emotional expression to maintain group harmony or rely on peer-based emotional support when confronting difficult reasoning tasks. A culturally attuned EI framework must therefore recognize how emotional expression and regulation are mediated by context, particularly in non-Western educational settings such as Indonesia.

Emotional intelligence as an enabling capacity in chemistry education

Taken together, these theoretical strands suggest that EI in chemistry education cannot be reduced to generic emotional skills or isolated affective variables. Instead, EI operates through the dynamic interplay of emotional abilities, epistemic emotions, regulatory processes, and sociocultural norms that shape participation in disciplinary practices. In this review, EI is conceptualized as an enabling capacity that supports learners' engagement with the epistemic demands of chemistry rather than as a prescriptive instructional framework or a discrete learning outcome.

From this integrative perspective, EI shapes how learners recognize emotionally salient moments (*e.g.*, uncertainty, confusion, failure), regulate their responses to these moments, and sustain engagement with chemistry disciplinary practices such as laboratory inquiry, representational reasoning, and socio-scientific argumentation. Epistemic emotions dynamically interact with these practices, influencing whether learners disengage, persist, or reorient their reasoning strategies. This positioning, illustrated in Fig. 2, provides the conceptual lens for synthesizing how EI-related competencies are implicitly embedded in chemistry learning across the reviewed studies, even when EI remains unnamed.

Method

This systematic review was conducted following the PRISMA 2020 guidelines, with the analytic aim of generating a disciplinary account of how Emotional Intelligence (EI) has been conceptualized, enacted, and investigated within chemistry education (Page *et al.*, 2021). Because EI appears across a broad and heterogeneous literature, the methodological challenge of this review lay not simply in retrieving studies but in establishing principled criteria for identifying research that speaks meaningfully to the epistemic and affective demands of chemistry. Accordingly, the review process involved two layers of selection: (1) a conventional SLR filtering procedure (identification → screening → eligibility → inclusion), and (2) a disciplinary-relevance appraisal that distinguished between core chemistry–affective studies and conceptually relevant EI studies.

Search strategy and identification

A comprehensive search was conducted in Scopus, selected for its broad coverage of education, psychology, and STEM disciplines. Although Scopus provides extensive interdisciplinary coverage of education, psychology, and STEM research, reliance on a single database may limit the retrieval of relevant studies published in specialized education or regional journals. This limitation was considered during interpretation of the findings, particularly with regard to the limited representation of studies from Indonesian and other Global South contexts.

To capture the intersection of chemistry education, affective constructs, and EI-related terminology, a Boolean expression was constructed integrating four conceptual clusters: (a) Emotional Intelligence and affective terms; (b) chemistry, chemical education, and science-learning contexts; (c) instructional modes relevant to chemistry (*e.g.*, inquiry, PBL, SSI); and (d) learner roles (students, teachers). Although the Boolean search string was designed to capture a broad range of emotional intelligence and affect-related terminology, variations in disciplinary vocabulary may have resulted in some relevant studies not being retrieved.

The final Boolean string was:

TITLE-ABS-KEY((''emotional intelligence'' OR ''social-emotional learning'' OR ''emotional competence'' OR ''emotion regulation'' OR ''affective domain'' OR empathy) AND (''chemistry education'' OR ''chemical education'' OR ''science education'' OR ''STEM education'' OR ''inquiry learning'' OR ''problem-based learning'' OR ''socio-scientific issues'') AND (student OR teacher* OR learning OR classroom)) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO(DOCTYPE, ''ar'')) AND (LIMIT-TO(LANGUAGE, ''English''))*

This search, conducted in November 2025, returned 292 records.

The construction of the search strategy was intentionally expansive to capture the conceptual breadth of EI-related research while avoiding premature disciplinary exclusion. Given that EI is not consistently labelled within chemistry education studies, the search terms were designed to include adjacent affective constructs that may implicitly reflect EI-aligned processes. This approach ensured sensitivity in retrieval while allowing subsequent stages of screening and appraisal to establish disciplinary relevance.

Screening and eligibility

The dataset was filtered using standard systematic literature review procedures. First, publication type and language criteria reduced the corpus to 184 articles. Second, duplicate records were removed using Mendeley, resulting in 172 unique records. Third, title screening guided by relevance to chemistry, affect, emotional intelligence, or inquiry reduced the set to 64 articles. Fourth, abstract screening followed by preliminary full text checks yielded 32 articles that met the formal inclusion criteria. To enhance the reliability of the screening process and minimize potential selection bias, the screening decisions were independently reviewed by a second researcher with expertise in chemistry education research. The second researcher examined the inclusion and exclusion decisions made during title and abstract screening as well as the preliminary full-text eligibility checks. Any discrepancies in article eligibility were discussed collaboratively until consensus was reached. Initial screening decisions demonstrated an agreement rate of approximately 88% between the two researchers. The remaining cases involved minor differences in interpretation of disciplinary relevance and were resolved through discussion until consensus was reached.

At this stage, the retained set of 32 articles reflected a broad intersection of affective research, science education, and inquiry-oriented learning contexts. However, preliminary examination indicated substantial variation in how directly these studies engaged with chemistry as a disciplinary domain. Some studies foregrounded emotional processes within generic STEM or inquiry settings, while others embedded affective analysis within chemistry-specific practices such as laboratory work, representational reasoning, or socio-scientific engagement. This heterogeneity necessitated an additional layer of appraisal to ensure that the final synthesis remained epistemically grounded in chemistry education rather than diffusely affective in scope. The overall study selection procedure following the PRISMA framework is summarized in Fig. 1.

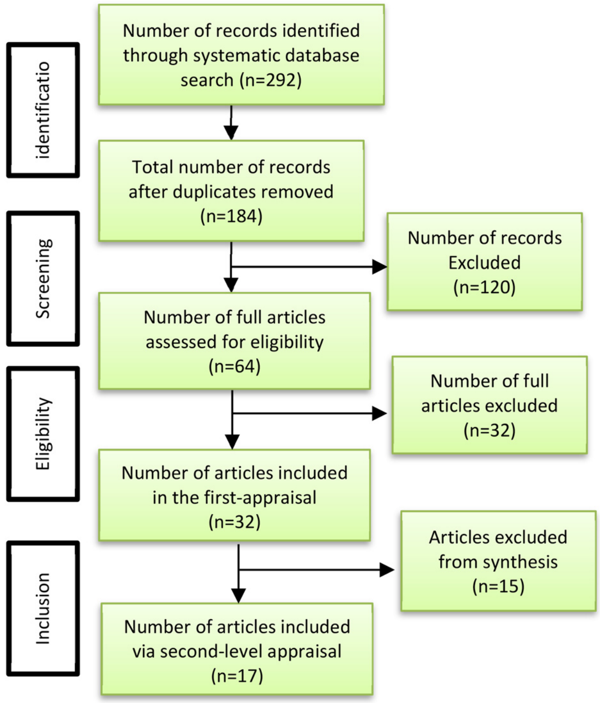

Fig. 1 Diagram of PRISMA procedure as a literature search and review process.

Disciplinary-relevance appraisal

Chemistry education is a discipline-specific field with established epistemic practices, representational norms, and laboratory conventions. To identify studies that genuinely illuminate EI as it relates to the work of learning chemistry, each of the 32 included studies was evaluated using four criteria:

1. Chemistry specificity

– involvement of chemistry content, laboratory practice, chemical representations, or chemical literacy.

2. Presence of EI-aligned affective constructs

– examination of emotional regulation, anxiety, engagement, epistemic affect, resilience, empathy, or socio-emotional competencies.

3. Relevance to disciplinary practices

– connection to inquiry, data interpretation, collaborative reasoning, or representational transitions.

4. Cognitive–affective integration

– evidence that emotions shaped students' thinking, participation, or identity in chemistry or closely related STEM contexts

Applying these criteria produced a structured reduction of the dataset:

• 8 studies met all criteria and were classified as core empirical chemistry-affective studies.

These studies formed the primary evidence base for answering the review questions.

• 9 studies did not examine chemistry directly but offered conceptually relevant EI or affective mechanisms in inquiry-based, STEM, or higher-education contexts.

These studies were retained as supporting literature to deepen theoretical interpretation.

• 15 studies were excluded due to insufficient relevance (*e.g.*, civic education, moral education, general humanities, or arts-based research without disciplinary overlap).

This two-stage appraisal ensured that the synthesis remained rigorous, chemically meaningful, and grounded in disciplinary epistemology rather than broad psychological generalities.

Data extraction and coding

For the 17 retained studies (8 core, 9 supporting), a structured extraction matrix was developed capturing bibliographic details; participant characteristics; disciplinary or instructional context; emotional constructs (*e.g.*, anxiety, epistemic affect, regulation); theoretical framing (*e.g.*, EI models, SRL, sociocultural perspectives); methodological approach (survey, interview, observation, mixed methods); chemistry-relevant phenomena (representation, inquiry, laboratory work); key affective findings; and implications for chemistry learning.

The extraction process was iterative. Preliminary codes were generated inductively, refined through constant comparison, and consolidated into four analytic themes aligned with the research questions: EI conceptualization, pedagogical integration, methodological trends, and conceptual gaps. To reduce potential interpretive bias, the coding process combined inductive and deductive procedures. Initial codes were generated through open reading of the studies to capture emerging patterns in how emotions were conceptualized and examined within chemistry learning contexts. These preliminary codes were then organized in relation to the four research questions. During this process, themes that did not directly align with the predefined questions were also documented and considered during synthesis to ensure that the analysis remained responsive to patterns emerging from the literature rather than solely constrained by the review framework. This approach helped ensure that the thematic structure reflected both the guiding questions of the review and the conceptual patterns emerging from the literature. To further enhance analytic reliability, the preliminary coding outcomes were independently reviewed by a second researcher. The initial coding comparison showed an agreement rate of approximately 84%, indicating substantial alignment between reviewers in the interpretation of thematic codes. Any discrepancies were discussed collaboratively, and the coding framework was refined until consensus was achieved.

Quality appraisal

Methodological quality was appraised using the Mixed Methods Appraisal Tool (MMAT), selected for its capacity to accommodate the diverse empirical designs represented across the reviewed studies. Rather than functioning as an exclusionary filter, the appraisal was used to characterize the evidentiary strengths and limitations shaping current knowledge of EI in chemistry education. All eight cores chemistry–affective studies met the minimum MMAT criteria for methodological adequacy; however, the appraisal revealed recurring structural constraints that delimit the interpretive scope of the literature. The MMAT assessment was conducted to evaluate the methodological adequacy of the included studies across diverse research designs. The appraisal outcomes were reviewed collaboratively by the research team to ensure consistency in the interpretation of MMAT criteria and to reduce potential bias in methodological evaluation. Minor differences in interpretation were discussed until agreement was reached. The MMAT results were used to characterize the overall quality and methodological patterns within the dataset rather than as exclusion criteria.

In particular, a predominant reliance on self-report instruments constrained the extent to which emotional processes could be examined as situated, dynamic phenomena unfolding during chemistry learning activities. Few studies captured emotions in real time or in close temporal proximity to laboratory inquiry, representational transitions, or collaborative reasoning. Additionally, several investigations were conducted in small-scale laboratory or course-specific contexts, limiting the transferability of findings across institutional and cultural settings. Notably, the reviewed corpus exhibited a sparse representation of Indonesian and other non-Western chemistry education contexts. This pattern may partly reflect the coverage characteristics of Scopus, which tends to index journals published primarily in Europe and North America. As such, the limited representation of Global South research should be interpreted cautiously, as relevant studies published in regional journals or non-English outlets may not have been captured within the present database search.

Supporting studies were appraised primarily in terms of conceptual clarity and explanatory coherence rather than chemistry specificity, as their contribution lay in articulating affective mechanisms that inform, but do not directly instantiate, chemistry classroom practice. Taken together, the quality appraisal underscores that current EI research in chemistry education is methodologically sound but epistemically constrained, pointing to the need for designs that foreground contextualized emotional dynamics and culturally responsive approaches.

Synthesis approach

A narrative thematic synthesis was adopted to support an interpretive and discipline-sensitive integration of findings, rather than to aggregate results across heterogeneous empirical designs. This approach was necessitated by the conceptual diversity of the included studies and by the fundamentally qualitative nature of emotional phenomena in chemistry learning. The synthesis proceeded through iterative comparison across studies, attending not only to reported outcomes but also to how emotions were positioned in relation to chemistry-specific practices such as laboratory inquiry, representational reasoning, and socio-scientific engagement.

Within this process, the eight cores chemistry–affective studies functioned as the primary analytic anchors from which disciplinary patterns were inferred, while the nine conceptually relevant EI studies were mobilized to interrogate, contextualize, and theoretically extend these patterns. Importantly, supporting studies were not treated as confirmatory evidence but as interpretive resources that illuminated underlying affective mechanisms often left implicit in chemistry education research. As such, the synthesis foregrounds patterns of emphasis and omission across the field rather than attempting to reconcile findings into a unified or cumulative model.

Results

The disciplinary-relevance appraisal yielded a final dataset of 17 studies, consisting of eight core chemistry–affective studies and nine conceptually relevant EI and inquiry-affective studies. Four interrelated themes emerged from the synthesis: (1) implicit conceptualizations of Emotional Intelligence (EI) within chemistry learning; (2) affective demands embedded in chemistry instructional contexts; (3) methodological patterns shaping how emotional phenomena are examined; and (4) structural conceptual gaps that delimit the field's present understanding of EI in chemistry.

These themes were unevenly distributed across the literature. Chemistry-specific studies primarily examined instructional contexts and measurement practices, whereas adjacent EI scholarship provided stronger theoretical accounts of affective mechanisms. To make this distribution visible, the studies were analytically mapped according to conceptual focus, pedagogical context, methodological approach, and attention to conceptual gaps (Fig. 2). The mapping serves as a heuristic tool for identifying patterns of emphasis and omission across the field. For analytic clarity, chemistry-focused studies are labelled C1–C8, while conceptually supporting studies are labelled S1–S9.

The mapping highlights the uneven distribution of empirical and theoretical emphases that characterizes current EI research in chemistry education.

EI as an implicit but structurally present construct in chemistry learning

Although none of the eight core studies explicitly employed Emotional Intelligence as a formal theoretical lens, competencies closely aligned with EI emerged consistently as structuring features of students' disciplinary engagement. Across studies examining chemistry laboratory learning, students' capacities to recognize, interpret, and regulate emotional responses were consequential for how they navigated experimental uncertainty, procedural breakdowns, and ambiguous outcomes (*e.g.*, (Galloway and Bretz, 2015a, 2015b; Galloway *et al.*, 2016; Kyynäräinen *et al.*, 2024)).

When confronted with inconclusive data, students who persisted demonstrated emotion-regulation behaviors such as reassessing procedures, seeking peer input, or reframing frustration as part of inquiry. These responses align with core EI processes as conceptualized in the broader affective literature, even though EI terminology was absent from the original analyses (Mayer *et al.*, 2008; Pekrun and Linnenbrink-Garcia, 2014).

Parallel patterns were observed in studies focusing on representational reasoning in chemistry. As students transitioned between macroscopic observations, particulate level explanations,

Study	Concept	Pedagogy	Methods	Gaps
C1 - Ramadhani et al. (2024)	○	●	○	○
C2 - Agustian et al. (2025)	○	●	○	○
C3 - Dori et al. (2018)	○	●	●	○
C4 - Galloway & Bretz (2015b)	○	●	●	○
C5 - Galloway et al. (2016)	●	●	●	○
C6 – Kyynäräinen et al., (2024)	○	●	●	●
C7 - Yonai & Blonder (2022)	○	●	●	○
C8 - Avargil & Piorko (2022a)	○	●	●	○
S1 - Zembylas (2023)	●	○	○	●
S2 - Sinatra et al. (2014)	●	○	○	●
S3 - Muis et al. (2018)	●	○	○	●
S4 - Pekrun & Linnenbrink-Garcia (2014)	●	—	—	○
S5 - Jaber & Hammer (2016)	●	○	●	●
S6 - Schindler et al. (2017)	●	○	○	●
S7 - Tang (2016)	●	○	○	●
S8 - Bellocchi (2019)	○	○	○	●
S9 – Tyng et al. (2017)	●	—	—	○

Legend: ● = primary focus; ○ = secondary/implicit contribution; — = not a focus.

Fig. 2 Analytical mapping of the 17 studies included in the thematic synthesis across four analytic dimensions. Pekrun and Linnenbrink-Garcia (2014); Sinatra *et al.* (2014); Galloway and Bretz (2015b); Galloway *et al.* (2016); Jaber and Hammer (2016); Tang (2016); Schindler *et al.* (2017); Tyng *et al.* (2017); Dori *et al.* (2018); Muis *et al.* (2018); Bellocchi (2019); Yonai and Blonder (2022); Avargil and Piorko (2022a); Zembylas (2023); Kyynäräinen *et al.*, (2024); Ramadhani *et al.* (2024); Agustian *et al.* (2025).

and symbolic representations, epistemic emotions such as confusion, irritation, and curiosity shaped the direction and continuity of their reasoning (Avargil and Piorko, 2022a). Students who navigated representational complexity often treated confusion not as a barrier but as a cue for strategic adjustment and conceptual reorganization.

When interpreted alongside the supporting EI and epistemic-affect literature, these findings gain additional clarity. Studies outside the chemistry-specific corpus consistently emphasize that recognizing and regulating emotional cues underpins persistence, motivation, and cognitive flexibility during complex learning tasks (Immordino-Yang and Damasio, 2007; Sinatra *et al.*, 2014; Muis *et al.*, 2018). Juxtaposing these bodies of work reveals that chemistry learning is underpinned by an implicit EI structure operating through epistemic emotions and disciplinary practices, even when EI remains unnamed. This implicitness, however, constrains the field's capacity to theorize emotion as a constitutive element of chemical meaning-making.

Emotional demands of chemistry instructional contexts

Across the 17 studies, chemistry learning contexts consistently elicited emotional demands that required EI-aligned competencies, though these demands manifested differently across instructional environments.

Laboratory inquiry

Laboratory-based studies demonstrated that inquiry is not a linear cognitive process but an emotionally turbulent one. Students routinely encountered ambiguity, procedural setbacks, unexpected results, and iterative troubleshooting, eliciting emotions ranging from anxiety to satisfaction (Galloway *et al.*, 2016; Rap *et al.*, 2023). Several studies reported that emotionally overwhelmed students were more likely to disengage cognitively, whereas those who could reappraise frustration as an inherent feature of scientific work engaged more deeply in inquiry cycles. These findings are consistent with affective models that position emotion regulation as foundational to adaptive decision-making in complex problem spaces (Pekrun and Linnenbrink-Garcia, 2014).

Contextual and socio-scientific chemistry

Studies embedding chemistry within environmental or socio-scientific contexts documented affective activation in the form of empathy, moral concern, and situational relevance (Rap *et al.*, 2023, 2025). Engagement with chemical pollution, risk, or sustainability dilemmas elicited emotional responses that helped students situate chemical knowledge within lived and ethical contexts. Such affective engagement supported chemical literacy by linking conceptual understanding with social responsibility, highlighting a natural intersection between EI-related competencies and socio-scientific reasoning (Zembylas, 2023).

Representational work and problem-solving

Representational reasoning constituted a cognitively demanding domain. Studies have shown that students experience substantial epistemic challenges when shifting between macroscopic observations, particulate-level explanations, and symbolic representations, particularly when algorithmic procedures obscure conceptual meaning (Avargil *et al.*, 2012; Dori *et al.*, 2018; Avargil and Piorko, 2022b). Learners who demonstrated greater emotional resilience and attentional control were more likely to persist and re-engage with challenging representational tasks, suggesting that EI-related competencies may actively enable conceptual reconstruction rather than merely accompany it.

Such representational work is often shaped through patterns of classroom discourse and the negotiation of meaning across representations (Tang, 2016). Across instructional contexts, emotional demands were structurally linked to the epistemic demands of chemistry. The discipline's representational and experimental complexity is affectively charged by design, rendering EI a productive lens for examining participation in chemistry learning.

Methodological patterns and blind spots in EI-related chemistry research

A third theme concerns the methodological tendencies that shape what the field is able to see or fails to see about EI in chemistry education. Most studies relied predominantly on self-report instruments, including Likert-scale surveys adapted from general education or psychology. Recent work has highlighted that emotion regulation during science learning is highly context dependent, pointing to limitations of approaches that rely solely on individual self-report measures (Bellocchi, 2019). While such tools captured broad affective constructs (*e.g.*, anxiety, engagement), they rarely addressed chemistry-specific emotional phenomena such as epistemic frustration, emotional responses to representational ambiguity, or affective dynamics during laboratory troubleshooting (D'Mello and Graesser, 2012; Galloway *et al.*, 2016; Tang, 2016; Muis *et al.*, 2018).

Few studies have employed qualitative, observational, or multimodal methods capable of capturing emotions as they unfold during learning. Only a small number of laboratory-based studies have attempted to access on-task affective experiences using momentary or real-time approaches, such as ecological momentary assessment (Kyynäräinen *et al.*, 2024). Although emerging work using real-time emotion recognition technologies has begun to offer insight into moment-to-moment affective responses in educational contexts (Choksi *et al.*, 2024), sustained investigation of real-time emotional processes in classroom learning remains limited.

Cultural representation also remained limited. With only one core study situated in Indonesia, the literature provides little insight into how cultural norms related to authority, emotional expression, and group harmony shape EI-related behaviors in chemistry classrooms. This absence is particularly consequential given the sociocultural grounding of emotion regulation and collaboration (Roth and Lee, 2007; Zembylas, 2023).

Finally, emotional intelligence constructs across the supporting literature were operationalized inconsistently, being framed as emotional abilities, personality traits, motivational dispositions, or components of self-regulation. When combined with the tendency in chemistry education research to avoid explicit emotional intelligence terminology, this fragmentation limits cross study synthesis and obscures conceptual coherence.

Structural conceptual gaps in EI–chemistry research

Synthesizing across the dataset, four persistent conceptual gaps emerge that collectively constrain the development of a coherent research programs on Emotional Intelligence (EI) in chemistry education. First, EI remains largely unnamed and undertheorized within chemistry education research. Although EI-aligned competencies such as emotion regulation, persistence under uncertainty, and affective awareness recur across laboratory, representational, and inquiry-based learning contexts, they are rarely positioned within an explicit or integrated affective framework. As a result, emotional phenomena are documented descriptively but not theorized cumulatively, limiting the field's capacity to build chemistry-specific accounts of how emotions function as epistemic resources rather than incidental learner attributes.

Second, EI and chemical literacy remain conceptually disconnected. Only one study engaged explicitly with chemical literacy, and none examined how EI-related competencies might support literacy outcomes involving contextual reasoning, ethical judgment, or societal decision-making. This disconnect is particularly consequential given that contemporary conceptions of chemical literacy extend beyond conceptual knowledge to include evaluative reasoning, socio-scientific engagement, and responsible action. The absence of EI from these discussions represents a missed opportunity to theorize how affective capacities enable learners to navigate the ethical and societal dimensions of chemistry.

Third, chemistry-specific EI measurement tools are notably absent. Existing studies rely predominantly on generic affective or psychological instruments that are insufficiently sensitive to the emotional dynamics of chemistry learning. Without tools designed to capture affective processes embedded in laboratory inquiry, representational transitions, or socio-scientific problem solving, EI remains artificially detached from the discipline's epistemic practices. This methodological gap not only constrains empirical insight but also reinforces the perception of EI as external to chemistry rather than as integral to doing chemistry.

Finally, cultural blind spots persist, particularly in Indonesian and other non-Western contexts. With the reviewed corpus dominated by Western educational settings, little is known about how cultural norms related to authority, emotional expression, and collective learning shape EI-related behaviors in chemistry classrooms. Without culturally grounded investigations, prevailing EI frameworks risk misalignment with local affective norms and pedagogical traditions, limiting their explanatory power and transferability.

Taken together, these gaps indicate that the challenge facing EI research in chemistry education is not a lack of affective phenomena, but a lack of theoretically integrated, methodologically situated, and culturally responsive approaches capable of capturing emotions as constitutive elements of disciplinary practice.

Discussion

The review reveals a central paradox in chemistry education: emotional processes are deeply embedded in disciplinary learning, yet Emotional Intelligence (EI) remains theoretically underdeveloped and empirically underexamined. Across the reviewed studies, emotions functioned not as peripheral reactions but as constitutive elements of chemistry learning, shaping how students engage with inquiry, representational reasoning, and socio-scientific decision making. Yet the absence of EI as a formal analytic lens has resulted in fragmented conceptualizations, methodological blind spots, and limited engagement with culturally grounded affective dynamics. Interpreted through the integrated epistemic–affective framework outlined earlier, these findings support three core arguments: (1) EI-aligned competencies underpin disciplinary participation in chemistry; (2) chemistry's epistemic practices generate distinctive emotional demands that necessitate EI; and (3) the current research landscape lacks the theoretical, methodological, and cultural grounding required to develop a coherent EI–chemistry education agenda.

Fig. 3 illustrates this positioning by conceptualizing EI as an enabling mechanism that shapes learners' epistemic emotions and, in turn, their engagement with core disciplinary practices such as laboratory inquiry, representational reasoning, and socio-scientific decision-making. Rather than depicting EI as an external input, the framework foregrounds the dynamic interplay between affective and epistemic processes in chemistry learning.

EI competencies as foundations of disciplinary participation

The eight cores chemistry–affective studies consistently demonstrated that students' participation in chemistry is contingent on their ability to recognize, regulate, and strategically deploy emotions. Whether confronting ambiguous laboratory results, representational inconsistency, or complex socio-scientific dilemmas, learners drew upon competencies closely aligned with EI—such as self-awareness, emotional regulation, resilience, and social attunement. These processes were most visible in laboratory investigations, where students responded to uncertainty by reappraising frustration, seeking peer support, or revisiting procedural steps. Such behaviors reflect EI not as an abstract trait, but as a set of enacted capacities that sustain reasoning under epistemic pressure.

Parallel patterns emerged in studies of representational reasoning. When students encountered dissonance between macroscopic observations, particulate explanations, and symbolic representations, their responses were mediated not only by conceptual knowledge but by affective stance. Learners who interpreted confusion as a signal for deeper reasoning engaged

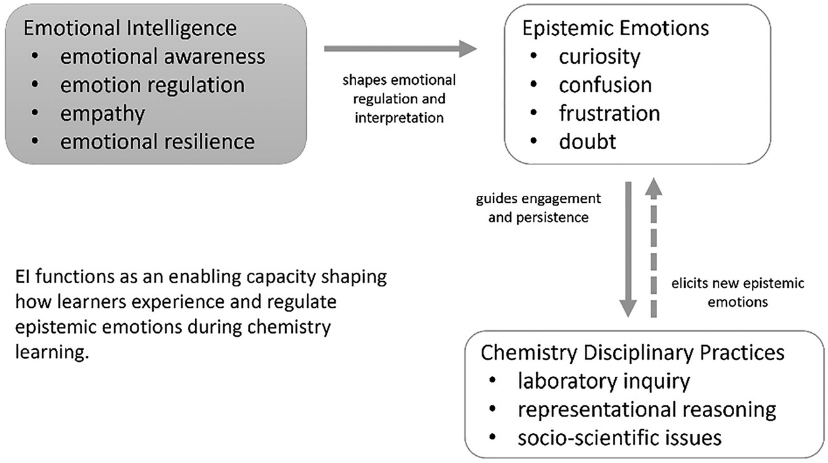

Fig. 3 Conceptual framework illustrating the role of Emotional Intelligence (EI) as an enabling mechanism in chemistry education.

more productively in representational reconciliation, whereas those who experienced confusion as threatening were more likely to disengage. This pattern aligns with research on epistemic emotions, which emphasizes how emotions guide inquiry trajectories by signaling the need for cognitive reorganization.

Supporting EI studies reinforce this interpretation. Across STEM contexts, emotion regulation, engagement, and self-efficacy consistently predicted persistence and conceptual growth. Viewed collectively, these findings suggest that EI is not an auxiliary variable but an underlying mechanism that enables the disciplinary work of chemistry. The field's tendency to examine "anxiety," "engagement," or "resilience" in isolation obscures this coherence and limits cumulative theoretical development. A key contribution of this review, therefore, lies in reframing these disparate constructs as interrelated components of an EI architecture that sustains disciplinary participation.

Chemistry's epistemic practices create unique emotional demands

A second argument emerging from the synthesis is that chemistry imposes emotional demands that are qualitatively distinctive. Chemical inquiry unfolds within a landscape of ontological uncertainty: invisible particulate entities, emergent phenomena, measurement error, and symbolic abstraction. These features generate emotional responses that are not incidental but epistemically consequential.

In laboratory settings, procedural setbacks and unexpected outcomes frequently elicited frustration, anxiety, or disappointment. When students possessed the regulatory capacity to harness these emotions productively, such experiences functioned as catalysts for deeper inquiry rather than as triggers for withdrawal. Chemistry therefore demands not only cognitive strategies but also affective ones, including tolerance for ambiguity, emotional persistence, and a willingness to reengage after failure.

Inquiry-oriented chemistry instruction has been shown to position students as active sense-makers who must navigate uncertainty, procedural setbacks, and ambiguous data. Reviews of inquiry learning in chemistry indicate that such environments require learners to persist through failure, negotiate meaning collaboratively, and adapt strategies in response to unexpected outcomes (Permatasari *et al.*, 2022). These conditions foreground the importance of emotion regulation and resilience, suggesting that EI-related competencies function as enabling mechanisms for sustained epistemic engagement. Evidence from Indonesian chemistry classrooms further indicates that conceptual development is closely linked to interaction patterns, teacher guidance, and affective engagement during inquiry-based learning (Mitarlis *et al.*, 2020; Saija *et al.*, 2022).

Socio-scientific and contextualized chemistry tasks activate a different affective profile. Engagement with issues such as environmental pollution, chemical risk, and sustainability dilemmas often evokes empathy, moral concern, and ethical tension. These emotions influence how students interpret evidence and evaluate claims, highlighting an underexplored synergy between emotional intelligence and chemical literacy. Chemical literacy therefore extends beyond conceptual mastery to include contextual reasoning, ethical judgment, and reflective decision-making in socio-scientific contexts. Context-based instruction has been shown to shape not only conceptual understanding but also students' engagement, values, and affective responses to chemical phenomena (Fadly *et al.*, 2022). These findings suggest that emotional engagement and regulation, as central components of emotional intelligence, play a critical role in supporting chemical literacy when learners confront socially and morally salient chemical issues.

Representational reasoning further illustrates chemistry's affective texture. Coordinating multiple representational levels is cognitively demanding and emotionally taxing. Students with stronger EI-aligned capacities demonstrated greater resilience in navigating representational breakdowns, suggesting that emotional regulation actively supports conceptual reconstruction. Collectively, these findings underscore that chemistry's epistemic practices are inseparable from the emotional work required to participate in them.

Limitations and conceptual constraints of EI research in chemistry education

Despite compelling evidence that EI-aligned processes shape chemistry learning, the field has yet to develop a coherent research agenda capable of capturing this complexity in a theoretically cumulative manner. Three interrelated limitations are particularly salient and collectively constrain how Emotional Intelligence is currently conceptualized and investigated within chemistry education.

First, conceptual fragmentation persists at the disciplinary level. Emotional intelligence remains largely unnamed in chemistry education research, with affective phenomena such as anxiety, engagement, frustration, or resilience examined as isolated constructs rather than as interconnected components of an integrated affective architecture. This fragmentation limits theory building by preventing the field from articulating how emotional competencies jointly support disciplinary reasoning, inquiry, and participation in chemistry. As a result, findings remain difficult to synthesize across studies, and insights related to emotional intelligence accumulate in parallel rather than converging into a coherent explanatory framework.

Second, methodological narrowness restricts analytic access to core affective mechanisms. The predominance of self-report instruments privileges retrospective and decontextualized accounts of emotion, while obscuring the dynamic emotional processes that unfold during laboratory inquiry, representational transitions, and collaborative reasoning. The scarcity of observational, multimodal, and process-oriented methodologies renders EI partially invisible precisely at moments of epistemic struggle, uncertainty, and decision-making that are central to chemistry learning. Consequently, existing studies capture what students report feeling, but rarely how emotions are regulated, negotiated, and mobilized *in situ*.

Third, cultural grounding remains theoretically underdeveloped. The limited representation of non-Western educational contexts within the reviewed literature reflects not merely a geographic gap, but a deeper theoretical blind spot regarding the cultural mediation of Emotional Intelligence in disciplinary learning. Prevailing EI frameworks have been developed largely within Western traditions that prioritize individual emotional expression, self-assertion, and autonomous regulation. Norms related to emotional restraint, relational harmony, and respect for authority can be observed across many educational settings, including Western classrooms. In some collectivist educational contexts such as Indonesia, however, these norms may shape how emotional expression and help-seeking behaviors are enacted within relational and hierarchical classroom structures (Li, 2012).

These sociocultural dynamics have significant implications for how EI-related competencies manifest in chemistry learning. Emotional regulation may take the form of self-suppression rather than expression, help-seeking may be mediated by hierarchical classroom relationships, and persistence may be enacted collectively rather than individually. Without empirically examining such contexts, EI research in chemistry risks reproducing culturally narrow assumptions that limit the validity and transferability of existing models. The absence of Indonesian chemistry education studies within the core empirical corpus thus represents a missed opportunity to interrogate the cultural boundaries of EI as a disciplinary construct.

Toward an epistemic – affective model of chemistry learning

Synthesizing across the reviewed studies, emotional Intelligence in chemistry education can be conceptualized as the dynamic integration of four interdependent dimensions: (1) affective competencies such as emotion recognition, regulation, and resilience; (2) epistemic emotions including curiosity, confusion, frustration, and satisfaction; (3) sociocultural emotional norms that shape participation and interaction; and (4) disciplinary practices such as inquiry, representational reasoning, and data interpretation. Importantly, these dimensions do not operate in isolation but co-constitute learners' engagement with the epistemic work of chemistry. From this perspective, EI is not a peripheral learner attribute nor an external psychological overlay, but a disciplinary necessity that mediates how students persist, adapt, and make meaning within chemistry's inherently uncertain and representationally complex practices.

Implications for DBER and chemistry education

These findings extend discipline-based education research by demonstrating that emotional competencies are integral to learners' participation in core chemistry practices, rather than ancillary to cognitive performance. EI frameworks offer chemistry education research a conceptual vocabulary for articulating how students navigate the emotional turbulence of inquiry, representational breakdowns, and the development of disciplinary identity. Integrating EI into teacher education, curriculum design, and assessment therefore holds potential not only for fostering emotionally responsive pedagogies, but also for strengthening students' sustained engagement with the epistemic demands of chemistry—particularly in culturally rich contexts such as Indonesia.

Implications

The findings of this review carry important implications for chemistry education research, instructional design, and teacher development. First, the prominence of emotion regulation, epistemic emotions, and resilience across the core studies indicates that competencies aligned with emotional intelligence are foundational to productive engagement in chemistry learning. Chemistry educators should therefore recognize emotional demands, particularly those arising from laboratory uncertainty, representational transitions, and socio scientific deliberation, as integral features of disciplinary practice rather than as peripheral or incidental factors. Pedagogical approaches that explicitly scaffold emotional regulation, normalize productive struggle, and support reflective engagement with frustration may enhance students' capacity to navigate the conceptual and procedural complexity of chemistry.

Second, chemistry teacher education programs must better prepare pre service and in service teachers to identify, interpret, and respond to students' emotional cues during inquiry, problem solving, and collaborative work. The limited presence of emotional intelligence as an explicit construct in existing teacher preparation highlights a missed opportunity. Integrating strategies informed by emotional intelligence into professional development, including modelling emotional reframing during laboratory troubleshooting, supporting collective emotional regulation in group work, and cultivating classroom climates that tolerate uncertainty, can strengthen both instructional practice and student learning.

Third, the methodological limitations identified in this review underscore the need for more robust tools to capture emotional dynamics in chemistry learning. Heavy reliance on self-report measures obscures the moment-to-moment affective trajectories that unfold during experimentation, representational reasoning, and socio scientific engagement. Incorporating multimodal approaches, including discourse analysis, video based affective coding, reflective artefacts, or physiological indicators, would deepen understanding of how emotions shape learning processes and reveal the mechanisms through which emotional intelligence supports disciplinary engagement.

Fourth, the limited cultural diversity of the empirical literature highlights an urgent need for contextually grounded research, particularly in Indonesia and other collectivist societies where emotional expression, relational harmony, and social norms play a significant role in classroom interaction. Developing culturally responsive EI frameworks for chemistry education could bridge global theoretical perspectives with local pedagogical realities, contributing to more inclusive and context-sensitive practice.

Finally, integrating emotional intelligence with chemical literacy, socio scientific reasoning, and inquiry-based learning frameworks offers a promising avenue for broadening the conceptual landscape of chemistry education. Emotional intelligence can function as a connective lens linking cognitive reasoning, ethical judgment, and emotional engagement, dimensions that are increasingly central to preparing learners to address complex chemical challenges in real world contexts. In this sense, attention to emotional intelligence may foster more holistic and human centered accounts of what it means to think, act, and participate as a chemist.

Taken together, these conceptual, methodological, and cultural constraints suggest that advancing EI research in chemistry education requires more than incremental refinement of existing approaches. Instead, the field must pursue integrative theoretical frameworks, methodologically innovative designs, and culturally grounded investigations that are explicitly aligned with the epistemic practices of chemistry. The following section outlines priority directions for future research that respond directly to these identified limitations. Taken together, these limitations indicate that advancing EI research in chemistry education requires not incremental refinement, but a reorientation toward discipline-sensitive theory building, methodologically situated inquiry, and culturally grounded investigation.

Future directions

The synthesis presented in this review reveals not merely opportunities for future research, but a set of structural imperatives for advancing a coherent and discipline-sensitive agenda on Emotional Intelligence (EI) in chemistry education. While affective phenomena are clearly embedded in chemistry learning, their systematic investigation remains constrained by conceptual ambiguity, methodological limitation, and cultural underrepresentation. Building on the epistemic–affective model articulated in this review (Fig. 4), future research must pursue interconnected directions that address these constraints if EI is to function as a meaningful disciplinary construct rather than a loosely attached psychological label.

Fig. 4 Integrative model synthesizing current limitations and future directions for Emotional Intelligence research in chemistry education. The model identifies key leverage points for advancing theory, pedagogy, and methodology, highlighting pathways toward contextually grounded and epistemically informed research and practice.

Developing chemistry-specific EI frameworks

A foundational priority is the development of EI frameworks grounded explicitly in the epistemic and affective work of chemistry. Continued reliance on generic EI models risks obscuring how emotional competencies operate within chemistry's distinctive practices, including laboratory troubleshooting, representational reasoning, and socio-scientific deliberation. Future frameworks must therefore theorize EI as a discipline-embedded capacity, accounting for how affective competencies, epistemic emotions, and sociocultural norms jointly shape participation in chemical inquiry. Without such chemistry-specific theorization, EI research will remain conceptually fragmented and insufficiently aligned with disciplinary meaning-making.

Advancing methodologies for capturing emotional dynamics in chemistry learning

Methodological innovation constitutes a second critical trajectory. The dominance of self-report measures has restricted insight into how emotions unfold dynamically during chemistry learning activities. Future research must adopt methodologies capable of capturing emotional processes *in situ*, including video-based affective analysis, discourse-oriented approaches, experience sampling, and process tracing. Such methods are essential for examining how EI-related competencies are enacted moment by moment during laboratory work, representational breakdowns, and collaborative reasoning. Without this shift, EI will continue to be inferred retrospectively rather than observed as an active component of disciplinary engagement.

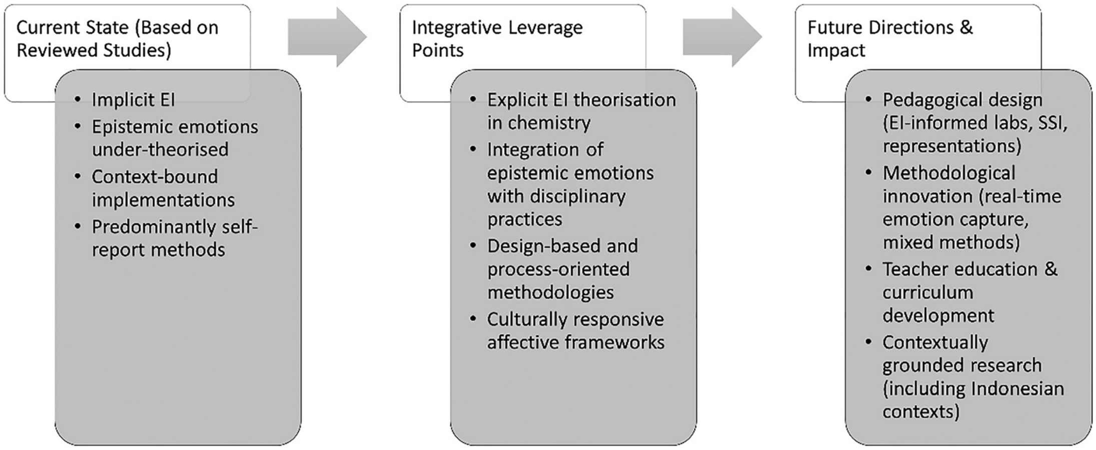

Fig. 4 Integrative model of EI in chemistry education (forward-looking).

Designing emotion-responsive pedagogies and learning environments

A third direction concerns the intentional design of pedagogies that respond to the affective demands of chemistry learning. Rather than treating emotions as incidental, future instructional research should examine how pedagogical scaffolds can normalize productive struggle, support emotional reframing during conceptual conflict, and facilitate empathic engagement in socio-scientific contexts. Intervention studies integrating EI with inquiry-based, problem-based, or socio-scientific pedagogies are particularly needed to clarify how emotional and cognitive dimensions of learning can be jointly optimized. Importantly, such work should also examine how teachers' own emotional competencies shape classroom climates and students' willingness to engage with uncertainty.

Culturally grounded EI research in chemistry education

Indonesian chemistry classrooms, characterized by collectivist norms and relationally oriented emotional regulation, offer an epistemic test case for examining how emotional intelligence operates beyond Western centric assumptions embedded in many existing frameworks. Given the strong sociocultural mediation of emotional expression and regulation, particularly in collectivist and hierarchical educational settings, future research must examine emotional intelligence within culturally situated chemistry classrooms. Investigating such contexts can illuminate how competencies related to emotional intelligence are enacted, constrained, or transformed by norms of relational harmony, respect for authority, and socially regulated emotional expression, thereby strengthening the theoretical robustness and transferability of emotional intelligence models in chemistry education.

Integrating EI with chemical literacy and identity formation

Another underdeveloped trajectory involves the integration of emotional intelligence with chemical literacy and chemistry identity. Reasoning about chemical issues with societal, ethical, and environmental implications is inherently affective, yet the emotional dimensions of literacy remain marginal in existing research. Future studies should examine how competencies related to emotional intelligence support ethical judgment, empathy, and sustained engagement with complex chemical problems. In parallel, research on chemistry identity formation should attend to how emotional experiences, including belonging, confidence, frustration, or exclusion, influence learners' trajectories into and within the discipline.

Prior work on context-based and socio-scientific chemistry instruction in Indonesian contexts suggests benefits for meaningful learning outcomes, including students' chemical literacy (Fadly *et al.*, 2022). Complementarily, evidence from systematic reviews highlights those multiple representations support representational understanding and conceptual learning in chemistry (Permatasari *et al.*, 2022). Future EI research in chemistry should build on these foundations by explicitly examining how emotional regulation, epistemic emotions, and identity-related affect interact within literacy-oriented and inquiry-based instructional designs.

Developing assessment tools for EI in chemistry contexts

Finally, advancing the field will require the development of assessment instruments that reflect the affective realities of chemistry learning. Existing EI measures are insufficiently sensitive to the emotional nuances of laboratory uncertainty, representational difficulty, and collaborative problem solving. Chemistry-specific EI assessments would enable more precise empirical work and provide educators with actionable insights into students' affective competencies as they engage in disciplinary practices.

Advancing emotional intelligence research in chemistry education therefore demands more than incremental extension of existing approaches. It requires a reconceptualization of emotional intelligence as an epistemic and affective capacity embedded in disciplinary practice, supported by methodologically robust, culturally responsive, and pedagogically grounded research. By situating emotional intelligence at the intersection of emotional experience, epistemic engagement, and disciplinary participation, future scholarship can move toward a more comprehensive and human centered understanding of what it means to learn and to become a chemist. This review provides a foundation for such work and delineates the conditions under which emotional intelligence can become a generative construct for chemistry education research.

Limitations

While this review provides a systematic and analytically coherent synthesis of EI-related research within chemistry education and closely aligned inquiry-based science contexts, several limitations warrant careful consideration.

First, although the PRISMA-guided search yielded a broad corpus of literature, the final analytic dataset was shaped by a disciplinary-relevance appraisal that prioritized chemistry-specific affective mechanisms. This approach was necessary to preserve epistemic coherence and avoid conceptual dilution; however, it may have excluded studies in which EI-related processes were present but not explicitly articulated within chemistry learning contexts. As such, peripheral or emergent contributions to EI in chemistry may not be fully represented.

Second, the relatively small number of core chemistry–affective studies constrain the generalizability of the review's conclusions. Only eight studies directly examined emotional dynamics within chemistry learning environments, and these were unevenly distributed across laboratory, representational, and contextual instructional settings. This limited empirical base restricts the extent to which robust cross-contextual claims about EI in chemistry can be made and underscores the nascent state of the field.

Third, methodological patterns within the included studies introduce further constraints. The predominance of self-report instruments limits access to the dynamic, situational nature of emotional processes that EI frameworks seek to explain. Most studies captured learners' retrospective perceptions rather than emotions as they unfolded during inquiry, representational breakdowns, or collaborative reasoning. In addition, variation in how affective constructs were operationalized across studies may introduce interpretive inconsistency, complicating direct comparison and synthesis.

Fourth, cultural representation within the dataset was limited. With only one core study situated in Indonesia and the majority conducted in Western educational contexts, the findings may not adequately capture how EI-related processes are shaped by culturally specific norms of emotional expression, authority, and classroom interaction. Given the sociocultural mediation of emotion, this limitation is particularly salient for interpreting EI in diverse chemistry education settings.

Finally, the review was confined to peer-reviewed English-language articles indexed in Scopus. This constraint introduces potential language and database biases, excluding grey literature, unpublished dissertations, and studies published in other languages—particularly those emerging from Asian or Global South contexts. Consequently, the cultural and methodological diversity of EI research in chemistry may be underrepresented.

Despite these limitations, the review offers a rigorous and discipline-sensitive synthesis that clarifies the current state of EI research in chemistry education. More importantly, the identified constraints are not merely limitations of this review but reflect structural characteristics of the existing literature, reinforcing the need for conceptual refinement, methodological diversification, and culturally grounded research in future work.

Conclusions

This systematic review demonstrates that emotional intelligence occupies a meaningful yet largely unarticulated position within chemistry education. Addressing the first research question, the synthesis reveals that emotional intelligence has not been explicitly theorized as a disciplinary construct in chemistry education. Instead, competencies aligned with emotional intelligence, including emotion regulation, resilience, and epistemic affect, appear implicitly across studies as structuring features of students' engagement with chemistry learning. These findings suggest that emotional intelligence is present not as a formal framework but as an underlying affective architecture embedded within disciplinary practice.

In response to the second research question, the review shows that EI has been integrated into chemistry classrooms primarily in indirect and fragmented ways. Emotional processes emerge most clearly within laboratory inquiry, representational reasoning, and socio-scientific engagement, where learners must navigate uncertainty, conceptual conflict, and ethical tension. However, these affective demands are rarely addressed through intentional instructional design. Instead, EI-related processes are treated as incidental rather than as pedagogically actionable components of chemistry learning environments and assessment practices.

Addressing the third research question, the analysis identifies clear research patterns and methodological characteristics across the reviewed studies. Empirical work on EI in chemistry education remains limited in scope, with a small number of chemistry-specific studies, heavy reliance on self-report instruments, and minimal use of methods capable of capturing real-time emotional dynamics. Moreover, the literature is dominated by Western educational contexts, with only marginal representation of Indonesian and other non-Western settings, constraining the cultural generalizability of existing findings.

Finally, in relation to the fourth research question, the review exposes several persistent conceptual and pedagogical gaps. EI remains theoretically fragmented, disconnected from chemical literacy and identity formation, and insufficiently grounded in disciplinary and cultural contexts. These gaps point to the need for chemistry-specific EI frameworks, multimodal methodological approaches, culturally responsive research designs, and pedagogies that explicitly engage with the emotional dimensions of chemical inquiry.

By situating EI at the intersection of affective, epistemic, and sociocultural dimensions of chemistry learning, this review offers a disciplinary lens for understanding how emotions shape participation in the work of chemistry. Advancing EI research within chemistry education holds promise for developing more holistic accounts of learning, informing emotionally responsive instructional design, and supporting learners' sustained engagement with the conceptual, procedural, and ethical demands of the discipline. Through such efforts, EI can function not as an external psychological add-on, but as a foundational component of what it means to learn—and to become—a chemist.

Author contributions

Conceptualization: Ika Farida Yuliana, methodology: Ika Farida Yuliana, I Wayan Dasna, formal analysis: Ika Farida Yuliana, Sri Rahayu, investigation: Ika Farida Yuliana, I Wayan Dasna, data curation: Ika Farida Yuliana, writing – original draft: Ika Farida Yuliana, writing – review & editing: Haris Munandar, Romelos Untailawan, supervision: I Wayan Dasna, Sri Rahayu, Munzil, validation: I Wayan Dasna, Sri Rahayu, visualization: Ika Farida Yuliana, Munzil, project administration: Ika Farida Yuliana.

Conflicts of interest

There are no conflicts to declare.

Data availability

This study is a systematic review based solely on published literature. No new primary data were created or analyzed. All data supporting the findings of this article are available within the cited sources and the supplementary information (SI) associated with the original publications. Supplementary information: (1) the Scopus search dataset (CSV), (2) the PRISMA 2020 screening summary, and (3) tables of included and excluded articles with eligibility codes. These materials provide full transparency regarding the data extraction procedures and article selection workflow. See DOI: https://doi.org/10.1039/d6rp00072j.

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