


INTEGRATING CRITICAL THINKING SKILLS IN SECONDARY CHEMISTRY TEACHING: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Critical thinking (CT) is the core of the chemical education curriculum, yet it is generally in an inconsequential understanding and practice with second-level teachers. The research is a review of the previous studies of the integration of CT in teaching secondary chemistry. The research aims to find out how CT is conceptualised, taught and assessed by chemistry teachers and its consistency behind these practices. The systematic review was performed through the PRISMA 2020 guidelines. In total, 23 empirical studies of the period 2021-2025 were identified through using Scopus, Web of Science, ERIC and ScienceDirect. Important findings were extracted by thematic analysis. The Majority of teachers have an infusion style, which inserts CT into chemistry lessons based on inquiry, project-based learning, and socioscientific issues. The CT training and corresponding evaluation is scarce. Feedback and scaffolding are applied irregularly, though they are good. The beliefs of the teachers regarding the importance of CT, as well as its reality in the classroom, have a very distinct gap. Practices of assessment usually fail to respond to CT objectives. Future studies are required to come up with chemistry-specific models of CT and assessment instruments. Effective integration should be backed by professional development.

Keywords: Critical Thinking, Instructional Strategies, Secondary Chemistry, Systematic Literature Review.



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INTRODUCTION

With the fast pace of modern society, the formation of critical thinking (CT) is now considered to be an important ability within secondary education, specifically in such sciences as chemistry (Ariyani et al., 2025; Beltran, 2025; Poulikova, 2025). Acquisition of CT abilities in students enables them to consider deep issues, critically analyse data, and make justified decisions – important skills for both academic inquiry and real-world decision-making. Therefore, there is a worldwide encouragement of science instruction by the global curriculum and policy documents to place a profound emphasis on CT.

While research indicates, however, an evident distinction is observed between the need described in curricular frameworks and its reflection within actual classroom activities. There are great differences in the application and teaching of critical thinking by secondary chemistry teachers (Wahyudiati, 2022). There is a prevalent problem among teachers of not having adequate preparation from training or theoretical knowledge to be able to detect and use CT effectively in instruction, activities, and evaluations.

The entirely distinct barriers encountered in the course of teaching chemistry, e.g., sophisticated abstract concepts, hands-on laboratory training, and formula-oriented thinking, illustrate how teachers' approaches to and understanding of CT affect pupils' intellectual development (Agustian et al., 2022). The purpose of this systematic review was to examine the way the teaching of critical thinking is defined as an integral part of teaching by the secondary chemistry tutors (Veerasinghan et al., 2021; Endra & Villafior, 2024; Afriani & Widodo, 2025). It works out which theoretical approaches the teachers are adopting, the way the instruction is presented, what assessment tools are chosen and how much the teachers' beliefs align with their teaching practice.

The foundation of modern science scrutiny, critical thinking (CT), presents students with the capability of analysing evidence, evaluating arguments, and making well-supported conclusions (OECD, 2019). CT came out as a super competency in many chemistry teaching models throughout the literature reviewed. Based on studies carried out by Arifin et al. (2025) and Syahana et al. (2023), CT is essential for improving students' conceptual knowledge and general competence in science. Veerasinghan et al. (2021) and Song et al. (2024) demonstrate that design thinking and project-based learning (PBL) encourage creative thinking, problem-solving and self-reflection skills in students, which are critical CT concepts. These approaches depict CT as an embedded component of science education, not as an ability to be acquired separately from science education. Inquiry-based learning as posited by Adayah and Aznam (2024) and Abu Khurma and El Zein (2024) fosters student engagement by making the students ask questions, analyse evidence, and present explanations. Inquiry-based learning increases engagement through critical questioning, evidence-based analysis and explanation, leading to deeper cognitive skills (Abu Khurma and El Zein, 2024; Cortés et al., 2025; Dzulfikar et al., 2025).

While recognising CT's benefits, the inclusion of it into teaching plans is still an issue. Results from various investigations show that institutional constraints and environmental challenges are barriers for critical thinking pedagogies from being adopted. From Jamil et al. (2024) and Kamila et al. (2024), heavy syllabi, test-oriented instruction and insufficient teacher training were found to limit teachers in the effective implementation of CT techniques. Lacking proficiency in CT concepts or assurance in successfully teaching these concepts to students, instructors often resorted to simplistic questions or taught content at a cost to deeper thinking (Raihanah et al. 2024). The scarcity of resource and restricted scheduling at schools in the UAE hindered the practice of student-led inquiry, which is a critical technique for CT development, according to Abu Khurma & El Zein (2024). Teachers prioritised CT, yet inflexible curricula and loss of pedagogical autonomy made it rarely incorporated (Mansyuarna et al., 2023; Setiawan et al., 2023; Ikhsan et al., 2025).

Stark differences in the secondary chemistry teachers' understanding of CT were evidenced in the reviewed studies (Gong et al., 2022). Some teachers associated CT with larger life competencies such as communicating, problem solving, and decision making (Jamil et al., 2024), while others firmly linked CT to scientific reasoning and analysis (Ho et al., 2023; Julianti et al., 2025). Krisandini & Anwar (2024) and Setiawan et al. (2023) reported that teachers' varied concepts of CT had a direct effect on instructional planning and resulted in asymmetric practices in the classroom. Adopting results by Raihanah et al. (2024), educators with significant TPACK were found to have higher effectiveness in integrating CT into the mechanism of studying chemistry using attractive digital materials or in the form of student-centred tasks. However, many researchers reported that the teacher preparation curricula usually did not offer a systematic training in CT, and accordingly, constrained instructors' ability to apply CT into practice (Kite and Park, 2022; Nou et al., 2025; Putri et al., 2025).

Various methods of teaching were identified as effective in promoting the development of CT in secondary chemistry. Inquiry-based learning took the leading role as it supported CT development because it encouraged students to ask, analyse information, and provide conclusions (Nwune et al., 2023; Arifin et al., 2025; Adayah & Aznam, 2024; Nwoji et al., 2025). Adayah & Aznam, 2024). Project-based learning interventions, reviewed by Zulyusri et al (2023), and socioscientific issue-based teaching, which was effective as shown by Çalık & Wiyarsi (2021), Prastika & Arianingrum (2024), created opportunities for students to examine practical problems, and they motivated them to apply chemistry in relevant settings, therefore promoting analysis, reflection, and argumentation. According to Hamzah et al. (2022), the work conducted uncovered that metacognitive-based teaching strategies positively influenced CT, with Ogegbo & Ramnarain (2024) stressing the necessity of culturally responsive approaches to support inclusive and reflective CT experiences. Structured worksheets, questioning prompts, and guided discussions, among other scaffolding methods, were often used in the chemistry classroom according to SYAHANA et al. (2023) and HO et al. (2023).

The evaluation of CT is frequently neglected and insufficiently covered by chemistry teaching. Research by Ismail & Osman (2024) and Nsabayeze et al. (2022) identified the inclusion of formative assessments, self-evaluation rubrics, and performance-based tasks, but many instructors adhere to traditional, memory-based tests. Sánchez Morales et al. (2024), Song et al. (2024) stressed the fact that a mismatch between teaching approaches and assessment practices eliminates the attempts to develop CT. As indicated by Hasnah et al. (2024), valuable curricular tools such as books are typically lacking in CT-related information, thus creating obstacles to both prohibiting opportunities to teach and assess students. Instances of when CT instruction occurred exhibited evaluation that was generally casual, with or without proper paperwork or not at all.

There is significant excitement about CT in science education, though significant gaps exist, primarily in the form of specific application of CT in the context of chemistry (McCollough and Rajiah, 2023). Research has mostly overlooked the topic of how CT is defined, taught, and evaluated in chemistry compared to general science education (Cooper and Stowe, 2018; Sigar et al., 2025; Yulisman et al., 2025). A set of initiatives on CT in chemistry was short, and they did not provide a lot of documentation about teaching methods, which made replicating and assessing these strategies difficult (Raihanah et al., 2024; Arifin et al., 2025). Increased attention is needed in the classroom to examine the changing nature of CT and ways in which it can be consistently used in teaching secondary chemistry (Bernardi and Pazinato, 2022). Nevertheless, digital technologies and online platforms (e.g., Iyamuremye et al., 2024; Prokop-Dorner et al., 2024), which are promising in general, have not been studied thoroughly in the context of chemistry-specific CT. Although Prokop-Dorner et al. (2024) have proven promising; the particular integration of developing CT involving chemistry remains unexplored.

Hence, this article fills these gaps by using a systematised literature review of 23 studies to identify secondary chemistry education published between 2021 and 2025. The focus of the review is to explore the meaning of CT as perceived, taught and evaluated by chemistry teachers and the consistency between teachers on the concepts of their beliefs, teaching instructions and the evaluation techniques. This review will help gain a better insight into the current practices and problematic issues of the present situation of integrating CT into secondary chemistry. The results would be used to direct future studies on the development of chemistry-specific CT modelling, inform teacher training programmes and provide advice to curriculum developers and policymakers to develop more effective, logical and evidence-based approaches to promoting CT in chemistry classrooms.

The main research question is “How do secondary chemistry school teachers understand and integrate critical thinking skills into their teaching practices?”. The five supplementary questions are also stated in the following section.

- What critical thinking (CT) models or theoretical frameworks inform secondary chemistry teachers’ understanding of CT?
- What types of instructional strategies do teachers use to embed CT in chemistry lessons?
- To what extent is the CT instruction process based (e.g., during experiments and problem-solving) or product based (e.g., assessments and outputs)?
- What tools or methods are used to assess students’ CT skills in chemistry classrooms?
- Is there consistency between teachers’ understanding of CT, their instructional implementation, and assessment practices?

RESEARCH METHOD

In line with PRISMA 2020 guidelines, this review carefully identified and reported all relevant literature transparently and rigorously (Salameh et al., 2020; O’Dea et al., 2021). The main aim of the review was to investigate the degree to which secondary chemistry teachers are aware of and use critical thinking (CT) skills in their teaching techniques (Alsaleh, 2020; Lorencová et al., 2019; Rushiana et al., 2023). A methodology for the screening system was described and recorded using a PRISMA flowchart to achieve methodological quality and allow others to reproduce the study.

The research began with the formulation of focused research questions to guide the search methodology. Key words were selected intentionally based on the aspects such as “critical thinking”, “secondary chemistry”, “teacher understanding”, “instruction”, and “pedagogy”. The search strategy included the use of Boolean operators such as AND and OR to effectively cluster search terms. To achieve maximum coverage, the research employed Scopus, Web of Science, ERIC, and ScienceDirect – four major sources that experts in the field of education and science also used.

A default search of the four databases identified 412 possible matches. As a part of the initial screening, researchers carefully reviewed titles and abstracts, eliminating non-empirical, replicated, and non-English publications. Consequently, there emerged only 234 articles that had potential relevance. A subsequent screening process was hence conducted to eliminate options which would leave studies which mentioned secondary education, chemistry, and teachers' comprehension or application of CT concepts. After this stage, 42 articles were identified and forwarded for full-text evaluation.

The remaining 42 articles were given a separate appraisal to determine which ones were relevant and methodologically excellent. Studies were excluded if they failed to explore teacher perceptions, were specific about their method of research, or excluded CT integration in their parameters. Numbering the 19 articles excluded, 19 articles were excluded, and 23 studies were included in the final review.

Throughout the process, documentation and transparency were allowed to persist following the principles in the guidelines provided by the PRISMA guidelines (Page et al., 2021b; Page et al., 2021a). The PRISMA diagram attached to this review is a pictorial representation of the iterative selection process and describes which sources were identified, analysed, and included. With this all-encompassing strategy, it maintains the trustworthiness and reinforcement of the review's conclusion, making way for other scholars to improve the conclusion by replicating or widening the methodology.

Table 1. Types of CT instructions

Form of Teaching CT	CT Principles	Content Used
Generic	Teach CT skills separately from chemistry content. CT is an explicit instructional goal.	Explicit
Infused	CT is integrated into chemistry teaching with a clear intention. Teachers guide students to think critically within the subject context. CT is an explicit goal.	Explicit
Immersion	Students are immersed in rich chemistry content and expected to develop CT through active engagement. CT is not taught explicitly.	Implicit
Mixed	A hybrid of infused and/or immersion approaches. CT may also be taught as a separate module within the chemistry curriculum.	Explicit (if generic + infused) Both (if generic + immersion)

Table 2. The search strings used in the database search

Database	Search String
Web of Science (WoS)	TS = (("critical thinking" OR "CT" OR "thinking skills") AND ("chemistry teaching" OR "secondary chemistry education") AND ("teacher understanding" OR "teacher perception" OR "science instruction" OR "pedagogy"))
Scopus	TITLE-ABS-KEY = (("critical thinking" OR "CT" OR "thinking skills") AND ("secondary chemistry" OR "chemistry education") AND ("teacher knowledge" OR "instructional practices" OR "integration" OR "teaching strategies"))
ERIC	("critical thinking" AND "chemistry teachers" AND "secondary school" AND ("teaching methods" OR "instruction" OR "professional knowledge"))
ScienceDirect	("critical thinking" AND "secondary chemistry education" AND "teacher understanding" AND ("pedagogical approaches" OR "teaching integration"))

Table 3. An overview of research on how Chemistry teachers cultivate CT in teaching

Article No.	Author(s) & Year	Contextual Settings	Data Analysis Method
1	Veerasinghan et al. (2021)	Malaysia, secondary chemistry education, design thinking for creativity and CT	Secondary
2	Adaayah & Aznam (2024)	Indonesia: guided inquiry in chemistry to support CT and concept mastery	ANOVA
3	Abu Khurma & El Zein (2024)	UAE; teacher perspectives on inquiry skills and CT in science classes	Secondary
4	Setiawan et al. (2023)	Indonesia: 21st-century skills in chemistry teaching; challenges in CT implementation	Primary
5	Ismail & Osman (2024)	Malaysia: Formative assessment in chemistry supporting CT and student engagement	Secondary
6	Hamzah et al. (2022)	Malaysia: metacognition-based HOTS modules fostering CT in science/chemistry	Statistical (t-tests, ANOVA)
7	Song et al. (2024)	Malaysia/China; PBL improving CT and language skills in EFL (transferable to chemistry)	Meta-analysis / Descriptive
8	Krisandini & Anwar (2024)	Indonesia: chemistry curriculum content and pedagogy supporting CT through ICT and inquiry	Secondary
9	Kamila et al. (2024)	Indonesia: Integration of local wisdom to foster CT and cultural awareness in science	Secondary
10	Ho et al. (2023)	Taiwan: Socratic questioning in medical biochemistry labs enhancing CT	Secondary
11	Raihanah et al. (2024)	Indonesia: TPACK among chemistry teachers and its impact on CT and tech integration	Descriptive statistics
12	Arifin et al. (2025)	Indonesia/Malaysia; meta-analysis confirms inquiry-based learning strongly improves CT	Meta-analysis
13	Jamil et al. (2024)	Pakistan: teachers' experiences with life skills (incl. CT) in secondary education	Thematic analysis
14	Ogegbo & Ramnarain (2024)	South Africa: indigenous knowledge integration in science teaching, enhancing CT	Thematic analysis
15	Syahana et al. (2023)	Indonesia: design thinking in chemistry enhances CT and science literacy	Secondary analysis
16	Prokop-Dorner et al. (2024)	Poland: cross-disciplinary methods enhancing CT in health and science education	Secondary Content analysis
17	Prastika & Arianingrum (2024)	Indonesia: SSI in chemistry improves CT, argumentation, and science literacy	Secondary
18	Sánchez Morales et al. (2024)	Spain: green chemistry as a framework for CT and sustainability in chemistry	Secondary content analysis
19	Zulyusri et al. (2023)	Indonesia; PjBL in science education improving creativity and CT	Primary
20	Nsabayezu et al. (2022)	Rwanda: Rubrics in chemistry education enhance CT and self-assessment	Secondary
21	Çalık & Wiyarsi (2021)	Turkey & Indonesia; SSI in chemistry education promote CT and relevance	Content analysis
22	Hasnah et al. (2024)	Indonesia: Lack of CT in EFL textbooks highlights implications for chemistry materials	Secondary
23	Iyamuremye et al. (2024)	Rwanda: web-based discussion in chemistry improves CT, collaboration, and engagement	Secondary

Table 4. A methodological view of reviewed studies.

Educational Level	Research Methods	Sampling Techniques	Data Collection	Data Analysis
Secondary education: 23 (100%)	Qualitative: 6 (26%) Quantitative experimental: 8 (35%) Mixed methods: 6 (26%) Systematic/Scoping review: 3 (13%)	Convenience or purposive: 11 (48%), Random: 5 (22%), Not mentioned: 7 (30%)	Questionnaire: 8 (35%) Interview: 6 (26%) Document review: 5 (22%) Observation: 3 (13%) Test: 1 (4%)	Content analysis: 10 (43%) SPSS/ANOVA/t-test: 6 (26%) Thematic coding: 5 (22%) Not mentioned: 2 (9%)

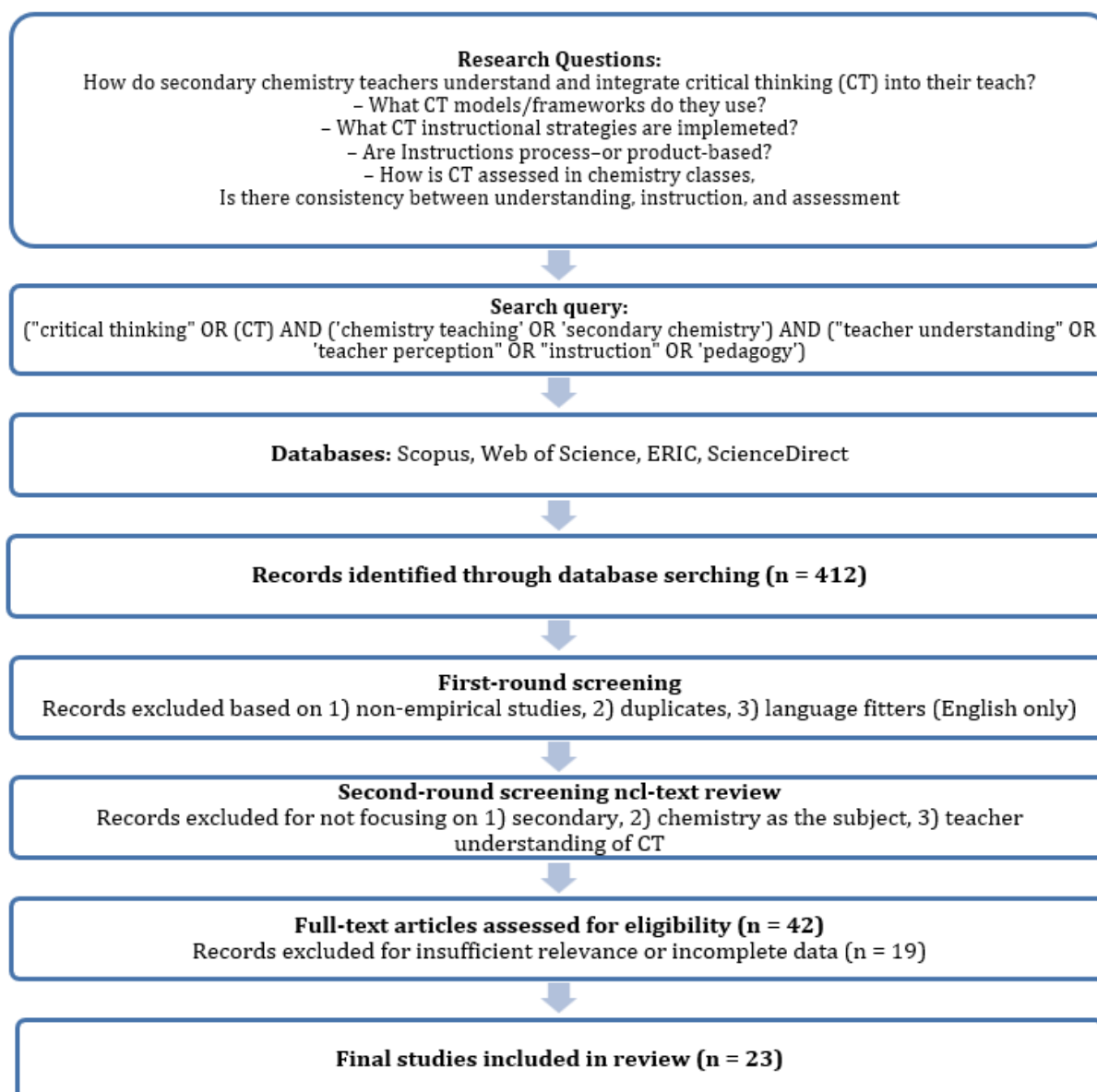


Figure. 1. Prisma flow diagram.

Since this research is a literature review and not a primary empirical research that involves participants, it is not possible to apply such concept as statistical power in its traditional sense of hypothesis testing. Rather, the number of included studies (n = 23) is the “sample size” in this review because of the inclusion depending on the strict screening procedures in accordance with PRISMA 2020

recommendations. The study of this review has very strong methodological breath and diversity of the researched studies included in it, which provide strong coverage of the current state of research direction in teaching critical thinking (CT) in chemistry education at the secondary stage (Wang and Jia, 2023). Although such a type of review does not involve formal statistical power analysis, the process of including studies conducted in various contexts and methodologies helps to improve the analytical depth and quality of findings. Therefore, the "power" of this review is embedded in its systematic design, comprehensive database coverage, and detailed thematic synthesis rather than numerical sample power.

RESULTS AND DISCUSSION

Contextual Strategy-Based Deep Learning in High School

For data analysis, the methodological strategies and teaching interventions descriptions of the 23 reviewed studies were considered as primary raw materials. Upon analysing the research findings and discussions in detail, the team relied on them as the foundation of coding and thematic analysis. Out of this process, a set of four major themes was developed, which capture the general patterns and the important findings linked to secondary chemistry teachers' approach to teaching critical thinking.

Methodological information

All 23 studies chosen for this systematic review focused on secondary education and were primarily based on chemistry. In these studies, research approaches indicated a relatively even balance of different methodologies. About a third (35%) of the studies employed quantitative experimental forms of study, mainly through using pre- and post-tests to determine the influence of instructional strategy in the development of critical thinking. Qualitative research taken up by the studies accounted for 26%, and it often involved employing interviews, classroom observation, or reviewing documents to trace teachers' views and practice. Mixed-methods research accounted for 26% of the studies and incorporated quantitative data and narrative descriptions in building a cohesive view. Furthermore, 13% of the studies were systematic or scoping reviews, which gave a general overview of such evidence that is available out there.

Within the studies, the largest study proportion used convenience or purposive sampling (48%), while random sampling followed at 22%. Interestingly, 30 % of the studies did not describe how they selected their sample. The main sources of data gathering by research teams included questionnaires, 35%, interviews, 26%, and document reviews, 22%. Observations (13%) or testing instruments (4%) were used in a few studies regarding data collection. Analysis of data was conducted using content or thematic analysis (43%), statistical testing (26%), which included ANOVA or t-tests, and qualitative coding (22%). Two of the studies (9%) did not specify what analysis method they used.

Although this is a systematic literature review, rather than a primary, quantitative research experiment, the statistics were taken into account when assessing methodologies of the chosen articles. Among the 23 reviewed studies, several utilized quantitative methods, including descriptive statistics, ANOVA, t-tests, and SPSS-based analyses, to measure the effects of instructional interventions on students' critical thinking (CT) skills. All quantitative studies mainly involved the comparison of pre- and post-intervention outcomes, the evaluation of the experimental and control group differences as well as correlation of the CT development and instructional strategies. Where applicable, effect sizes were used to determine the strength of impact of certain teaching techniques. Moreover, meta-analytic studies that were reviewed to enhance generalizability employed pooled effects size. Nevertheless, no original statistic calculations were made on this current review; instead the results of statistical calculations published in articles were compiled. It was this that provided balanced interpretation of both quantitative and qualitative data to give a complete conclusion.

Interpretation of data results and comparing with previous studies

As outlined in the findings of this review, despite secondary chemistry teachers seeing the value of critical thinking (CT), its practical application exists in an uneven and disjointed fashion. As in some of the prior research (e.g., Abu Khurma & El Zein, 2024; Setiawan et al., 2023; Somantri, 2024; Roath et al., 2025), this review has demonstrated the existence of a gap between teacher knowledge on CT, instructional behavior and assessment. Although inquiry-based learning (IBL), project-based learning (PBL), and socioscientific issues (SSI) can be widely employed to facilitate CT, clear teaching and assessment models are underrepresented, resulting in the incompatibility between the purposes of instructions and the results of assessment. These results support the findings of prior literature implying

that CT is appreciated in theory, but it is improperly expressed in classroom practice. The generalization of this review is that teachers find it very difficult to integrate theory and practice when they lack articulate structures and trainings in a systematic manner. The implications indicate that there is an urgent necessity in terms of the development of the professionals involving using the assistance of the CT-specific instructional strategies and assessment strategies aimed at the teaching of the chemistry subject. Nonetheless, the study is constrained to its use of existing publications, which differ in terms of methodological rigor and reporting clarity. Longitudinal studies and intervention designs should be studied further to gauge the lasting effectiveness of explicit CT instruction on chemistry. The following recommendations are proposed: (i) inclusion of CT training in teacher education programmes, (ii) the design of standardised CT assessment instruments congruent with chemistry content and (iii) additional research pertaining to the use of online platforms to improve CT teaching and assessment.

Table 5. CT Models, Teaching Implementation, and Assessment Across Reviewed Studies

CT Concepts Understanding	CT-related Models/ Frameworks	Teaching Implementation	Performance Assessment	Consistency between CT Concepts, Teaching, and Assessment
Clear CT definition	Design Thinking (Stanford)	CT-focused classroom activities and workshop modelling	Not stated	No
Clear CT components	Inquiry-Based Learning (IBL)	Guided inquiry activities across chemistry topics	Academic achievement tests	Yes
CT through inquiry	Inquiry Model (Scientific Method)	Teacher interviews on IBL practices	Not reported	Partially
Implicit understanding	4Cs Framework	21st-century skill integration in content delivery	Survey & descriptive stats	Partially
Implicit CT integration	Formative Assessment Models	Use of rubrics, feedback loops, and classroom questioning	Not directly assessed	Partially
HOTS + CT combined	Metacognitive Model	Modular instruction: plan, monitor, evaluate	Mixed (tests + reflection)	Yes
Explicit CT focus	PBL + Bloom's Taxonomy	Project-based tasks with presentations and discussions	Rubrics + interviews	Yes
Implied in curriculum delivery	ICT-Inquiry Models	E-resources and simulations for CT-based learning	Not stated	No
Contextual CT awareness	Local Wisdom Frameworks	PBL and SSI tasks with cultural themes	Observation & feedback	Yes
Explicit, structured CT	Socratic Method (Paul & Elder)	Structured questioning in lab-based instruction	Rubric + written reflections	Yes

CT Concepts Understanding	CT-related Models/ Frameworks	Teaching Implementation	Performance Assessment	Consistency between CT Concepts, Teaching, and Assessment
Tech-integrated CT	TPACK Framework	Tech-pedagogical resource integration for CT tasks	Not specified	Partially
Strong CT effect analysis	IBL Framework + Meta-analysis	Data synthesis from previous CT-intervention studies	Meta effect sizes (quant)	Yes
CT within life skills	UNICEF Life Skills Framework	Reflective interviews on CT through class interaction	NVivo qualitative analysis	Yes
Argumentation + contextual	Two-Eyed Seeing, SSI	Cultural debates and issue-based learning	Thematic content analysis	Yes
Explicit design-based CT	Design Thinking (Stanford)	Empathise, define, ideate, and prototype activities	Science literacy & CT rubric	Yes
Multidimensional CT	WHO & Facione models	Six CT dimensions applied in lessons	Typology-based coding	Yes
Strong SSI-CT linkage	SSI Framework + Bloom's HOTS	Real-world controversies + class debate	Argumentation performance	Yes
Systems thinking with CT	Green Chemistry + SDGS	Contextual eco-problems & project work	Qualitative tools	Yes
Pjbl with creativity + CT	PjBL Model + CT sub-skills	Design and implementation of science projects	Creativity & CT indicators	Yes
Structured CT through rubrics	Holistic Rubric Framework	Use of analytic/task rubrics for assessment	Rubric scores & reflection	Yes
High CT orientation	SSI + Informal Reasoning	SSI tasks in chemistry (e.g., bioethics, pollution)	Relevance model coding	Yes
Lacks CT structure	Ilyas CT Framework (applied to textbooks)	Textbook evaluation (not classroom-based)	Frequency coding	No
Strong digital CT orientation	Community of Inquiry Model	Web-based discussions with teaching presence	Thematic discourse analysis	Yes

Table 6. 3Micro-settings: Main Features of CT Instructional Implementation in Chemistry Teaching

Studies	Types of CT Instruction	Process-based	Explicit Instruction	Direct CT Concepts	Social Constructivist Environment	Scaffolding	Questioning Technique	Teacher/Peer Feedback	Online Techniques
Veerasinghan et al. (2021)	Infused	✓	✓	✓	✓	✓	✓	✓	
Adaayah & Aznam (2024)	Infused	✓	✓	✓	✓	✓	✓	✓	
Abu Khurma & El Zein (2024)	Immersion				✓		✓	✓	
Setiawan et al. (2023)	Infused		✓		✓	✓		✓	
Ismail & Osman (2024)	Infused	✓	✓	✓	✓	✓	✓	✓	
Hamzah et al. (2022)	Infused	✓	✓	✓	✓	✓	✓		
Song et al. (2024)	Mixed (Infused + PjBL)	✓	✓	✓	✓	✓	✓	✓	
Krisandini & Anwar (2024)	Infused	✓	✓	✓	✓	✓	✓		
Kamila et al. (2024)	Infused	✓	✓		✓	✓		✓	
Ho et al. (2023)	Infused	✓	✓	✓	✓	✓	✓	✓	
Raihanah et al. (2024)	Infused	✓			✓	✓		✓	✓
Arifin et al. (2025)	Infused	✓	✓	✓	✓	✓	✓		
Jamil et al. (2024)	Immersion		✓		✓			✓	
Ogegbo & Ramnarain (2024)	Infused	✓	✓	✓	✓	✓	✓	✓	

Studies	Types of CT Instruction	Process-based	Explicit Instruction	Direct CT Concepts	Social Constructivist Environment	Scaffolding	Questioning Technique	Teacher/Peer Feedback	Online Techniques
Syahana et al. (2023)	Mixed (Infused + Design)	✓	✓	✓	✓	✓		✓	
Prokop-Dorner et al. (2024)	Infused	✓	✓	✓	✓	✓		✓	✓
Prastika & Arianingrum (2024)	Mixed (Infused + SSI)	✓	✓	✓	✓	✓	✓		
Sánchez Morales et al. (2024)	Infused	✓	✓	✓	✓	✓			
Zulyusri et al. (2023)	Mixed (Infused + PjBL)	✓	✓	✓	✓	✓	✓		
Nsabaye zu et al. (2022)	Infused	✓	✓	✓	✓	✓		✓	
Çalık & Wiyarsi (2021)	Infused	✓	✓	✓	✓	✓	✓	✓	
Hasnah et al. (2024)	Infused								
Iyamuremye et al. (2024)	Infused	✓	✓	✓	✓	✓		✓	✓

Main Elements: CT Concepts, Teaching Implementation, and Assessment

The studies revealed that there are high differences in the way the secondary chemistry teachers define and teach critical thinking. Some research papers are based on structured models such as Facione’s or Paul & Elder’s model, while others treat CT as a generalised higher-order skill to be applied in inquiry or project designs (Yuan et al., 2022). Based on the intervention implementation, most of the “infused” interventions reported that CT was taught within the chemistry subjects, and not as a separate subject. Instructional strategies involved guided inquiry, Socratic questioning, application of problems, the use of relevant tasks, and dialogue on socioscientific issues. The integration of in-class scaffolding, relevant feedback from teachers and students’ reflection was critically important for deep thinking. However, in only some of the studies were explicit CT instruction or targeted CT concept teaching to be found. Rubrics, reflective assignments, and performance tasks were used in assessment regularly, but several studies did not tie CT goals to assessment strategies applied. At the end of the tale, it became apparent that there is a high demand for coherent, model-centred instruction and assessment approaches in all contexts.

Main Features: CT Instructional Implementation in Chemistry Teaching

Each study showed a different series of instructional strategies in action. Many of the interventions included the CT development within the core chemistry topics, such as acids and bases, equilibrium and environmental chemistry (Weerarathna et al., 2024). Some research used process-based instruction, with special focus on the stages of planning, reasoning, and reflection. Socratic questioning, cooperative group work, and project-based assignments were also quite common. It was very crucial to give students peer and instructor feedback to improve their metacognition and self-awareness. Digital tools, including online forums and simulated labs, were used by a few studies to support CT learning in hybrid or remote formats. Learning material that is scaffolded in nature, such as structured worksheets or discussion guides, was very beneficial to students as they reasoned around learning activities. Of the studies reviewed, direct instruction in CT concept and focusing on CT explicitly were not common methods. It was possible to witness student-centred pedagogy as the norm at the classroom level, and the heterogeneity in its application highlights the importance of providing teachers with custom-made training and resource packages.

Main Features: CT Instructional Implementation in Secondary Chemistry Teaching

The multiple approaches in which CT was embedded within the context of secondary chemistry instruction exhibited a wide variety within the reviewed works, conditioned by different settings of education, subject matter, and ways of instruction (Ahmad et al., 2023; Ye et al., 2023). The bulk of the reviewed studies relied on the “infused” model, which embedded CT within the core of chemistry instruction (by analysis of experiments, engaging in inquiry investigations, solving problems with chemical processes). Using this synthesis, students improved their competency in analysing, reasoning, and assessing while covering essential chemistry topics (Alberto et al., 2024).

Some of the studies described process-based instruction, employing tactics such as posing hypotheses, reading data, and reflective assessments (Seel, 2017; Phuong et al., 2023). Often, these were accompanied by structured worksheets, guided prompts, and digital tools. The use of Socratic questioning and group discussion frequently promoted improved reasoning, and the use of both teachers’ and peers’ feedback was valuable in students’ self-monitoring and metacognitive practices. Although all the classrooms created student-centred instruction, the explicit teaching and assessment of CT were very divergent. Most of the interventions failed to directly teach CT concepts or to adequately connect CT assessments with established outcomes. Awareness of such a variation implies that it is essential to promote clear model-driven instructional protocols and teacher capacity building to ensure that CT is meaningfully anchored into chemistry and can be nurtured and evaluated wisely.

The findings of the systematic literature review based on PRISMA 2020 and the thematic analysis can be used to answer the research questions with references to such patterns in 23 identified studies. It would appear that the insights of secondary chemistry teachers about critical thinking (CT) differ, some of them overtly use well-known frameworks such as Blooms Taxonomy, Design Thinking, or Inquiry-Based Learning (IBL), whereas others implicitly apply CT in everyday classroom life, with no theoretical foundation evident. Instructional processes mainly involve inquiry-based activities, project-based learning (PBL), and socioscientific issue (SSI) discussions, focusing on process-centered teaching producing reasoning and reflection. Nonetheless, CT teaching is more widely possible. In terms of assessment, most studies have employed rubrics, reflective activities, and performance tasks, but there was not much correspondence between CT teaching and assessment (Cutumisu et al., 2019). These results are indications of a consistent disconnect between teachers sharing beliefs about the significance of CT and their action, notably during assessment activities. The synthesized answer which will respond to the research questions is synthesized by considering the results of different methodologies in this analysis (Schick-Makaroff et al., 2016; Kastner et al., 2016; Flemming et al., 2019; Gurevitch et al., 2018).

The identification of the major components that contribute to CT adoption in secondary chemistry classrooms is done through a review (Saad and Zainudin, 2024). Although most teachers endorse CT, only a few directly teach concepts of CT, yet implicitly promote them (Pardede, 2019). Raising the level of group work and with the help of stimulating questions raises the level of interest within the students, and through well-constructed learning materials and useful teacher commentaries, more advanced reasoning capacities can be achieved (van der Hoeven Kraft, 2017). However, the current inconsistencies in practice and the gap between assessment approaches versus method of teaching act as obstacles. Digital assets can greatly contribute towards CT development, but proper training is needed to take advantage of these resources (Mihai et al., 2022). Strategies for further progress of CT in chemistry will be based on

prioritising model-based CT instruction, developing all-encompassing resources, and professional training for teachers (Paul et al., 2024; Sanchez et al., 2024).

CONCLUSION

The main conclusion of this systematic literature review is that secondary chemistry teachers are well aware of the importance of critical thinking (CT) in science teaching, yet there is an evident disparity between understanding, teaching practice and assessment itself. The results demonstrate that the majority of teachers adhere to a strategy of an infusion of CT, thereby incorporating it into subject content using inquiry-based learning, project-based assignments, as well as socioscientific issues. Nevertheless, there is a lack of development of clear CT teaching and organised test measures. The lack of correspondence can be compared with the trends featured in past research and expresses the necessity to pay more attention to alignment between teacher beliefs and classroom strategies and assessment procedures. The results of this study support the implication that the topic of teacher professional development should be focused on CT-specific pedagogies and assessments that would fit the unique nature of chemistry. Moreover, curriculum designs need to provide more plain instructions and effective examples in the process of integrating CT. Although this survey does not come up with a new theory, it reinforces the current knowledge that CT will remain irregularly used until a clear set of guidelines and the professional preparation of practitioners are in place. Areas that should be investigated in future research include longitudinal effects of explicit CT instruction and how the growth of digital technologies can be used to both teach and assess in the field.

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AUTHOR CONTRIBUTIONS

D Sarasvati Doraisamy organized the study, searched the literature, extracted the data, and wrote the first draft manuscript. Rafiza Abdul Razak reviewed the research approach, advised on its performance, and edited the manuscript to improve its meaning. I was involved in analysing the theme, interpreting the analysis, and editing the salient parts of the report. All authors read and confirmed the final version of the manuscript and are responsible for all parts of the research.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

REFERENCES

- Adauyah, R., & Aznam, N. (2024). Guided Inquiry Learning Model in Chemistry Education: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, 10(3), 77-87. <https://doi.org/10.29303/jppipa.v10i3.6373>.
- Afriani, H. N., & Widodo, A. (2025). Designing a green chemistry-based practical guide: enhancing learning on reaction rates and chemical equilibrium. *Journal of Chemical Learning Innovation*, 2(1), 73-80. <https://doi.org/10.37251/jocli.v2i1.1922>
- Agustian, H. Y., Finne, L. T., Jørgensen, J. T., Pedersen, M. I., Christiansen, F. V., Gammelgaard, B., & Nielsen, J. A. (2022). Learning outcomes of university chemistry teaching in laboratories: A systematic review of empirical literature. *Review of Education*, 10(2), e3360. <https://doi.org/10.1002/rev3.3360>.

- Ahmad, Z., Ammar, M., Sellami, A., & Al-Thani, N. J. (2023). Effective pedagogical approaches used in high school chemistry education: a systematic review and meta-analysis. *Journal of Chemical Education*, 100(5), 1796-1810. <https://doi.org/10.1021/acs.jchemed.2c00739>.
- Alberto, M. C. L., Viviana, B. V. C., Vladimir, B. E. C., & Fernanda, P. A. P. (2024, July). Innovative strategies to strengthen teaching-researching skills in chemistry and biology education: a systematic literature review. In *Frontiers in Education* (Vol. 9, p. 1363132). Frontiers Media SA. <https://doi.org/10.3389/educ.2024.1363132>.
- Alsaleh, N. J. (2020). Teaching critical thinking skills: Literature review. *Turkish Online Journal of Educational Technology-TOJET*, 19(1), 21-39.
- Arifin, Z., Saputro, S., & Kamari, A. (2025). The effect of inquiry-based learning on students' critical thinking skills in science education: A systematic review and meta-analysis. *Eurasia Journal of Mathematics, Science and Technology Education*, 21(3), em2592. <https://doi.org/10.29333/ejmste/15988>.
- Ariyani, W. R., Marmoah, S., & Winarno, W. (2025). Effectiveness of literacy program in primary education. *Journal of Basic Education Research*, 6(2), 206-217. <https://doi.org/10.37251/jber.v6i2.1758>
- Bernardi, F. M., & Pazinato, M. S. (2022). The case study method in chemistry teaching: A systematic review. *Journal of Chemical Education*, 99(3), 1211-1219. <https://doi.org/10.1021/acs.jchemed.1c00733>.
- Beltran, K. A. (2025). Development and validation of microbiology and parasitology laboratory manual for science education. *Integrated Science Education Journal*, 6(2), 62-71. <https://doi.org/10.37251/isej.v6i2.1543>
- Çalık, M., & Wiyarsi, A. (2021). A systematic review of the research papers on chemistry-focused socio-scientific issues. *Journal of Baltic Science Education*, 20(3), 360. <https://dx.doi.org/10.33225/jbse/21.20.360>.
- Cooper, M. M., & Stowe, R. L. (2018). Chemistry education research—From personal empiricism to evidence, theory, and informed practice. *Chemical reviews*, 118(12), 6053-6087. <https://doi.org/10.1021/acs.chemrev.8b00020>.
- Cortés, R. R., Thanjangreed, W., & Chertenko, T. (2025). Relationship between environmental sanitation and dengue hemorrhagic fever incidents. *Journal of Health Innovation and Environmental Education*, 2(1), 43-51. <https://doi.org/10.37251/jhiee.v2i1.1736>
- Cutumisu, M., Adams, C., & Lu, C. (2019). A scoping review of empirical research on recent computational thinking assessments. *Journal of Science Education and Technology*, 28(6), 651-676. <https://doi.org/10.1007/s10956-019-09799-3>.
- Dzulfikar, A., Turmudi, T., Herman, T., & Kusnandi, K. (2025). How ICT supports the mathematical problem-solving learning process of secondary school students: A systematic literature Review. *Journal Evaluation in Education (JEE)*, 6(3), 924-936. <https://doi.org/10.37251/jee.v6i3.1649>
- Endra, K., & Villafior, G. M. (2024). Integration of the POE model and metaphorical thinking in student worksheets: improving mathematical reasoning abilities in the modern education era. *Journal of Educational Technology and Learning Creativity*, 2(1), 41-53. <https://doi.org/10.37251/jetlc.v2i1.981>
- Fernandez, L., Vega, M. G., & Wahyuningsih, E. N. (2025). Exploring the interplay of self-regulated learning, critical thinking, and scientific communication: insights from international biology learners. *Journal of Academic Biology and Biology Education*, 2(1), 123-131. <https://doi.org/10.37251/jouabe.v2i1.2107>
- Flemming, K., Booth, A., Garside, R., Tunçalp, Ö. and Noyes, J. (2019). Qualitative evidence synthesis for complex interventions and guideline development: clarification of the purpose, designs and relevant methods. *BMJ Global Health*, [online] 4(Suppl 1), e000882. <https://doi.org/10.1136/bmjgh-2018-000882>.
- Gong, X., Wei, B., Bergey, B. W., & Shockley, E. T. (2022). Unpacking chemistry teachers' pedagogical reasoning and decisions for a PhET simulation: a TPACK perspective. *Journal of Chemical Education*, 100(1), 34-44. <https://doi.org/10.1021/acs.jchemed.2c00397>.
- Gurevitch, J., Koricheva, J., Nakagawa, S., & Stewart, G. (2018). Meta-analysis and the science of research synthesis. *Nature*, 555(7695), 175-182. <https://doi.org/10.1038/nature25753>.
- Hamzah, H., Hamzah, M.I. and Zulkifli, H., 2022. Systematic literature review on the elements of

- metacognition-based higher order thinking skills (HOTS) teaching and learning modules. *Sustainability*, 14(2), 813. <https://doi.org/10.3390/su14020813>.
- Hasnah, Y., Ginting, P., Supiatman, L., Kharisma, A.J. and Siahaan, H.S., 2024. How do locally produced EFL textbooks endorse critical thinking skills in Indonesia? A content analysis. *Journal of Language Teaching and Research*, 15(1), 190-200. <https://doi.org/10.17507/jltr.1501.21>.
- Ho, Y.R., Chen, B.Y. and Li, C.M., 2023. Thinking more wisely: using the Socratic method to develop critical thinking skills amongst healthcare students. *BMC medical education*, 23(1), 173. <https://doi.org/10.1186/s12909-023-04134-2>.
- Ikhsan, M., Atun, S., Agusta, F., Unayah, H., Buhera, R., Pamungkas, O., Sarip, M., & Sitorus, P. A. (2025). Development of critical thinking essay test instrument and prosocial intention questionnaire for environmental care in students. *Journal Evaluation in Education (JEE)*, 6(1), 66-78. <https://doi.org/10.37251/jee.v6i1.1273>
- Ismail, N.H. and Osman, K., 2024. Exploring formative assessment strategies in the chemistry classroom in secondary school: a systematic literature review (SLR). *International Journal of Academic Research in Progressive Education and Development*, 13(2), 464-484.
- Iyamuremye, A., Niyongabo Niyonzima, F. and Twagilimana, I., 2024. Web-based discussion in teaching and learning organic chemistry: a scoping literature review on its current trends, cognitive, social, and teaching aspects. *Cogent Education*, 11(1), 2431947. <https://doi.org/10.1080/2331186X.2024.2431947>.
- Jamil, M., Zahra, H. and Fida, F., 2024. Integrating Life Skills in Secondary Education: Teachers' Perspectives and Challenges. *Journal of Social and Organizational Matters*, 3(4), 01-10. <https://doi.org/10.56976/jsom.v3i4.112>.
- Julianti, R. T., Sahiner, M., & Khalid, N. (2025). Utilization of MOOC for Subak values extension: Maintaining Balinese local wisdom in modern education. *Journal of Educational Technology and Learning Creativity*, 3(1), 131-137. <https://doi.org/10.37251/jetlc.v3i1.1569>.
- Kamila, K., Wilujeng, I., Jumadi, J., & Ungirwalu, S. Y. (2024). Analysis of Integrating Local potential in science learning and its effect on 21st century skills and student cultural awareness: Literature review. *Jurnal Penelitian Pendidikan IPA*, 10(5), 223-233. <https://doi.org/10.29303/jppipa.v10i5.6485>.
- Kastner, M., Antony, J., Soobiah, C., Straus, S.E. and Tricco, A.C. (2016). Conceptual recommendations for selecting the most appropriate knowledge synthesis method to answer research questions related to complex evidence. *Journal of Clinical Epidemiology*, 73, pp.43-49. <https://doi.org/10.1016/j.jclinepi.2015.11.022>.
- Katsarov, J., Andorno, R., Krom, A. and van den Hoven, M. (2021). Effective strategies for research integrity training a Meta-analysis. *Educational Psychology Review*, 34(2), pp.935-955. <https://doi.org/10.1007/s10648-021-09630-9>.
- Khurma, O.A. and El Zein, F., 2024. Inquiry skills teaching and its relationship with UAE secondary school students' critical thinking: Systematic review of science teachers' perspectives. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(2), p.em2397. <https://www.ejmste.com/download/inquiry-skills-teaching-and-its-relationship-with-uae-secondary-school-students-critical-thinking-14155.pdf>
- Kite, V. and Park, S. (2022). What's computational thinking?: secondary science teachers' conceptualizations of computational thinking (CT) and perceived barriers to CT integration. *Journal of Science Teacher Education*, pp.1-24. <https://doi.org/10.1080/1046560x.2022.2110068>.
- Krisandini, T. and Anwar, S., 2024. A systematic literature review: Content and pedagogy that developed in chemistry teaching and learning materials at secondary school. *Didaktika: Jurnal Kependidikan*, 13(2), 2103-2110. <https://doi.org/10.58230/27454312.458>.
- Lorencová, H., Jarošová, E., Avgitidou, S. and Dimitriadou, C. (2019). Critical thinking practices in teacher education programmes: a systematic review. *Studies in Higher Education*, 44(5), pp.844-859. <https://doi.org/10.1080/03075079.2019.1586331>.
- Mansyuarna, M., Silajdžić, A., & Hamzah, M. S. (2023). Application of the demonstration method in islamic religious education learning in improving student learning outcomes. *Jurnal Pendidikan Agama Islam Indonesia (JPAIL)*, 4(4), 80-83. <https://doi.org/10.37251/jpail.v4i4.781>.
- McCollough, C.H. and Rajiah, P. (2023). Milestones in CT: Past, Present, and Future. *Radiology*, 309(1). <https://doi.org/10.1148/radiol.230803>.
-

- Mihai, S., Yaqoob, M., Hung, D.V., Davis, W., Towakel, P., Raza, M., Karamanoglu, M., Barn, B., Shetve, D., Prasad, R.V., Venkataraman, H., Trestian, R. and Nguyen, H.X. (2022). Digital Twins: A Survey on Enabling Technologies, Challenges, Trends and Future Prospects. *IEEE Communications Surveys & Tutorials*, 24(4), 2255–2291. <https://doi.org/10.1109/comst.2022.3208773>.
- Nsabayeze, E., Iyamuremye, A., Nahimana, J. P., Mukiza, J., Kampire, E., & Nsengimana, T. (2022). The progress in the application of rubric materials in chemistry teaching and students' learning enhancement during 21st century: a systematic review. *Discover Education*, 1(1), 5. <https://doi.org/10.1007/s44217-022-00005-y>.
- Nou, H., Mok, S., Lim, S., & Em, S. (2025). The relationship between students' attitudes towards cooperative learning strategies and their academic achievement. *Journal of Social Knowledge Education (JSKE)*, 6(2), 200-210. <https://doi.org/10.37251/jske.v6i2.1606>.
- Nwune, E. C., Oguezie, N. K., & Odum, B. I. (2023). Secondary school students' perception of science laboratory accident status and preventive measures in Awka education zone. *Integrated Science Education Journal*, 4(3), 104-110. <https://doi.org/10.37251/isej.v4i3.550>.
- Nwoji, Q., Gada, B. A., & Alqahtani, Z. M. (2025). New media, learning outcomes, and social development of children: a case study of digital technology use in Nigeria. *Journal of Educational Technology and Learning Creativity*, 3(1), 185-193. <https://doi.org/10.37251/jetlc.v3i1.1854>.
- O'Dea, R.E., Lagisz, M., Jennions, M.D., Koricheva, J., Noble, D.W.A., Parker, T.H., Gurevitch, J., Page, M.J., Stewart, G., Moher, D. and Nakagawa, S. (2021). Preferred Reporting Items for Systematic Reviews and Meta-analyses in Ecology and Evolutionary biology: A PRISMA Extension. *Biological Reviews*, 96(5). <https://doi.org/10.1111/brv.12721>.
- Ogegbo, A.A. and Ramnarain, U., 2024. A systematic review of pedagogical practices for integrating indigenous knowledge systems in science teaching. *African Journal of Research in Mathematics, Science and Technology Education*, 28(3), pp.343-361. <https://journals.co.za/doi/pdf/10.1080/18117295.2024.2374133>
- Putri, E. N., Mahdavi, M., & Awlqadir, M. S. (2025). An analysis of students' motivation and their achievement in learning english at the department of english education. *Journal of Language, Literature, and Educational Research*, 2(1), 43-50. <https://doi.org/10.37251/jolle.v2i1.1698>.
- Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S. and McGuinness, L.A. (2021a). The PRISMA 2020 statement: an Updated Guideline for Reporting Systematic Reviews. *British Medical Journal*, 372(71). <https://doi.org/10.1136/bmj.n71>.
- Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M. and Moher, D. (2021b). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *Journal of clinical epidemiology*, 134, 103-112. <https://doi.org/10.1016/j.jclinepi.2021.02.003>.
- Pardede, P. (2019). Using fiction to promote students' critical thinking. *Journal of English Teaching*, 5(3), 166-178. <https://doi.org/10.33541/jet.v5i3.1309>.
- Paul, S.G., Saha, A., Hasan, Md.Z., Sheak and Moustafa, A. (2024). A systematic review of graph neural network in healthcare-based applications: recent advances, trends, and future directions. *IEEE access*, 12, 15145–15170. <https://doi.org/10.1109/access.2024.3354809>.
- Poulikova, I. (2025). *Validating a Critical Thinking Questionnaire for Young Adolescents: A Preparatory Study for a Longitudinal Research*. [online] Ssrn.com. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5342974 [Accessed 14 Jul. 2025].
- Prastika, F.N.K. and Arianingrum, R., 2024. The Socioscientific Issues Approach in Chemistry Education: A Literature Study and Its Implication. *Jurnal Pendidikan MIPA*, 25(4), pp.1880-1892. <https://doi.org/10.23960/jpmipa/v25i4.pp1880-1892>.
- Prokop-Dorner, A., Piłat-Kobla, A., Ślusarczyk, M., Świątkiewicz-Mośny, M., Ożegalska-Łukasik, N., Potysz-Rzyman, A., Zarychta, M., Juszyk, A., Kondyjowska, D., Magiera, A. and Maraj, M., 2024. Teaching methods for critical thinking in health education of children up to high school: A scoping review. *Plos one*, 19(7), e0307094. <https://doi.org/10.17605/OSF.IO/46TEZ>.
- Raihanah, D., Putri, N. M., Fatmawati, T. K., & Nurjayadi, M. (2024). Analysis of technological pedagogical content knowledge (TPACK) ability for prospective chemistry teacher students and chemistry teachers: A literature review. *Jurnal Pijar Mipa*, 19(1), 67-74.

- <https://doi.org/10.29303/jpm.v19i1.6395>.
- Rushiana, R.A., Sumarna, O. and Anwar, S. (2023). Efforts to develop students' critical thinking skills in chemistry learning: Systematic literature review. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, 9(3), pp.1425–1435. <https://doi.org/10.29303/jppipa.v9i3.2632>.
- Roath, C., Alkaki, Z. R. A., & James, J. S. (2025). Critical thinking as a key to solving mathematical problems: findings from the timss framework in middle schools. *Interval: Indonesian Journal of Mathematical Education*, 3(1), 95-101. <https://doi.org/10.37251/ijome.v3i1.1626>
- Saad, A., & Zainudin, S. (2024). A review of teaching and learning approach in implementing Project-Based Learning (PBL) with computational thinking (CT). *Interactive Learning Environments*, 32(10), 7622-7646. <https://doi.org/10.1080/10494820.2024.2328280>.
- Salameh, J.-P., Bossuyt, P.M., McGrath, T.A., Thombs, B.D., Hyde, C.J., Macaskill, P., Deeks, J.J., Leeftang, M., Korevaar, D.A., Whiting, P., Takwoingi, Y., Reitsma, J.B., Cohen, J.F., Frank, R.A., Hunt, H.A., Hooft, L., Rutjes, A.W.S., Willis, B.H., Gatsonis, C. and Levis, B. (2020). Preferred Reporting Items for Systematic Review and meta-analysis of Diagnostic Test Accuracy Studies (PRISMA-DTA): explanation, elaboration, and Checklist. *BMJ*, p.m2632.
- Sánchez Morales, R., Sáenz-López, P., & de las Heras Perez, M. A. (2024). Green chemistry and its impact on the transition towards sustainable chemistry: a systematic review. *Sustainability*, 16(15), 6526. <https://doi.org/10.3390/su16156526>.
- Sanchez, J. M., Picardal, M., Fernandez, S., & Caturza, R. R. (2024). Socio-scientific issues in focus: A meta-analytical review of strategies and outcomes in climate change science education. *Science Education International*, 35(2), 119-132.
- Schick-Makaroff, K., MacDonald, M., Plummer, M., Burgess, J. and Neander, W. (2016). What synthesis methodology should i use? a review and analysis of approaches to research synthesis. *AIMS Public Health*, 3(1), 172–215. <https://doi.org/10.3934/publichealth.2016.1.172>.
- Seel, N.M. (2017). Model-based learning: a synthesis of theory and research. *Educational Technology Research and Development*, 65(4), 931–966. <https://doi.org/10.1007/s11423-016-9507-9>.
- Setiawan, N.C.E., Putri, D.E.K., Marfu'ah, S., Pramesti, I.N. and Rosli, M.S., 2023. 21st century skills: The perspective of chemistry teachers in Indonesia. *Hydrogen: Jurnal Kependidikan Kimia*, 11(4), 354-364.
- Song, X., Razali, A. B., Sulaiman, T., Jeyaraj, J. J., & Ds, P. (2024). Impact of project-based learning on critical thinking skills and language skills in EFL context: A review of literature. *World*, 14(5). <http://dx.doi.org/10.5430/wjel.v14n5p402>.
- Syahana, S., Suyanta, S., Sari, D. R., Asmiati, L., & Pujiana, E. (2023). Design Thinking as an Effort to Enhance Critical Thinking and Science Literacy in Chemistry Learning: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, 9(SpecialIssue), 275-284. <https://doi.org/10.29303/jppipa.v9iSpecialIssue.4709>.
- Sigar, P. A., Nguyen-Quang, D., & Hendry, R. (2025). Can private schools overcome promotional limitations through a 4P-based digital marketing strategy? a case study in Malaysia. *Journal of Educational Technology and Learning Creativity*, 3(1), 166-174. <https://doi.org/10.37251/jetlc.v3i1.1843>
- Somantri, Y. N. (2024). Analysis of the physical education learning process through online media. *Multidisciplinary Journal of Tourism, Hospitality, Sport and Physical Education*, 1(1), 11-15. <https://doi.org/10.37251/jthpe.v1i1.1037>
- Stéphan, V. L., Carlos, G. S., Mathias, B., Meritxell, F. B., Gwénaél, J., Joaquin, U., & Quentin, V. (2019). *Educational Research and Innovation Fostering Students' Creativity and Critical Thinking What it Means in School: What it Means in School*. OECD Publishing.
- Uyen, B. P., Tong, D. H., & Ngan, L. K. (2023). Online Project-Based learning for teacher education during the COVID-19 Pandemic: A systematic review. *Contemporary Educational Technology*, 15(3). <https://doi.org/10.30935/cedtech/13238>.
- van der Hoeven Kraft, K.J. (2017). Developing student interest: An overview of the research and implications for geoscience education research and teaching practice. *Journal of Geoscience Education*, 65(4), 594–603. <https://doi.org/10.5408/16-215.1>.
- Veerasinghan, K., Balakrishnan, B., Damanhuri, M.I.M. and Gengatharan, K., 2021. Design thinking for creative teaching of chemistry. *International Journal of Academic Research in Business and Social Sciences*, 11(3), 670-687.
- Veerasinghan, K., Balakrishnan, B., Damanhuri, M.I.M. and Gengatharan, K. (2021). Design Thinking

-
- for Creative Teaching of Chemistry. *International Journal of Academic Research in Business and Social Sciences*, 11(3). <https://doi.org/10.6007/ijarbss/v11-i3/8979>.
- Wahyudiati, D. (2022). Critical thinking skills and scientific attitudes of Pre-Service chemistry teachers through the implementation of problem-based learning model. *Jurnal Penelitian Pendidikan IPA*, 8(1), 216–221. <https://doi.org/10.29303/jppipa.v8i1.1278>.
- Wang, D. and Jia, Q. (2023). Twenty years of research development on teachers' critical thinking: current status and future implications a bibliometric analysis of research articles collected in WoS. *Thinking Skills and Creativity*, 101252. <https://doi.org/10.1016/j.tsc.2023.101252>.
- Weerarathna, I.N., Kumar, P., Luharia, A. and Mishra, G. (2024). Engineering with Biomedical Sciences Changing the Horizon of Healthcare-A Review. *Bioengineered*, 15(1). <https://doi.org/10.1080/21655979.2024.2401269>.
- Ye, H., Liang, B., Ng, O.-L. and Chai, C.S. (2023). Integration of computational thinking in K-12 mathematics education: a systematic review on CT-based mathematics instruction and student learning. *International Journal of STEM Education*, 10(1). <https://doi.org/10.1186/s40594-023-00396-w>.
- Yuan, R., Liao, W., Wang, Z., Kong, J. and Zhang, Y. (2022). How do English-as-a-foreign-language (EFL) teachers perceive and engage with critical thinking: A systematic review from 2010 to 2020. *Thinking Skills and Creativity*, 43, 101002. <https://doi.org/10.1016/j.tsc.2022.101002>.
- Yulisman, H., Wardiah, W., Artika, W., Pada, A. U. T., & Nurina, C. I. E. (2025). Evaluation of changes in students' perceptions of scientific article writing skills through a cohort survey. *Indonesian Journal of Education Research (IJoER)*, 6(2), 168-176. <https://doi.org/10.37251/ijoeer.v6i2.1607>
- Zulyusri, Z., Elfira, I., Lufri, L. and Santosa, T.A., 2023. Literature study: Utilization of the PjBL model in science education to improve creativity and critical thinking skills. *Jurnal Penelitian Pendidikan IPA*, 9(1), 133-143. <https://doi.org/10.29303/jppipa.v9i1.2555>.