



## Effects of STEAM-Based Chemistry Learning on High School Students' Critical Thinking Skills: A Systematic Review

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### Abstract

In the 21st century, the world of education faces new challenges that are far more comprehensive and multidimensional. Education in this century requires students to adapt to developments in science by mastering 21st-century competencies, including critical thinking. Chemistry learning as part of the science field is one of the educational facilitators that has great potential in developing critical thinking skills. However, in reality, chemistry is often considered a difficult subject because it involves complex, invisible (submicroscopic) concepts that require high analytical skills. One relevant approach to improving critical thinking skills is the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach. The purpose of this study was to analyse the effect of the STEAM approach on high school students' critical thinking skills in chemistry. This study used the Systematic Literature Review (SLR) method, which analyses relevant articles using inclusion and exclusion criteria in accordance with the PRISMA guidelines. The exclusion criteria include articles that are not fully accessible, non-empirical articles (e.g., opinions, editorials), articles that measure contexts other than high school/MA chemistry, and articles that do not measure critical thinking skills. On the other hand, the inclusion criteria in this SLR included articles published between 2015 and 2025, research contexts on high school/MA students, a focus on the application of STEAM in chemistry learning, peer-reviewed articles (journals, proceedings, published theses), and articles that measured critical thinking skills. The study found that the STEAM approach in chemistry instruction was effective in improving high school students' critical thinking skills.

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## INTRODUCTION

Amid rapid global changes and the world entering the 21st century, the education sector faces new challenges that are far more comprehensive and multidimensional. To address these developments, Indonesians are encouraged to develop various competencies and skills, one of which is 21st-century competencies (Suardana et al., 2018). Education in this century requires students to adapt to developments in science by mastering 21st-century competencies. This condition is because in the 21st century, technological developments have begun to influence the structure of human life. Gradually, human labour is often replaced by technology, resulting in many workers becoming redundant because they are unable to compete globally (Partono et al., 2021). This situation needs to be addressed by all parties, especially the education

sector, as it is closely related to the urgency of equipping the current generation with 21st-century skills. The four 21st-century skills are critical thinking, creativity, collaboration, and communication. (Redhana, 2019), that students must be prepared to face global dynamics.

Chemistry education as part of science is one of the educational facilitators that has great potential in developing 21st-century competencies, especially critical thinking skills. However, these educational challenges have not been fully overcome. In fact, in the field, chemistry is still often considered a difficult subject because it frequently involves complex, invisible (submicroscopic) concepts that require high analytical skills. This is supported by the opinion of Ristiyani & Bahriah (2016), who stated that the complex and submicroscopic nature of chemistry

learning makes it difficult for students to understand the representations of these concepts, which cannot be directly observed by students (Andriani et al., 2019). In addition, chemistry is considered difficult by most high school students because it is characterised by relatively low learning outcomes (Sudiana et al., 2019). This problem is further exacerbated by current chemistry teaching strategies in the field, which still prioritize memorization of facts over understanding the relevant chemical context.

According to Sanchez Ruiz et al. (2022), teaching conditions still emphasise mastery of concepts by demanding more memorisation rather than training higher-order thinking and other lifelong skills (Anwar et al., 2024). Students need enthusiasm and a tendency to think critically, as these will help them apply these skills in their daily lives (Redhana & Wahyuni, 2021). The presence of critical thinking skills in chemistry learning can help improve students' understanding of chemistry concepts that tend to be complex, resulting in deep and meaningful learning. This is supported by the statement made by Sastrika et al. (2013), that critical thinking skills in chemistry learning play a role in helping students in the process of analysing existing symptoms or phenomena, so it is very necessary to instill these skills from an early age. The tendency for chemistry learning to be theoretical is one factor contributing to low student interest and skills in critical thinking skills. This is in line with the 2022 PISA results, which show that the average science score of Indonesian students is only 383, and only about 34% of students can reach level 2 or higher in science. This data shows that science education, including chemistry, has not been particularly effective in improving students' critical thinking skills.

Recognising the importance of critical thinking in life, various learning innovations have been developed, including the STEAM approach. This approach provides a platform for students to develop critical thinking skills because it involves five disciplines, namely science, technology, engineering, art, and mathematics, making learning more varied and meaningful. In chemistry education, the STEAM approach has been widely applied to help students improve their critical thinking and become more structured. For example, in a study by Muhammad et al. (2024), results show that

applying STEAM in chemistry learning on electrolyte and non-electrolyte solutions has been effective in improving students' critical thinking skills. Other research by Ananda et al. (2023) confirms that learning through the STEAM approach effectively improves students' critical thinking skills in redox reactions. Furthermore, a study by Rahmawati et al. (2020) found that STEAM is effective in improving critical thinking skills regarding acids and bases. This is also supported by the results of a study by Sukro et al. (2021), which found that integrating STEAM in chemistry learning, particularly on molecular structure and chemical bonds, has been proven effective in improving students' critical thinking skills.

However, not all STEAM implementations show optimal results. For example, research conducted by Rahmawati et al. (2020) found that integrating STEAM into chemistry learning, specifically in thermochemistry, has not yielded optimal results. Of the five critical thinking indicators measured by the researchers, only four showed optimal results: conceptual understanding, the ability to connect ideas, the ability to identify and analyse assumptions, and the ability to conclude. One critical thinking indicator that has not developed optimally is the ability to identify problems. Research by Mardikaningrum et al. (2025) indicates that the STEAM approach makes it easier for students to understand concepts in chemistry concepts. However, in the process of integrating it in the classroom, several challenges are encountered, especially on the teachers' side. These challenges include time constraints, limited availability of facilities and infrastructure, and the complexity of the STEAM implementation process.

Based on this, STEAM has great potential to improve students' critical thinking skills, especially in chemistry learning, although there are still challenges in its implementation that need to be studied in depth to design STEAM-based chemistry learning more effectively.

There have also been many studies on the influence of STEAM and critical thinking skills in chemistry learning in high schools. Still, to date, there has been no systematic synthesis that comprehensively summarises these findings. This has resulted in an overall picture of STEAM's role in improving critical thinking skills in chemistry learning that remains unstructured. Therefore,

this topic was chosen to be studied systematically through SLR to collect, analyze, and evaluate the results of previous studies, so that it can help serve as a reference in creating a more meaningful learning experience for students. Therefore, the research questions in this study are as follows:

1. What research methods are used in integrating the STEAM approach into chemistry learning in high schools?
2. What STEAM learning models are used in integrating the STEAM approach into chemistry learning in high schools?
3. What chemistry materials are used in integrating the STEAM approach into chemistry learning in high schools?

## METHOD

### Research Type

This study uses the SLR method to identify and analyse research on the integration of the STEAM approach in chemistry learning in high schools that focuses on developing critical thinking skills. According to Liberati et al. (2009), SLR is a research method and process for identifying and critically assessing relevant research, as well as for collecting and analysing data from previous studies (Snyder, 2019). According to Moher et al. (2009), the SLR process follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which assist evidence-based research by reducing bias and improving the reliability of results through transparent, organised reporting (Rusyati et al., 2025).

### Research Procedures

The articles that served as data sources in this study were obtained from the Google Scholar, Scopus, Sinta, and GARUDA databases. The keywords used in the literature search were STEAM, "chemistry learning," "chemistry instruction," "chemical instruction," "chemical learning," and "critical thinking." The selected articles were those published between 2015 and 2025. This time

frame was chosen so that the analysed articles would remain relevant to the latest developments in the application of STEAM in chemistry learning to improve high school students' critical thinking skills.

The literature selected and included within this time frame provides a relevant overview of the research methods used, the STEAM models integrated, the chemistry topics studied, and the results of STEAM implementation on improving high school students' critical thinking skills. This systematic review uses two types of criteria, namely exclusion and inclusion criteria. Each criterion used serves to sort and ensure that the articles analyzed are relevant to the objectives of the systematic review and the variables studied. The exclusion and inclusion criteria for this literature are shown in Table 1.

**Table 1. Exclusion and Inclusion Criteria**

Exclusion Criteria	Inclusion Criteria
1) The article cannot be accessed in its entirety	1) Articles published between 2015 and 2025
2) The article is not a research article	2) Articles using the context of senior high school/vocational high school
3) The article does not use a high school chemistry context	3) Articles focusing on the application of the STEAM approach in chemistry learning
4) The article does not measure critical thinking skills	4) Articles from published journals, proceedings, and theses
	5) Peer-reviewed articles
	6) Articles measuring critical thinking skills

## RESULTS AND DISCUSSION

### Result

Based on the systematic literature review, 15 articles were identified as suitable for analysis. The results of the study are presented in Table 2.

**Table 2. Results of Article Analysis on the Effect of STEAM on Chemistry Learning to Develop Critical Thinking Skills in High School Students**

No	Author and Year	Title	Method	Model	Material	Class	Effective-ness	Journal Indexing
1.	Muhammad et al. (2024)	Improves Critical Thinking Skills And Self-Efficacy of Learners Using The PjBL-STEAM	Quasi-experiment	PjBL-STEAM	Electrolyte and non-electrolyte solutions	X High School	Effectively improves high school students' critical thinking skills in chemistry learning.	SINTA 3

No	Author and Year	Title	Method	Model	Material	Class	Effective-ness	Journal Indexing
		Model In Wetland Contexts						
2.	Ananda et al. (2023)	Critical Thinking Skills of Chemistry Students by Integrating Design Thinking with STEAM-PjBL	Qualitative	PjBL-STEAM	Redox reactions	X High School	Effectively improves high school students' critical thinking skills in chemistry learning.	Q2
3.	Yani et al. (2023)	Pengembangan LKPD Terintegrasi STEAM-PjBL pada Materi Sel Volta untuk Meningkatkan Keterampilan Berpikir Kritis Peserta Didik Kelas XII SMA/MA	R&D (Research and Development)	PjBL-STEAM	Volta cell material	XII High School	Effectively improving high school students' critical thinking skills in chemistry learning.	SINTA 3
4.	Rahmawati et al. (2020)	Developing critical and creative thinking skills through STEAM integration in chemistry learning	Qualitative	PjBL-STEAM	Acid base	X High School	Effectively improving high school students' critical thinking skills in chemistry learning.	Q4
5.	Ridwan et al. (2022)	Development of 21st Century Skills in Acid-Base Learning Through STEAM Projects	Qualitative	PjBL-STEAM	Acid base	XI High School	One effective way to improve 21st-century skills is to enhance high school students' critical thinking in chemistry.	SINTA 2
6.	Ridwan et al. (2020)	Developing 22 <sup>nd</sup> century skills through the integration of STEAM into smoke absorber project	Qualitative	PjBL-STEAM	Absorption	XI High School	Effectively improving high school students' critical thinking skills in chemistry learning.	Q4
7.	Sukro et al. (2021)	Developing Students' Critical Thinking Skills through the Integration of Environment-based STEAM Project in Chemistry Learning	Qualitative	PjBL-STEAM	Molecular structure and chemical bonds	X High School	Effectively improving high school students' critical thinking skills in chemistry learning.	Q4
8.	Setyawan et al. (2023)	Model pembelajaran RADEC berbasis STEAM pada materi sistem	Quasi-experiment	RADEC (Read, Answer, Discuss, Explain,	Colloid	XI High School	Effectively improving high school students' critical thinking	SINTA 4

No	Author and Year	Title	Method	Model	Material	Class	Effective-ness	Journal Indexing
		koloid mampu meningkatkan keterampilan berpikir kritis siswa		and Create) - STEAM			skills in chemistry learning.	
9.	Setyawan & Patonah (2022)	Profil Kemampuan Berpikir Kritis Siswa pada Materi Senyawa Hidrokarbon Melalui Pendekatan STEAM di Kelas XI IPA SMA Negeri 2 Mranggen	Qualitative	STEAM	Hydrocarbon	XI High School	Effectively improving high school students' critical thinking skills in chemistry learning.	SINTA 5
10.	Suryaning Sih & Nisa (2021)	Kontribusi STEAM Project Based Learning dalam Mengukur Keterampilan Proses Sains dan Berpikir Kreatif Siswa	Quantitative descriptive	PjBL-STEAM	Acid-base titration	XI High School	Effectively improves science process skills, including critical thinking skills, with a score of 83.8% (very high category)	SINTA 2
11.	Lisdiana et al. (2023)	Development Of 21st Century Skills Through STEAM PjBL in The Topic of Salt Hydrolysis And Buffer Solutions	Qualitative	PjBL-STEAM	Hydrolysis of salts and buffer solutions	XI High School	One effective way to improve 21st-century skills is to enhance high school students' critical thinking in chemistry.	SINTA 2
12.	Apriliansa et al. (2017)	Pengembangan <i>Soft Skills</i> Peserta Didik melalui Integrasi Pendekatan <i>Science, Technology, Engineering, Arts, and Mathematics</i> (STEAM) dalam Pembelajaran Asam Basa	Qualitative	PjBL-STEAM	Acid base	XI High School	One effective way to improve soft skills is to enhance high school students' critical thinking in chemistry.	SINTA 4
13	Gusman et al. (2024)	The Effect of Chems sketch on STEAM-Based Learning in Improving Critical Thinking Skills on Chemical Bonding Materials	Quasi-experiment	STEAM-based learning	Chemical bond	X High School	Effectively improving high school students' critical thinking skills in chemistry learning.	SINTA 2
14.	Rahmawati et al. (2020)	Developing Students' Critical Thinking: A	Qualitative	PjBL-STEAM	Thermochemistry	XI High School	Effectively improved 4 out of 5 critical thinking indicators set by	Non-Scopus (Universal Journal of

No	Author and Year	Title	Method	Model	Material	Class	Effective-ness	Journal Indexing
		STEAM Project for Chemistry Learning.					researchers, namely conceptual understanding, ability to connect ideas, ability to identify and analyse assumptions, and ability to conclude. One indicator that has not been achieved is the ability to identify problems.	Educational Research)
15.	Rahmawati et al. (2024)	Developing Students' Chemical Literacy Through The Integration of Dilemma Stories Into A STEAM Project on Petroleum Topic	Qualitative	PjBL-STEAM	Petroleum (hydrocarbon)	XI High School	Effectively improving chemistry literacy skills, one of which is critical thinking skills of high school students in chemistry learning	Q2

Based on the analysis of 15 articles, it was found that the research methods used to examine the effectiveness of implementing STEAM in chemistry learning to improve critical thinking skills of high school students varied, with predominance of qualitative research method. The distribution diagram of the research method used in the 15 articles is presented in Figure 1.

■ Qualitative                      ■ Quasi-experiment  
■ R&D                                      ■ Quantitative descriptive

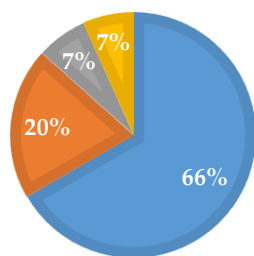


Figure 1. Research method distribution diagram

Furthermore, the analysis of the most widely used STEAM models in each article found that the PjBL-STEAM model was the most commonly used. The distribution diagram of STEAM learning models used in the 15 articles reviewed is shown in Figure 2.

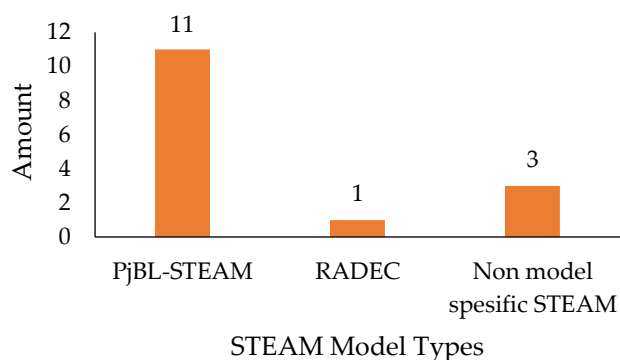


Figure 2. STEAM learning model

In addition, the analysis results show that the most studied chemistry topics in the application of STEAM in chemistry learning to improve high school students' critical thinking skills are acids and bases, as shown in Figure 3.

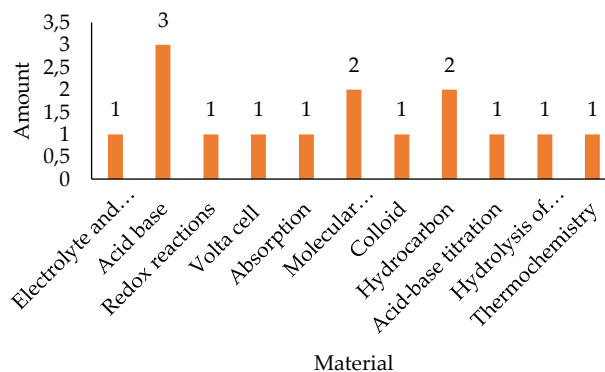


Figure 3. Chemical material distribution diagram

## Discussion

Based on a review of 15 articles, the most widely used research method was qualitative. The distribution diagram of the research methods used in the 15 articles reviewed is shown in Figure 1. A total of 10 articles (66%) used qualitative methods as the primary strategy to explore information on the implementation of STEAM in improve high school students' thinking skills in chemistry learning. Furthermore, three articles (20%) used quasi-experimental methods with a pretest-posttest control group design to measure students' initial and final abilities before and after the implementation of the STEAM learning model. Meanwhile, 1 article used the Research and Development (R&D) method, and 1 used the quantitative descriptive method.

According to Moleong (2012), the characteristics of qualitative methods focus on understanding what research subjects experience, such as behaviour, perceptions, motivation, and actions, holistically through descriptions in words and language (Ratnaningtyas et al., 2023). The ultimate goal of using qualitative methods is to discover interactive patterns of relationships, develop theories, describe complex realities, and gain meaningful understanding (Sugiyono, 2013). In the context of developing critical thinking skills in chemistry learning through STEAM, qualitative methods help researchers understand the process of creating patterns and interactive relationships among teachers, students, and learning materials, as well as how critical thinking skills can be formed through STEAM's influence on chemistry learning in high school. Through this method, researchers can explore broader information on the learning process, social interactions, and even student learning experiences related to STEAM integration.

In the 10 articles, it was found that the data collection techniques used were generally in the form of interviews with research subjects, classroom observations, and reflective journaling. These three data collection techniques are in line with the qualitative methods used. Through in-depth observation and interviews with participants, researchers can directly observe indicators of critical thinking developing in the student learning environment, such as how students formulate questions or answers, gather information, conclude the best solutions, and commu-

nicate to find effective solutions to problems (Ratnaningtyas et al., 2023). On the other hand, through reflective journals, researchers can understand how STEAM-based critical thinking processes can be developed from students' perspectives. In addition, observation techniques can be used to assess the effectiveness of the learning process by observing student engagement in learning (Subagia & Wiratma, 2020). Using qualitative methods, data and information can be obtained more comprehensively to improve the STEAM integration process in efforts to improve critical thinking skills among high school students.

In contrast, five articles used quantitative research methods, including quasi-experimental, R&D, and quantitative descriptive methods. Quantitative methods focus on data collection using statistical, mathematical, or computational techniques (Sofwatillah et al., 2024). In research on the influence of STEAM on students' critical skills in chemistry learning, this method is still rarely used, possibly because it requires a rigorous research design, including a control group, a treatment group, and a large sample size. This is sometimes difficult to implement optimally in a natural classroom setting.

Some possible reasons include time constraints, which limit researchers' ability to fully implement quantitative methods. This is because quantitative methods are considered complete when all planned activities have been carried out, whereas qualitative methods are considered complete when there is no new or saturated data (Sugiyono, 2013). Another possible explanation is that most researchers are more interested in how critical thinking skills develop in students through STEAM implementation. This is evident in the 10 articles that used qualitative methods rather than simply measuring final learning outcomes, such as test scores.

Thus, the small number of articles using quantitative methods indicates that the majority of research on the influence of STEAM on chemistry learning to develop critical thinking skills in high school students focuses on the process or mechanism of developing critical thinking skills, rather than on student learning outcomes. Furthermore, based on a review of 15 articles, the most widely used STEAM learning

model was the PjBL-STEAM model. The distribution diagram of STEAM learning models used in the 15 articles reviewed is shown in Figure 2. A total of 12 articles used the PjBL-STEAM or STEAM-based Project-Based Learning model, 3 articles used the STEAM approach (non-specific STEAM model), and 1 article used the RADEC-based STEAM model.

The dominance of the PjBL-STEAM learning model indicates that the majority of researchers consider this model to be the most effective in developing students' critical thinking skills in chemistry learning. PjBL is a learning model that emphasises students' active role in designing, developing, and completing a real-world project. This model enables students to effectively develop 21st-century skills such as critical thinking (Subiyantoro, 2025). PjBL is well-suited for STEAM integration because it provides students with space to develop critical thinking by integrating elements of science, technology, art, and mathematics through project-based activities. In addition, PjBL is a learning model that is able to integrate cross-disciplinary knowledge so that it is in line with STEAM, which consists of various disciplines. Through PjBL-STEAM, students are not only guided to understand the material but also succeed in creating critical ideas that are useful for life through the projects or products they create. This learning model reflects the principle of learning by doing, meaning students learn through practice rather than just theory. PjBL provides systematic activity steps and facilitates meaningful learning—the integration of PjBL with STEAM results in learning that develops students' critical thinking skills in chemistry.

In addition to the PjBL-STEAM learning model, based on the review results, two articles were found that used the STEAM approach without combining it with a specific learning model. This is generally done to provide flexibility for researchers to be able to develop more realistic learning steps with the students' learning environment in integrating STEAM without being fixated on one of the existing models. For example, in a study conducted by Setyawan and Patonah (2022) in an article entitled "Understanding the Profile of Students' Critical Thinking Skills in Hydrocarbon Material Using the STEAM Approach," it is explained that the researchers developed learning activity steps for

STEAM integration based on critical thinking indicators, without being tied to any one learning model. Although the non-specific STEAM model offers researchers flexibility in determining the learning flow, the number of studies that use it to develop critical thinking skills in high school students remains very limited. This is due to the absence of a learning model, resulting in a lack of systematic standards and formal learning steps. This condition requires researchers to design a cross-disciplinary integration process, which can be difficult due to time constraints or pedagogical limitations.

If the learning steps are not systematically arranged, students' thinking skills will not develop optimally because there are no explicit stages that facilitate critical thinking. In addition, one article uses the RADEC-STEAM model, suggesting that it is not yet commonly used to integrate STEAM into chemistry learning to develop critical thinking skills. Researchers tend to use PjBL-STEAM, which is more common and widely used in the learning process.

Based on the most researched chemistry topics, a review of 15 articles found that the most commonly used chemical materials were acids and bases. Still, the use of STEAM to develop critical thinking skills was actually evenly distributed across all chemistry materials. The distribution of chemical materials used in the 15 reviewed articles is shown in Figure 3. Based on the review, it was found that acid-base materials were the most widely used or studied in the STEAM approach to develop critical thinking skills in high school students, while other materials were studied in only 1-2 studies. From this, it can be seen that STEAM can actually be applied evenly to various topics in chemistry in an effort to develop students' critical thinking skills. Based on the data obtained, the STEAM approach is adaptable and not limited to a single chemistry subject. Acids and bases are among the most widely used chemistry topics in STEAM applications. However, the dominance of acids and bases does not show a significant difference from other chemistry topics, suggesting that the selection of learning topics in chemistry tends to be relatively even.

Generally, acids and bases are chosen as learning topics because they are part in basic chemistry concepts, are relevant to everyday life phenomena, and are easy to apply through an

interdisciplinary approach in line with STEAM approach. Acid and base materials are also the most widely used because they require an understanding of three levels of chemical representation: macroscopic, submicroscopic, and symbolic (Redhana et al., 2020).

This makes acids and bases a relevant topic to study through STEAM in integrating all three levels of chemical representation while developing critical thinking skills. This learning topic helps improve students' reasoning skills, a key component of critical thinking in students. Furthermore, chemical structure and hydrocarbons are two learning topics that are used relatively often after acids and bases. On the other hand, materials such as electrolytes, redox reactions, voltaic cells, adsorption, colloids, acid-base titration, hydrolysis, and thermochemistry appear to be used as learning topics in almost equal amounts. This distribution pattern illustrates that the use of STEAM in chemistry learning to improve critical thinking in high school students is not limited to a single chemistry material, but can be widely integrated into various topics.

Based on a systematic review, the effectiveness of using acid-base material in STEAM implementation to improve critical thinking skills did not differ significantly from that of other chemistry topics. For example, research conducted by Rahmawati et al. (2020) on acids and bases showed that the application of STEAM was effective in improving critical thinking skills in chemistry learning. This study explains that integrating STEAM into acid-base learning enables students to develop critical thinking skills, including the ability to ask questions, formulate problems, find supporting evidence, analyse assumptions, and interpret the results of problem-solving.

On the other hand, research conducted by Ananda et al. (2023), which examined the topic of redox reactions, showed that the application of STEAM in this topic was also effective in improving students' critical thinking skills. The study explained that students' thinking skills were classified as optimally developed, in which students were able to search for and process information obtained related to existing phenomena, and were able to interpret, reflect on, and explain the data obtained using logical reasoning. This is also supported by research by

Muhammad et al. (2024), which examined electrolyte and non-electrolyte solutions. The study found that students' critical thinking skills in this topic improved through the application of the STEAM approach. This study also explains that the critical thinking indicators that were successfully improved include the ability to interpret, analyze problems, evaluate, and draw conclusions.

Upon review, the use of chemical materials remains relatively limited in each topic, indicating that the STEAM approach in chemistry education remains scattered across various materials. STEAM studies are still in the exploratory stage to test the suitability of STEAM in various chemistry topics. Most likely, the selection of diverse materials with low frequency is also due to differences in learning needs and educators' perspectives regarding topics considered relevant for study. This explains why there is no strong dominance of any one learning topic, resulting in the distribution pattern shown in diagram 3. Thus, the low number of occurrences of each material does not cause limitations in the STEAM approach used, but shows that there are still many research opportunities that can be explored in applying STEAM to improve the critical thinking skills of high school students.

## CONCLUSION

Based on a systematic literature review of 15 articles, the dominant research method was qualitative, accounting for 66%. This dominance indicates that most studies focused on broader aspects of the learning process, social interactions, and even student learning experiences related to STEAM integration in chemistry. Furthermore, in terms of learning models, the STEAM-integrated Project-Based Learning (PjBL) model was the most widely used, with 11 articles. PjBL is well-suited for STEAM collaboration because it provides students with space to develop critical thinking skills by integrating elements of science, technology, art, and mathematics through project-based activities.

Finally, based on the analysis of the articles, it was found that the most commonly used learning topic in integrating STEAM to improve high school students' critical thinking skills was acid-base material. However, the difference in the use of acid-base material compared to other materials was relatively small, indicating that the STEAM

approach is flexible and can be applied to any material in high school chemistry learning. Overall, STEAM-based chemistry learning has strong potential to improve high school students' critical thinking skills. However, further research is still needed on the variety of research methods, research models, and chemistry materials to expand STEAM in chemistry learning. The results of this systematic review can serve as a comprehensive overview of the application of STEAM in chemistry instruction to improve critical thinking skills among high school students. In addition, the results of this study can serve as a reference for teachers and researchers to develop more effective, contextually relevant STEAM in chemistry learning.

## RECOMMENDATION

Based on the results of the systematic literature review, further research is recommended to examine the application of STEAM using more diverse methods, models, and chemistry topics in high school chemistry education. This is recommended to obtain a more integrated understanding of the effectiveness of STEAM in various types of methods, models, and chemistry topics to improve students' critical thinking skills.

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