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Inquiry-Based Learning in Stoichiometry: A Systematic Literature Review and Bibliometric Analysis

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Abstract: This study aims to map the variations in the implementation of inquiry-based learning in stoichiometry and to analyze its effectiveness through a systematic literature review guided by the PRISMA framework, combined with a bibliometric analysis using VOSviewer. Articles published between 2015 and 2025 were retrieved from two databases, namely Google Scholar and Scopus, and subsequently selected based on inclusion and exclusion criteria related to topic relevance, educational level, and publication quality. Following the screening process, 21 articles were used for the bibliometric analysis, three of which were examined in depth through the systematic review. The results indicate that inquiry-based learning in stoichiometry is associated with improvements in students' conceptual understanding, representational skills, critical thinking abilities, and problem-solving skills. Bibliometric visualization reveals a shift in research focus from conceptual studies toward the development of inquiry-based and STEM-based teaching materials. These findings suggest that guided inquiry, inquiry-based practicum, and STEM-based learning are consistently reported to enhance students' learning outcomes in stoichiometry, although evidence regarding the consistency of these effects across different contexts and durations remains limited. This study reinforces the position of inquiry-based learning as an effective strategy for supporting chemistry learning at the secondary school level, while also identifying gaps that need to be addressed by future research.

Keywords: Bibliometric analysis inquiry based learning; Stoichiometry; Systematic literature review

Introduction

Stoichiometry is one of the fundamental topics in chemistry education that serves as a prerequisite for understanding other, more complex chemical concepts, such as chemical equilibrium, reaction rate, and electrochemistry. Its abstract nature, together with the demand for mathematical ability and multi-level representation (macroscopic, microscopic, and symbolic), makes stoichiometry one of the topics most frequently associated with conceptual misunderstandings among both secondary and undergraduate students (Kurniawati et al., 2016). This characteristic underlies why the present review focuses specifically on stoichiometry rather than on other basic chemistry topics such as redox reactions or acid–base chemistry.

Common misconceptions include misunderstandings about relative mass, the constituent particles of compounds, molar mass units, and the relationships among macroscopic, microscopic, and symbolic representations (Gani, 2025). Learning processes that remain dominated by lecture-based methods tend to make students passive, so that their science process skills develop poorly. In response to this issue, inquiry-based learning has been widely proposed as a pedagogical strategy that encourages students to actively construct concepts through direct experience, rather than passively receiving information.

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In practice, inquiry-based learning is not a single approach but encompasses various forms, including guided inquiry, structured inquiry, open inquiry, inquiry-based laboratory work, and the inquiry learning cycle. Each of these variations offers students a different degree of freedom and guidance in formulating questions, designing investigations, and drawing conclusions. These variations have been widely implemented and studied separately in the context of stoichiometry learning, for example through guided-inquiry practicum (Erwanto, 2018; Susilawati et al., 2022), inquiry-oriented teaching materials (Hamid, 2020), and POGIL-based modules (Zammi et al., 2020). On a broader scale, Jegstad (2024) systematic review of 102 inquiry-based chemistry education articles at the primary and secondary school levels also found that research in this field generally reports positive learning outcomes, but remains dominated by a conceptual and affective focus, with considerably less attention given to the epistemic dimension and to the systematic mapping of implementation variations.

However, to the best of our knowledge, these variations in inquiry implementation have not yet been systematically mapped specifically within the context of stoichiometry, so that their usage patterns, contexts of application, and the consistency of their effectiveness across variations remain unclear. This gap is important to address for at least three reasons. First, findings on the effectiveness of inquiry-based learning in stoichiometry remain scattered and have not been synthesized, making it difficult to conclude whether the results are consistent across different variations and contexts. Second, the implementation characteristics of each inquiry variation (duration, level of teacher guidance, integration with technology or STEM) have not been mapped, making it difficult for teachers and researchers to determine which variation is most suitable for a given learning context. Third, the learning contexts most conducive to the implementation of inquiry in stoichiometry such as educational level, class size, or laboratory availability have not been extensively discussed explicitly in the existing literature.

Although reviews such as Jegstad (2024) have examined inquiry-based learning in chemistry education in general, systematic reviews that focus specifically on the implementation of inquiry-based learning in stoichiometry, while also combining this with bibliometric analysis to map the structure and direction of research, remain limited. Therefore, this study aims to conduct a systematic review and bibliometric analysis of the implementation of inquiry-based learning in stoichiometry. Specifically, this study aims to: (1) map publication trends and the structure of knowledge (keyword co-occurrence, citation patterns) in this field through bibliometric analysis; (2) identify the forms, variations, or strategies of inquiry-based learning implementation used in stoichiometry instruction; and (3) analyze the main findings regarding the effectiveness of inquiry-based learning on students' learning outcomes and conceptual understanding in stoichiometry.

Method

This study employed a combined approach of bibliometric analysis and systematic literature review (SLR) guided by the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to examine the implementation of inquiry-based learning in stoichiometry instruction. Bibliometric analysis was conducted to identify publication trends, keyword relationships, and research networks, while the systematic literature review was used to analyze the implementation strategies and effectiveness of inquiry-based learning on students' learning outcomes and conceptual understanding.

Data Sources and Data Collection

The literature search was conducted using two databases, namely Google Scholar and Scopus, covering articles published between 2015 and 2025, in both Indonesian and English. The search used a combination of keywords with the following Boolean operators: ("pembelajaran berbasis inkuiri" OR "inquiry-based learning" OR "guided inquiry" OR "inkuiri terpadu") AND ("stoikiometri" OR "stoichiometry") AND ("pembelajaran kimia" OR "chemistry education"). In the Scopus database, the search was conducted on the title, abstract, and keywords (TITLE-ABS-KEY), limited to the subject areas of Chemistry and Social Sciences. In Google Scholar, the search was restricted by excluding documents not categorized as journal articles or review papers.

Inclusion and Exclusion Criteria

Inclusion criteria: (1) the article discusses the implementation of inquiry-based learning on the topic of stoichiometry in chemistry education; (2) published between 2015 and 2025; (3) is a peer-reviewed journal article or review paper; (4) full text is available.

Exclusion criteria: (1) the article is unrelated to chemistry education, including irrelevant search results from other fields (for example, molecular biology articles inadvertently captured by the search keywords); (2) conference abstracts without full text, editorials, or opinion pieces; (3) the article does not specifically address stoichiometry.

Quality Assessment

Every article that passed the title and abstract screening stage was assessed for quality using a checklist adapted from the Critical Appraisal Skills Programme (CASP) for quantitative and mixed-methods studies, covering: clarity of research objectives, appropriateness of the research design to the research question, clarity in the description of the inquiry intervention applied, validity of the learning outcome measurement instruments, and clarity in reporting the results and limitations of the study. Articles that did not meet the minimum standard on these criteria were excluded from the in-depth systematic review analysis.

Selection Process and PRISMA Diagram

The initial search yielded 532 publications (520 from Google Scholar and 12 from Scopus). After merging the results using the Zotero reference management software and applying the initial inclusion criteria, 498 publications were retained for the next screening stage. Duplicate records were then removed (337 records), leaving 161 publications for title and abstract screening. Following this stage, 22 articles were deemed to meet the initial eligibility criteria. During further examination, one article identified as a false positive (a molecular biology article on the Cas4-Cas1-Cas2 complex in the CRISPR system, which was irrelevant to either stoichiometry or chemistry education) was excluded from the corpus, resulting in a final corpus of 21 articles for the bibliometric analysis. Of these 21 articles, 3 were identified as most relevant to the research objectives and were examined in depth through the systematic review. The complete PRISMA flow diagram is presented in Figure 1.

Data Analysis Strategy

The collected publications were analyzed using VOSviewer, Harzing's Publish or Perish, Zotero, and Microsoft Excel software. Zotero was used as a reference manager to organize publication data, remove duplicate documents, and ensure consistent metadata formatting before the data was imported into VOSviewer. Harzing's Publish or Perish was used to identify the number of authors, productive authors, affiliations, and citation metrics for each publication (Fauzan et al., 2024). Microsoft Excel was used to support the organization and tabulation of descriptive data. This study applied three stages of analysis: descriptive analysis to map publication trends, productive authors and journals, publishing countries, dominant keywords, and citation patterns. Bibliometric network analysis to visualize relationships between authors, institutional/country collaboration, keyword co-occurrence, and citation linkages; and qualitative analysis through an SLR approach to examine in depth the pedagogical strategies, empirical findings, and factors influencing the effectiveness of inquiry-based learning in stoichiometry, as well as to highlight research gaps for future studies.

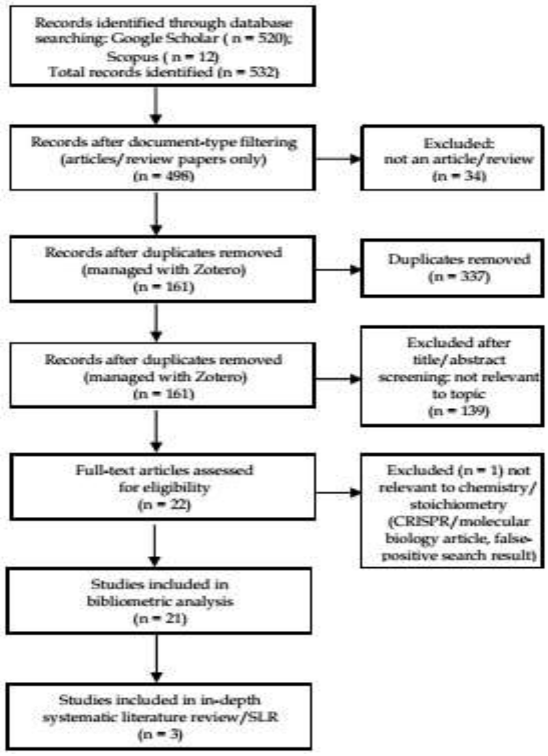

Figure 1. PRISMA flow diagram of the article selection

Result and Discussion

Publication Trends and Highly Cited Articles

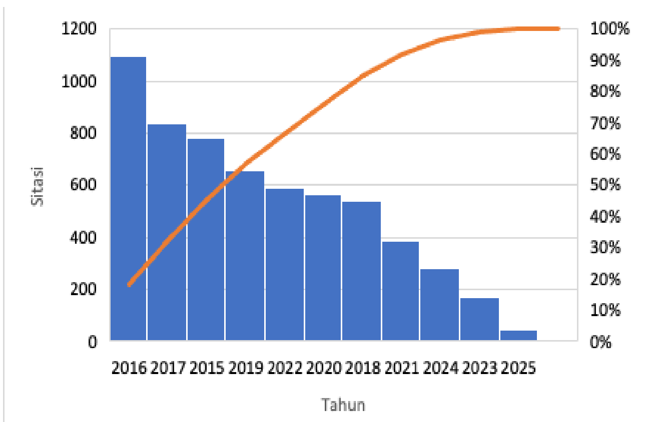

Figure 2. Systematic search literature records

Based on the results of the systematic search, the number of publications related to inquiry-based learning in stoichiometry shows a declining trend over the 2015-2025 period (Figure 2), with a publication peak in 2016 and a gradual decline in subsequent years, accompanied by a decrease in annual citation counts

(Noeraida, 2020). Nevertheless, the cumulative curve shows that the research contribution continues to increase over time, indicating that this topic remains academically relevant despite the decline in annual publication productivity.

Table 1 presents the nine most frequently cited articles in the corpus, after one irrelevant article (see the Methods section) was excluded from the analysis. Most of these publications focus on inquiry-based chemistry learning, the effectiveness of teaching strategies such as POGIL, STEM approaches in stoichiometry, and factors influencing student achievement.

Based on publication year, most of the most frequently cited articles were published between 2015 and 2019. This period can be considered an active phase in the development of inquiry-based learning research in chemistry education. The high citation rates of these articles indicate that earlier research continues to serve as an important reference for current studies.

Table 1. Most-Cited Inquiry-Stoichiometry Literature

Author	Title	Year	Citation
(Galloway et al., 2016)	Investigating affective experiences in the undergraduate chemistry laboratory: students' perceptions of control and responsibility	2016	432
(Vishnumolakala et al., 2017)	Students' attitudes, self-efficacy and experiences in a modified process-oriented guided inquiry learning undergraduate chemistry classroom	2017	176
(Gupta et al., 2015)	Impact of guided-inquiry-based instruction with a writing and reflection emphasis on chemistry students' critical thinking abilities	2015	151
(Chonkaew et al., 2016)	Development of analytical thinking ability and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (STEM education) in the study of stoichiometry	2016	137
(Davenport et al., 2018)	Whether and how authentic contexts using a virtual chemistry lab support learning	2018	125
(Victor et al., 2017)	Effect of gender on senior secondary chemistry students' achievement in stoichiometry using hands-on activities	2017	113
(Galloway et al., 2015)	Measuring meaningful learning in the undergraduate general chemistry and organic chemistry laboratories: a longitudinal study	2015	100
(Schultz et al., 2020)	Development and use of kitchen chemistry home practical activities during unanticipated campus closures	2020	95
(Ralph et al., 2018)	Chemistry topics posing incommensurate difficulty to students with low math aptitude scores	2018	78

Bibliometric Mapping Analysis

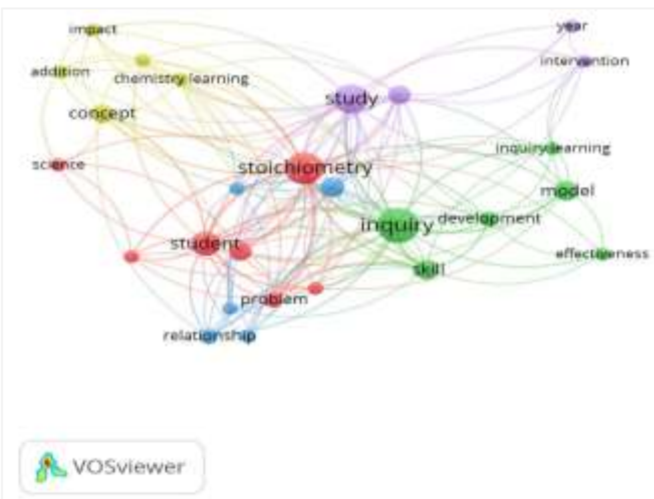

Figure 3. Network Visualization

The bibliometric analysis using VOSviewer on the 21 articles in the corpus produced three types of visualizations: network visualization, overlay visualization, and density visualization. Keyword co-occurrence analysis yielded five thematic clusters, as indicated by the different colors in Figure 3, namely: (1) a cluster centered on stoichiometry and student understanding (effect, high school student, problem, science, stoichiometry, student, understanding); (2) an inquiry and learning model cluster (development, effectiveness, inquiry, inquiry learning, model, skill); (3) a learning outcomes and context cluster (high school, learning, outcome, relationship, use); (4) a chemistry learning concept and impact cluster (addition, chemistry learning, concept, impact, subject); and (5) a research design cluster (chemistry, intervention, study, year).

In this network visualization, the keywords "stoichiometry" and "inquiry" occupy the most central positions, with the largest node size and the highest connectivity, serving as the main links between clusters. This finding indicates that stoichiometry research in chemistry education is consistently examined within the context of inquiry-based learning, and that these two terms serve as the pivot connecting the conceptual understanding cluster (Cluster 1) with the inquiry models and skills cluster (Cluster 2). Cluster 4 (chemistry learning concepts and impact) and Cluster 3 (learning outcomes and context) appear as more peripheral thematic groups, yet remain closely connected to these two core clusters, whereas Cluster 5 (research design) shows a looser connection, indicating that methodological aspects (intervention duration, study year) have not yet been fully integrated with the substantive discussion of inquiry and stoichiometry.

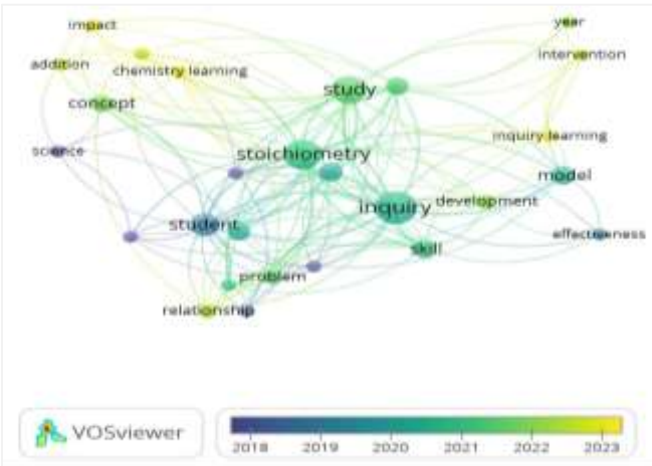

Figure 4. Overlay visualization

The overlay visualization (Figure 4) shows the shift in research focus from 2018 to 2023. Topics such as science and effectiveness tend to appear in publications from the earlier period (2018–2019), while stoichiometry, inquiry, concept, study, skill, and student dominate the middle period (2020–2021) as the core of conceptual and instructional discussion. In the more recent period (2022–2023), keywords such as impact, intervention, inquiry learning, chemistry learning, and relationship become more prominent, indicating a shift in research attention from merely testing the conceptual effectiveness of inquiry toward a more specific examination of the impact and relationships of learning interventions.

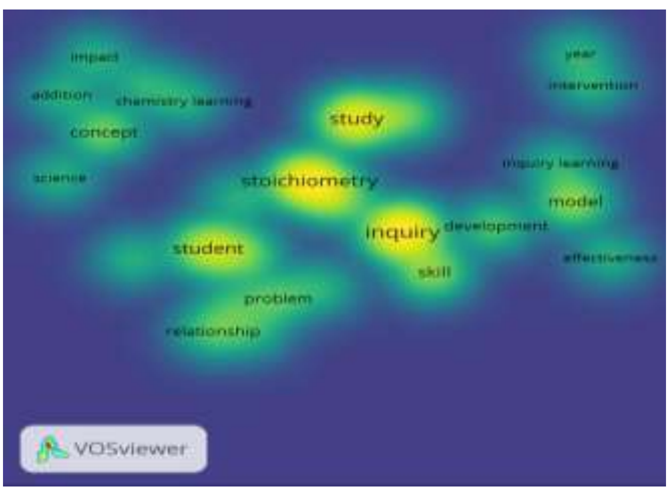

Figure 5. Density visualization

The findings from the network and overlay visualizations are reinforced by the density visualization (Figure 5), which shows that the keywords stoichiometry, inquiry, and study have the highest occurrence intensity (density), displayed in bright yellow, confirming their position as the thematic core of the corpus. Meanwhile, keywords in Clusters 3 and 5 (such as relationship, intervention, and year) show lower intensity, indicating that the relationships between variables and long-term research designs remain relatively underexplored areas with potential for development in future research.

Discussion of Inquiry-Based Learning in Stoichiometry

The findings of the systematic review reveal that inquiry-based learning in stoichiometry has been implemented in various forms, including guided inquiry, inquiry-based practicum, POGIL, and inquiry-based STEM approaches (Zammi et al., 2020). Among these variations, guided inquiry and POGIL appear to be the most dominant and are the most consistently reported to be successful. This dominance is presumably related to the characteristics of both approaches, which provide explicit structure and guidance (scaffolding) to help students connect macroscopic, microscopic, and symbolic representations in stoichiometry, while still allowing room for active exploration and group discussion. The elements of cooperative learning and the emphasis on metacognition within POGIL are specifically thought to contribute to strengthening conceptual understanding (Susanti et al., 2018), although this causal mechanism has not been extensively tested directly in the reviewed articles.

It is important to note that the picture of success in inquiry-based learning is not always uniform. For example, Hosbein et al. (2022) meta-analysis of 21 POGIL studies found that this approach yielded only a small effect on conventional measures of academic achievement (effect size = 0.29), although it substantially increased students' odds of passing the course. This finding indicates that the effectiveness of POGIL and other guided-inquiry approaches is context-dependent and does not always show a uniform magnitude across different learning outcome measures. Consistent with this, systematic review of inquiry-based chemistry education research in general also noted that the methodological quality of studies in this field remains variable, with many studies not explicitly reporting details of the intervention or the study's limitations (Jegstad, 2024).

Based on these observations, a number of limitations were also identified in the reviewed articles, including: relatively short intervention durations, meaning long-term effects cannot yet be ascertained; sample sizes limited to single-class or single-school contexts; and minimal reporting on teacher readiness and training in implementing inquiry-based learning, even though the success of this approach depends heavily on teachers' competence in facilitating the inquiry process (Kimberlin et al., 2016).

Compared with reviews of inquiry-based learning in chemistry education in general, such as that conducted by Jegstad (2024), the main contribution of this review lies in its mapping that focuses specifically on stoichiometry as a prerequisite topic that consistently gives rise to misconceptions, as well as its integration of bibliometric analysis with qualitative SLR synthesis. Thus, this review not only demonstrates the effectiveness of inquiry-based learning but also maps the structure of knowledge and the shifting direction of research over time specifically on the topic of stoichiometry.

The integration of the systematic review findings with the bibliometric analysis further reinforces the conclusion that inquiry-based learning has become one of the main approaches in chemistry education research, particularly in stoichiometry learning. The keyword "inquiry" emerges as a central focus in the research network and shows a strong relationship with conceptual understanding, problem solving, and impact. Although the publication trend has declined in recent years, the academic relevance and influence of inquiry-based learning remain significant in the development of chemistry education research.

Conclusion

This systematic review and bibliometric analysis show that inquiry-based learning in stoichiometry has been implemented through various variations, including guided inquiry, inquiry-based laboratory work, POGIL, and inquiry-based STEM approaches, which are generally reported to improve students' conceptual understanding, representational skills, critical thinking abilities, and problem-solving skills, although the magnitude of the effects varies across studies. The bibliometric analysis shows that the keywords "inquiry" and "stoichiometry" are the most central nodes in the research network, with a shift in focus from conceptual issues toward the development of teaching materials and the evaluation of learning effectiveness. Nevertheless, variations in inquiry implementation have not been widely compared directly, and evidence regarding the role of teacher training and long-term effects remains limited. Future research needs to address these gaps, including exploring the integration of inquiry-based learning with AI-assisted learning, virtual laboratories, and immersive technologies to support the future of chemistry education.

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Author Contributions
The author contributed to all aspects of this study and approved the final version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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