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Towards a Typology of Inquiry-Based Learning Syntax in Science Education: A Systematic Literature Review (2016–2025)

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Abstract: This study reviewed 41 articles published between 2016 and 2025 that addressed the implementation of Inquiry-Based Learning (IBL) in science education. While several previous studies have discussed inquiry learning models and their relevance to various science disciplines, few have systematically examined the variation of IBL syntax across models and how its implementation aligns with educational contexts and developmental levels. The purpose of this study is to map and analyze the use of IBL syntax across models, learning environments, educational levels, and technology integration, thereby providing a clearer framework for teachers and curriculum developers. This study employed a systematic literature review method. Article characteristics were described based on year of publication, publication type, research method, country of origin, educational level, and scientific content. The analysis revealed that IBL syntax varies depending on context, learning model, educational level, and technology use. In elementary school settings, inquiry activities generally focus on initial engagement, observation, and simple exploration. At the secondary school level, IBL emphasizes more complex investigative skills, data analysis, and interpretation. In secondary and higher education, syntax often encompasses elaboration, evaluation, reflection, collaboration, and technology-supported activities such as virtual laboratories, simulations, or project-based investigations. Based on these findings, a practical typology of IBL syntax is proposed that organizes instructional steps by frequency of use, learning objectives, and alignment with students' developmental stages. This typology can serve as a methodological framework to guide teachers and curriculum developers in adapting IBL models to classroom contexts and student characteristics. This study provides theoretical insights and practical guidance for designing structured and context-sensitive inquiry activities. Future research is recommended to explore underutilized syntax, validate the proposed typology in classroom settings, and examine strategies to support teacher readiness and resource availability, thereby encouraging a more systematic and context-appropriate implementation of inquiry-based learning in science education.

Keywords: systematic literature review, science education, learning syntax, and inquiry-based learning.

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INTRODUCTION

Improving the quality of science education is a major challenge worldwide, as reflected in international assessments showing stagnant student scientific literacy outcomes in many countries despite increasing investment in education (OECD, 2019). Numerous international reports and studies from various countries indicate that science learning in many contexts is still dominated by a teacher-centered approach, in which teachers do most of the talking while students play a passive role as listeners. This learning pattern results in low student engagement in the learning process and limits their opportunities to develop deep conceptual understanding and scientific thinking skills applicable to real-life situations (Furtak et al., 2012; Lazonder & Harmsen, 2016; OECD, 2019). These findings indicate that science learning focused on transmitting information has not encouraged students to deeply understand concepts and transfer knowledge to new contexts. Consistent with this, several studies report that students often experience difficulties in carrying out authentic science practices and applying learned knowledge to everyday situations. This condition indicates the need for transformation in science education, which should not only emphasize mastery of facts but also develop critical thinking, scientific reasoning, and problem-solving skills relevant to current and future challenges (Fiska, 2021; Relisma et al., 2022).

Given the low level of student engagement in science learning described above, science teaching practices that actively involve students in the learning process are urgently needed. To address this condition, many teachers have implemented student-centered instructional models, such as Problem-Based and Project-Based Learning, to increase students' active participation in science classrooms. However, these models are often implemented at the classroom level and require a broader pedagogical framework to consistently support students' engagement in scientific practices. One such framework is Inquiry-Based Learning (IBL), which is conceptualized as a learning approach that emphasizes students' active involvement in scientific inquiry processes, including asking real-world questions, conducting investigations, and using evidence to construct answers. Through IBL, students are encouraged to generate their own questions, plan experiments, analyze data, and draw conclusions, directly addressing the limitations of information-transmission-oriented science instruction and supporting the development of scientific thinking skills essential for life in the modern world (Efendi, 2025; Lazonder & Harmsen, 2016).

Within this context, the development of students' scientific abilities becomes a critical concern for both current and future societal demands, as traditional learning practices that limit exploration tend to position students as passive learners and hinder their ability to meaningfully understand science concepts (Fiska, 2021; Relisma et al., 2022). This condition reinforces the urgency of implementing learning approaches that systematically promote active engagement, exploration, and knowledge construction, rather than isolated instructional activities. As a learning approach, Inquiry-Based Learning (IBL) provides a coherent foundation for organizing science instruction, ensuring that learning activities consistently engage students in inquiry processes aligned with the goals of scientific literacy and the development of critical and scientific reasoning skills.

Previous studies have reported that Inquiry-Based Learning (IBL) has the potential to engage students in essential scientific practices, such as formulating questions, proposing hypotheses, planning experiments, analyzing data, interpreting findings, and drawing conclusions (Kousloglou, 2023). Research by Abaniel (2021) also suggests that implementing IBL can support the development of students' 21st-century skills, learning attitudes, and conceptual understanding. From a theoretical perspective, IBL is grounded in constructivist learning principles that emphasize active student engagement through interaction with the environment and meaningful learning experiences (Aktamiº et al., 2016). In line with this perspective, IBL positions students as active participants in the construction of scientific knowledge, which is consistent with the goals of modern scientific literacy (Roberts & Bybee, 2014).

General characteristics of IBL that can be seen in its constituent elements include direct involvement with real phenomena, experimental activities, asking open questions, and reflective discussions. Students learn in groups to develop ideas and solutions collaboratively, a process central to IBL (Dostál, 2015; Lau et al., 2017). This approach is highly relevant to the context of science learning because it provides direct experience in applying scientific methods, ultimately strengthening conceptual understanding and increasing students' interest in learning. Confirmatory, structured, guided, and open-ended inquiries are among the commonly used IBL models (Banchi & Bell, 2008). Variations in the stages of student independence and in teachers' responsibility for guiding the learning process are evident across the inquiry learning models. Conceptual understanding, critical thinking skills, learning motivation, and students' scientific attitudes have been shown to increase with the IBL approach (Haatainen & Aksela, 2021; Laksana et al., 2019). The advancement of IBL in education can strengthen the drive to master science concepts and teaching skills of prospective teachers (Strat et al., 2023).

Several systematic literature reviews of inquiry-based learning in science education have been conducted. Berie et al. (2022) analyzed the trends and characteristics of IBL research in science education in Ethiopia during 2010–2021, including Frequently Researched Topics, Inquiry Models Used, Research Methodology, and Research Subjects. At the same time, Hinostroza et al. (2024) reviewed the role of digital technology in implementing Inquiry-Based Learning (IBL) for K-12 students, particularly in mapping technology at every stage of the inquiry cycle. Vo et al. (2025) evaluated assessment techniques in technology-based inquiry learning and identified global trends and developments in scientific inquiry assessment. Alarcon et al. (2023) synthesized IBL instructional models in science education, Thematic Areas, and science content developed by teachers in secondary education globally. Research by Efendi et al. (2025) and Wardani et al. (2024) examined how the Inquiry Learning strategy affected junior high school students' scientific learning outcomes.

In addition to earlier systematic literature reviews, a systematic review and meta-analysis by Arifin et al. (2025) looked at how inquiry-based learning (IBL) affects students' critical thinking skills in science education. Adeyele (2023) also examined how IBL is used in early childhood science teaching and its effects on learning outcomes. Even though many previous reviews and meta-analyses have examined the effectiveness of IBL in improving student learning outcomes, critical thinking, and motivation in science education, most studies have focused on the outcomes rather than how IBL is actually taught in the classroom. Specifically, not much attention has been given to the learning syntax, which means the order of steps that teachers use to guide students through the inquiry process.

IBL is taught using different models, such as confirmatory, structured, guided, and open-ended inquiry. Each model has its own learning syntax that helps students ask questions, conduct investigations, analyze data, and draw conclusions. Previous reviews have not deeply explored how these syntaxes differ between the models. This is an important area of study because the learning syntax directly affects how engaged students are, how well IBL works, and how practical it is for real classrooms.

In addition to differences in learning syntax, the use of IBL models may vary across educational levels, regions, and research methodologies. Understanding these patterns, or typologies, provides insights into global and local trends in IBL implementation and identifies best practices that can be adapted to real classroom contexts.

To answer this question, this study looked at 41 major international articles published between 2016 and 2025. The goal was to identify the common features of Inquiry-Based Learning in science education and to compare the learning syntax used across different IBL models. Based on this, the study was guided by the following research questions:

1. What are the common features of Inquiry-Based Learning in science education?
2. How do different learning syntaxes work in various Inquiry-Based Learning models?
3. Do patterns of IBL model use differ by educational level, region, or type of research?

METHOD

Research Design

This study employed a Systematic Literature Review (SLR) with a descriptive, mapping-oriented design to examine how Inquiry-Based Learning (IBL) is implemented in science education, particularly focusing on the learning syntax, or inquiry stages, applied in instructional practice. A descriptive and mapping-oriented SLR is appropriate when the objective is not to measure effect sizes but to identify, classify, and synthesize patterns, trends, and characteristics of research within a specific field (Arksey & O'Malley, 2005; Grant & Booth, 2009).

This study aimed to map variations in IBL models, instructional steps, and implementation contexts across empirical studies in science education. The review process followed the PRISMA 2020 guidelines to ensure transparency, replicability, and systematic reporting throughout the identification, screening, eligibility assessment, and inclusion stages (Page et al., 2021).

Data Sources and Search Strategy

The literature search was conducted primarily using the Scopus database, supplemented by a manual search of the International Journal of Science Education (IJSE). Scopus was chosen because it offers broad, multidisciplinary coverage of peer-reviewed journals in science education and education, and provides sophisticated filtering tools to support systematic reviews. The search was limited to articles published between 2016 and 2025 to capture recent developments and contemporary teaching practices in Inquiry-Based Learning (IBL). Two primary search strings were applied:

"Inquiry-Based Science Learning"
"Inquiry-Based Learning, Science Education"

The initial search yielded 9,379 records from Scopus (5,705 and 3,474 articles, respectively). An additional 285 open-access articles were identified through a manual search of IJSE, bringing the total to 9,664 records. The selected articles are listed in Table 1.

Table 1. Summary of selected journals for review

No.	Name of journal	f	(%)	Indexed by	H-Index (SJR 2024)
1.	Sustainability	2	04.88	Scopus (Q1)	207
2.	Educational Technology Research and Development	1	02.44	Scopus (Q1)	117
3.	BMC Medical Education	1	02.44	Scopus (Q1)	107
4.	Behaviour and Information Technology	1	02.44	Scopus (Q1)	103
5.	Journal of Science Education and Technology	1	02.44	Scopus (Q1)	85
6.	Research in Science Education	1	02.44	Scopus (Q1)	72
7.	Education Science	3	07.32	Scopus (Q1)	68
8.	Chemistry Education Research and Practice	1	02.44	Scopus (Q1)	62

9.	Smart Learning Environments	1	02.44	Scopus (Q1)	41
10.	Malaysian Journal of Learning and Instruction	1	02.44	Scopus (Q1)	20
11.	International Journal of Science Education	3	07.32	Scopus (Q2)	132
12.	Journal of Chemical Education	1	02.44	Scopus (Q2)	109
13.	Eurasia Journal of Mathematics, Science and Technology Education	2	04.88	Scopus (Q2)	63
14.	Frontiers in Education	1	02.44	Scopus (Q2)	55
15.	Physics Education	1	02.44	Scopus (Q2)	38
16.	Turkish Online Journal of Distance Education	1	02.44	Scopus (Q2)	37
17.	International Journal of Early Childhood	1	02.44	Scopus (Q2)	34
18.	Journal of Baltic Science Education	2	04.88	Scopus (Q2)	29
19.	Journal of Turkish Science Education	2	04.88	Scopus (Q2)	27
20.	Journal of Technology and Science Education	1	02.44	Scopus (Q2)	23
21.	European Journal of Science and Mathematics Education	1	02.44	Scopus (Q2)	9
22.	International Journal of Interactive Mobile Technologies	2	04.88	Scopus (Q3)	41
23.	Jurnal Pendidikan IPA Indonesia (Indonesian Journal of Science Education)	4	09.76	Scopus (Q3)	30
24.	Eurasian Journal of Educational Research	1	02.44	Scopus (Q3)	30
25.	African Journal of Research in Mathematics, Science and Technology Education,	2	04.88	Scopus (Q3)	22
26.	Journal of Education and e-Learning Research	1	02.44	Scopus (Q3)	14
27.	Higher Learning Research Communications	1	02.44	Scopus (Q3)	12
28.	Science Education International	1	02.44	Scopus (Q3)	11
	Total	41	100		

According to Table 1, the selected articles were published in 28 reputable international journals that are Scopus-indexed, with journal rankings ranging from Q1 to Q3 (Scimago Journal & Country Rank, scimagojr.com). Many of these journals also have high H-indices, indicating broad scholarly recognition. However, bibliometric indicators alone do not guarantee the methodological rigor of individual studies. Therefore, the methodological quality and reliability of each article were formally assessed using the Mixed Methods Appraisal Tool (MMAT, version 2018; Hong et al., 2018). Based on the MMAT evaluation, 30 studies were classified as High Quality and 11 as Moderate Quality. Thus, claims regarding the reliability and scholarly quality of the reviewed articles are supported by both journal-level metrics and formal MMAT assessment (see Supplementary Table 1 for full MMAT assessment details).

Inclusion and Exclusion Criteria

Study selection in the systematic review was guided by pre-established inclusion and exclusion criteria to ensure relevance, consistency, and methodological rigor. These criteria were established prior to the article screening process, in accordance with recommendations for systematic observational research in education (Page et al., 2021).

Table 2. The criteria for inclusion and exclusion

Criteria	Inclusion	Exclusion
Publication timeline	2016-2025	Prior to the year 2016
Type of record	Original article findings	Book chapter, conference proceedings, review paper
Language	English	Non-English
Source type	Journal	Non-journal
Content	Relevant to the research questions or objectives	Irrelevant or off-topic content
Participant	Involving students, teachers, and those related to education	No identifiable participants or populations outside the scope
Title	Contains keywords related to the topic	Title unrelated to the research focus

Study Selection Process

The study selection followed the four-stage PRISMA 2020 process: identification, screening, eligibility, and inclusion (Page et al., 2021). After removing duplicate records, titles, and abstracts were screened to exclude studies that did not meet the inclusion criteria. Full-text screening was then conducted to assess methodological relevance and alignment with the research objectives. Through this process, 41 articles were identified as eligible and included in the final review. The study selection procedure is illustrated using PRISMA 2020 Flow Diagram, cited directly from the source (Page et al., 2021).

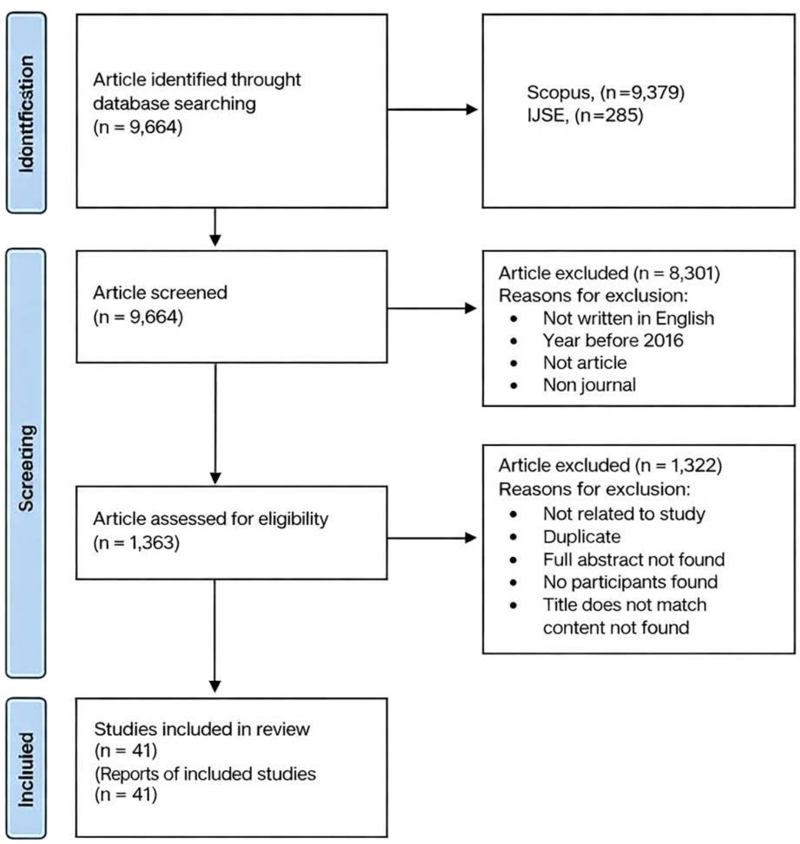

Figure 1. PRISMA 2020 flow diagram of the study selection process (page et al., 2021)

Data Extraction and Synthesis

Data extraction was conducted manually using a structured extraction form to ensure consistency across studies. The extracted information included: Author(s) and publication year; Journal name; Educational level; Science discipline; Type of IBL model applied and Description of learning syntax or inquiry stages. The data were analyzed using descriptive synthesis, which is suitable for mapping instructional characteristics and synthesizing qualitative patterns across studies (Popay et al., 2006). The synthesis focused on identifying similarities and differences in inquiry stages, instructional sequences, and implementation approaches across various IBL models.

Methodological Quality Assessment Using MMAT

In this review, 41 selected articles were systematically assessed for methodological quality using the Mixed Methods Appraisal Tool (MMAT, version 2018; Hong et al., 2018), which evaluates qualitative, quantitative, and mixed-methods studies. This assessment followed a structured four-step process to ensure transparency and reproducibility:

Study Categorization

Each article was first classified based on its research design: (1) Qualitative studies used observations, interviews, case studies, and thematic analysis. (2) Non-randomized quantitative studies used quasi-experimental designs, pre-post tests, and correlational studies. (3) Descriptive quantitative studies used surveys and cross-sectional measurements. (4) Mixed methods studies combined qualitative and quantitative designs with data integration. No studies were classified as Randomized Controlled Trials (RCTs), so RCT criteria were not applied.

Evaluation Using the MMAT Core Criteria

Each study was assessed based on the five MMAT core criteria (S1–S5):

S1: Clarity and appropriateness of the research question; S2: Appropriateness of the sampling method; S3: Reliability of data collection; S4: Appropriateness of data analysis to the design; S5: Consistency of interpretation with data. Each criterion was answered with a Yes, No, or Can't tell, based on the information available in the article. For example, articles that did not provide details about confounding control or statistical analysis were scored "Can't tell" for the relevant criterion.

Scoring and Quality Classification

Score = number of "Yes" answers (0–5). High Quality: 5/5; Medium Quality: 4/5; Low Quality: d"3/5. Of the 41 articles analyzed, 30 studies received a score of 5 out of 5, thus being categorized as High Quality. These studies included mostly mixed-methods, qualitative, and quantitative descriptive/non-randomized designs, which clearly reported methodological procedures, used valid measurement tools, and conducted analyses consistent with the research design. Eleven other studies scored 4 out of 5. They were categorized as Moderate Quality due to incomplete or insufficient information regarding several MMAT criteria, such as controlling for confounding factors, integrating components in mixed-methods studies, and aspects of outcome measurement (Cairns, 2019; Abaniel, 2021). No articles scored 3 or lower. Overall, this assessment demonstrated good methodological consistency and reliability, enabling data from these articles to be used to synthesize findings on the application of Inquiry-Based Learning (IBL) across various educational contexts. Of the 41 articles, 30 scored 5/5 (High Quality), and 11 scored 4/5 (Moderate Quality). No articles scored below 4. This formal assessment, combined with journal-level bibliometric indicators (Scopus Q1–Q3 rankings and H-index), supports the reliability and scholarly quality of the studies reviewed. Detailed MMAT scoring for all studies is provided in Supplementary Table S1.

RESULT AND DISCUSSION

Research Question 1: What are the general characteristics of the Inquiry-Based Learning approach in science learning?

The distribution of this research is separated by general characteristics, including publication type, year of publication, the nations that use inquiry-based learning, research approach, educational stage, and science content.

Research distribution by year of publication

The research distributions considered span 2016 to 2025. The complete data is displayed in Figure 2.

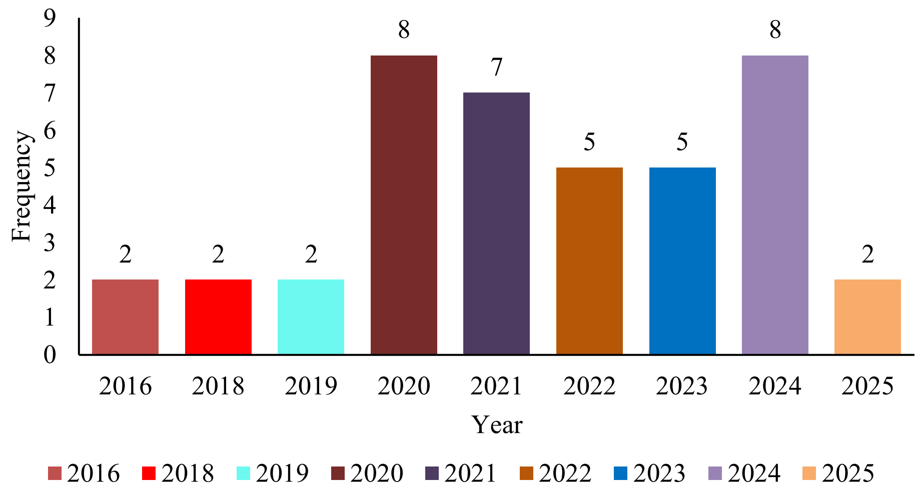

Figure 2. The research's distribution by year of publication

Figure 2 shows the distribution of research publications on Inquiry-Based Learning (IBL) in science education from 2016 to 2025. The general trend shows an increase in publications over the past decade, with peaks in 2020 and 2024. Although the number of publications has increased over the past decade, this pattern indicates continued growth in interest and research activity in IBL, in line with the global focus on active learning and students' critical literacy (Berie et al., 2022; Alarcon et al., 2023).

Representation of Research by Publication Type

The study's findings have been published in various formats, including journals, proceedings, books, and theses. Research representation by publication type shown in Table.

Table 3. Representations of research according to the type of publication

No.	Type of Publications	Numberof articles (f)	%
1.	Journal	41	100
2.	Proceeding, book, thesis, or others	0	0
	Total	41	100

Table 3 shows that 41 of the analyzed articles were published in international journals. This study intentionally selected only journal articles and excluded proceedings, books, theses, or other publications to ensure the quality and validity of the findings. Therefore, the analyzed data reflect peer-reviewed research and adhere to credible research practices in the field of

Inquiry-Based Learning (IBL) in science education.

The distribution of research based on the research approach

The research approach is based on the research method described in the article. The research approch data are presented in Table 4.

Table 4 shows that IBL research uses four main approaches: qualitative, quantitative, mixed methods, and research and development (R&D). The mixed methods approach is the most dominant, with 18 articles (43.90%), followed by quantitative (36.59%) and qualitative (17.07%). The R&D approach is the least used, with only one article (2.44%).

Table 4. Representations of research based on the research approach

No.	Research Approach	F	(%)
1.	Qualitative	7	17.07
2.	Quantitative	15	36.59
3.	Mixed Methods	18	43.90
4.	Research & Development	1	2.44
	Total	41	100

The dominance of mixed methods reflects researchers' efforts to combine the strengths of quantitative data and qualitative insights to gain a more comprehensive understanding of IBL, such as student engagement, problem-solving processes, and collaborative skills (Johnson, Onwuegbuzie, & Turner, 2007; Creswell & Plano-Clark, 2018). Qualitative approaches are used to explore classroom interactions and the implementation of inquiry steps, while quantitative approaches are generally used to measure learning improvement and knowledge retention.

These results emphasize the diversity of methods in IBL research, which aligns with IBL's principle of simultaneously targeting cognitive, procedural, and affective learning outcomes (Bybee et al., 2006; National Research Council [NRC], 2000). These diverse approaches support a more comprehensive analysis and enhance understanding of IBL's effectiveness across educational contexts.

Distribution of research by country that implements inquiry-based learning in science learning

Countries that implement Inquiry-Based Learning in science education are shown in Figure 3. The distribution of research shown in Table 5.

Table 5. Distribution of inquiry-based learning research in science education by country

No.	Country	F	(%)	E.g., (only first author cited)
1.	Indonesia	7	17.06	Panjaitan (2020), Hairida (2016), Rusdiyana (2024), Purspitasari (2020), Hendratmoko (2023), Sapriati (2024), Pradani (2020)
2.	Netherlands	4	9.76	Roudriguez (2020), Slim (2022), van Schijndel (2018), Meulenbroeks (2024)
3.	China	3	7.31	Ong (2020), He (2021), Wang X (2021)
4.	Spain	3	7.31	Anna (2021), Rodriguez (2019), Zudaire (2022)
5.	Philippines	2	4.88	Tan (2020), Abaniel (2021)
6.	Jordan	2	4.88	Al Qawasmi (2024), Khasawneh (2024)
7.	Germany	2	4.88	Streich (2020), Olschewski (2023)

8.	Hungary	1	2.44	Oroz (2023)
9.	Greece	1	2.44	Kousloglou (2023)
10.	Slovakia	1	2.44	Gerhátová (2021)
11.	Turkey	1	2.44	Duran (2016)
12.	Morocco	1	2.44	Ouahi (2024)
13.	Hong kong	1	2.44	Wong (2025)
14.	Thailand	1	2.44	Premthaisong (2024)
15.	Norway	1	2.44	Zhang (2024)
16.	Singapore	1	2.44	Wen (2023)
17.	Ghana	1	2.44	Aidoo (2022)
18.	Brazil	1	2.44	Natalie (2021)
19.	Israel	1	2.44	Langbeheim (2020)
20.	United States of America	1	2.44	Lameras (2021)
21.	South Africa	1	2.44	Lamprecht (2025)
22.	Saudi Arabia	1	2.44	Dean (2019)
23.	Ethiopia	1	2.44	Areghegagn (2022)
24.	Finland	1	2.44	Joni (2018)
25.	Rwanda	1	2.44	Manishimwe (2022)
	Total	41	100	

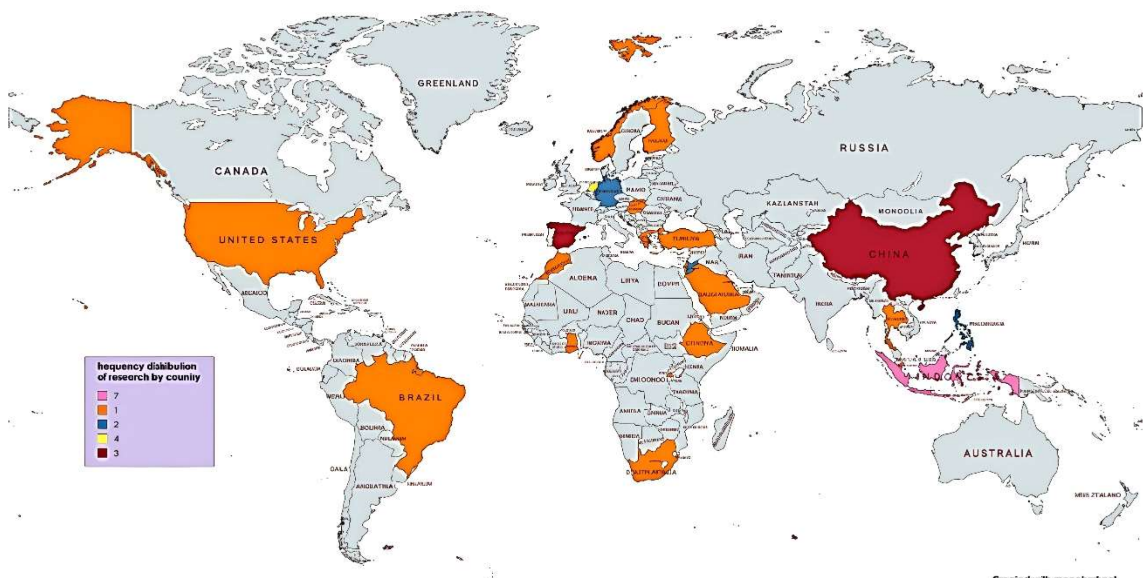

Figure 3. Distribution of research by country that implements inquiry-based learning in science learning

Table 5 and Figure 3 show the distribution of IBL research in science education by country. Indonesia had the highest number of publications, with 7 articles (17.06%), followed by the Netherlands (4 articles; 9.76%), China and Spain (3 articles each; 7.31%), and other countries, most represented by only one study.

The dominance of publications from Indonesia in this sample indicates the high volume of IBL research conducted there. Most countries have only one or two studies, making it challenging to generalize IBL trends in other developing countries. This finding underscores the need to expand IBL research across national contexts to better understand its practices and effectiveness.

Research Representation Based on Education Level

Research participation can determine the level of education in this study. Based on education level, the distribution of this study is shown in Table 6.

Table 6. Representations of research based on the educational level

No.	Participants	Educational Level	F	(%)	Total (%)
1.	Student	Pre School	1	2.44	35 (85.36)
		Elementary School	8	19.51	
		Secondary School	12	29.27	
		High School	7	17.07	
		Undergraduate Student	7	17.07	
2.	Teacher	middle school	2	4.88	3 (7.32)
		Secondary	1	2.44	
3.	Others	Teacher and Prospective teacher student	1	2.44	3 (7.32)
		Elementary School Student, Elementary School Teacher, Principals, Parent of Student, Supervisor	1	2.44	
		Pre-Service Teacher	1	2.44	
Total			41	100	41 (100)

Table 6 shows that the majority of IBL studies used students as participants, with the largest proportion coming from junior high school levels, indicating that this is the most common level of research. Participation from teachers, parents, principals, or supervisors remains relatively limited, accounting for only a small proportion of studies.

These findings confirm that IBL can be applied across educational levels, but implementation and research at the college level and with non-student participants remain limited. This suggests opportunities for further research at the higher education level and the involvement of other stakeholders. The IBL approach has been widely supported as an active, contextualized learning approach in science education (Bybee et al., 2006; National Research Council [NRC], 2000).

Research Representation Based on Science Content

Based on the science content, the research representation is shown in Table 7. The research approach data are presented in Table 4 and visualized in Figure 4.

Table 7. Representations of research based on science content

No.	Science content	F	(%)
1.	Science	14	34.15
2.	Physics	9	21.95
3.	Biology	8	19.51
4.	Chemistry	4	9.76
5.	A combination of science and technology	6	14.63
	Total	41	100

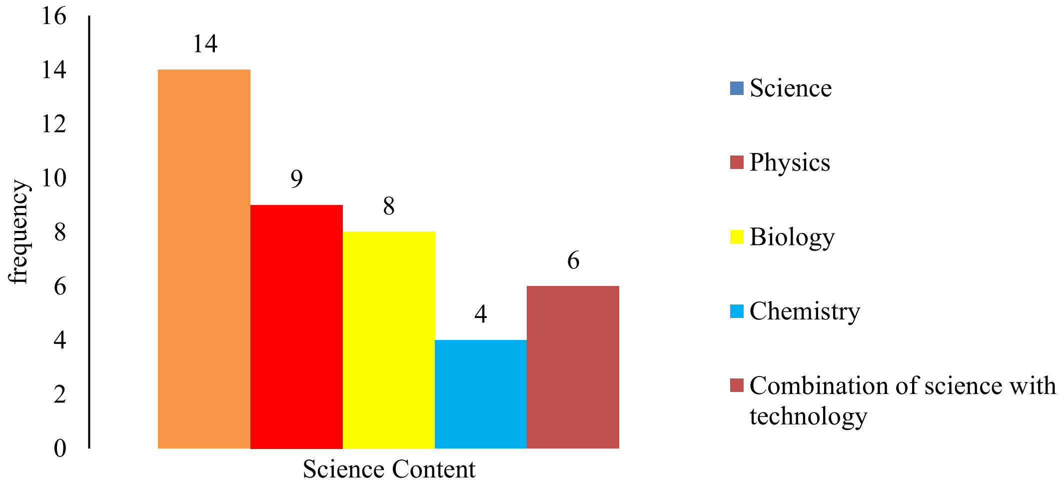

Figure 4. Proportional distribution of disciplines in inquiry-based learning

The distribution of inquiry-based learning research by science content is presented in Table 7 and visualized in Figure 4, showing that most studies were applied to general science or integrated content, followed by physics and biology. At the same time, chemistry was the least researched discipline. This pattern suggests that IBL is more frequently used in cross-disciplinary or integrated contexts, allowing students to connect concepts from different science fields.

Research integrating science and technology accounts for a moderate share, reflecting the trend of using technology to support inquiry-based learning. This approach can increase student engagement, facilitate data collection and experimentation, and support more contextually and authentically implemented IBL (Wen, 2023; Zhang, 2024).

Overall, this distribution confirms that IBL is predominantly applied in general or integrated science contexts, while research opportunities in less-researched disciplines, such as chemistry, remain open for further exploration.

RQ 2: How is the syntax of Inquiry-Based Learning used in the context of science learning?

Syntax learning demonstrates the steps researchers take in their research. The analyzed articles applied various Inquiry-Based Learning models in line with the research objectives. The relationship between the models and syntax is depicted in Figure 5.

Based on Figure 5, SankeyMatics shows that, among the 26 IBL models with a total of 190 learning syntaxes, most syntaxes overlap and center on the core stages of inquiry: engagement, exploration, explanation, elaboration, and evaluation, with the 5E model as the most dominant universal syntax framework. The dominance of the 5Es can be explained by this model's systematicity, alignment with the curriculum, ease of implementation for teachers, and proven ability to improve conceptual understanding, critical thinking skills, and student engagement (Bybee, 2014; Berie et al., 2022). The syntax displayed in the diagram shows different patterns according to educational level: in elementary school, the focus is on developing curiosity and basic skills such as observation, questioning, and simple reasoning; in junior high school, the syntax activates higher-order thinking skills, data analysis, scientific argumentation, and collaboration; in higher education, IBL emphasizes evidence-based research, independence, and academic reasoning (Bybee et al., 2006; NRC, 2000).

The diagram also shows the differences in the characteristics of guided and open inquiry, where guided inquiry emphasizes teacher

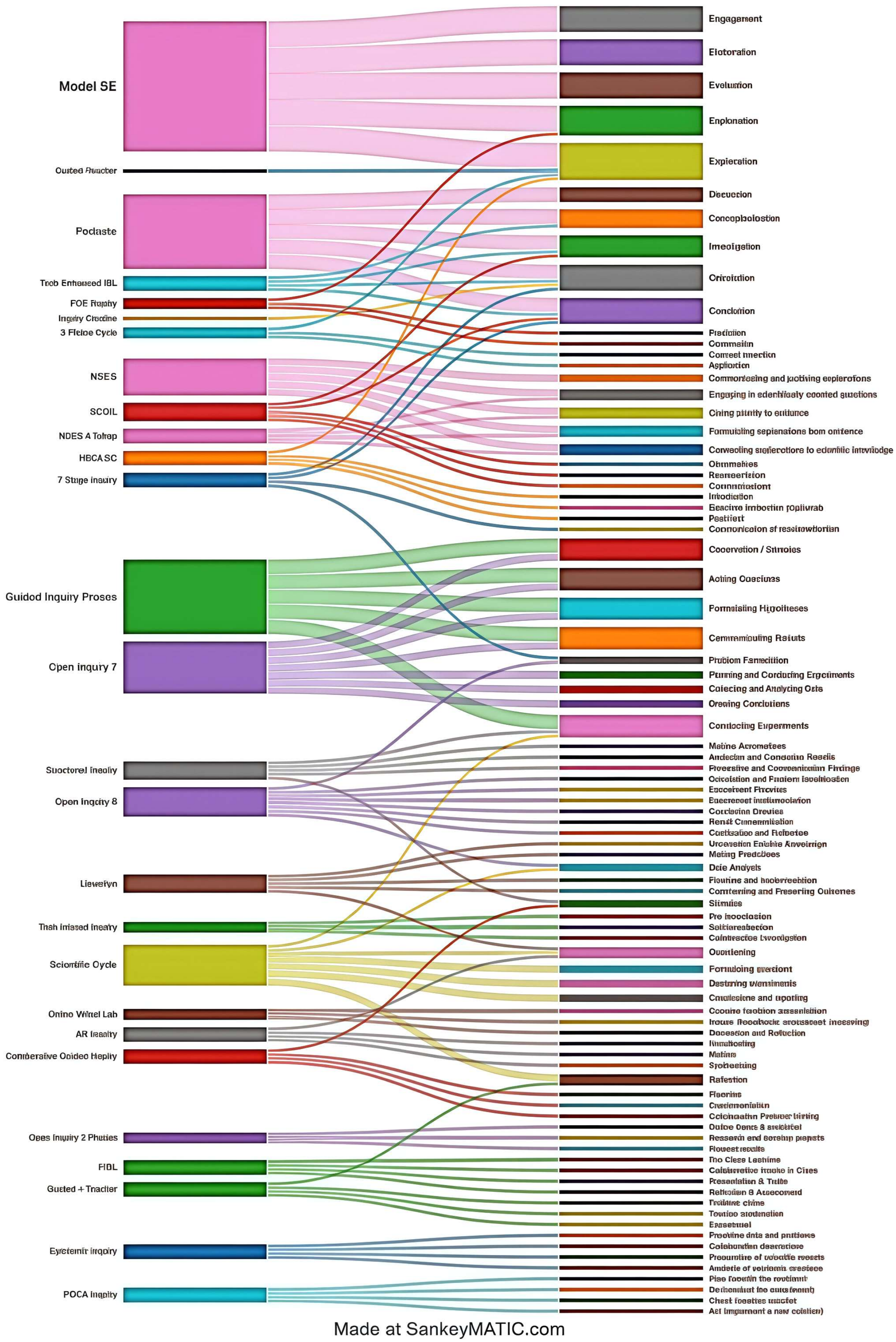

Figure 5. Mapping of learning syntaxes across inquiry-based learning models

guidance in observation, hypothesis-making, and data analysis. In contrast, open inquiry emphasizes student independence in designing experiments and reflection. Empirical examples support these findings: for example, the elaboration stage in the 5Es enhances students' ability to explain phenomena (Slim, 2022), and the investigation stage in SCOIL strengthens collaborative skills (Pursitasari, 2020). Modern technology-based IBL models, such as QIMS and SCOIL, support collaboration, self-directed learning, and epistemic practices without altering the core 5Es, while also opening up opportunities for syntax innovation for underrepresented contexts and disciplines.

Compared to other models such as PjBL and PBL, IBL emphasizes the process of developing scientific knowledge, metacognitive reflection, and evidence-based reasoning, thus contributing to students' scientific literacy and higher-order thinking skills. Overall, the differences between the models are more contextual and terminological. At the same time, the core pedagogical principles remain grounded in the inquiry process, while providing practical guidance for teachers in adapting syntax to suit the educational level, learning objectives, and expected learning outcomes.

RQ 3: Do patterns of IBL model use differ by educational level, region, or type of research?

Patterns of Inquiry-Based Learning (IBL) implementation across educational levels show clear differences in the type of inquiry, the level of teacher guidance, and the learning syntax, tailored to students' readiness and learning needs. These findings are summarized and shown in Table 8.

Table 8 presents a typology of Inquiry-Based Learning (IBL) syntax by educational level. Analysis of 41 selected studies revealed

Table 8. Typology of inquiry-based learning syntax based on educational level

Educational Level	Dominant IBL Type	Core Syntax Characteristics	Representative Studies (1–41)
Preschool & Elementary School	Guided Inquiry / Technology-Assisted Guided Inquiry	The inquiry phase is highly structured with strong teacher support. Activities emphasize observation, guided exploration, simple experiments, and conceptual clarification. The inquiry questions, procedures, and interpretations are largely teacher-directed. AR, POE, serious games, and simulations serve as cognitive and motivational supports to support early scientific engagement and reasoning, rather than epistemic autonomy.	Gerhátová et al. (2021). Rusdiyana et al. (2024); Slim et al. (2022); Alqawasmi et al. (2024); Premthaisong & Srisawasdi (2024); Zhang et al. (2024); Wen et al. (2023); He et al. (2021); van Schijndel et al. (2018); Zudaire et al. (2022)
Secondary School (Junior & Senior High School)	Guided to Semi-Guided Inquiry	Students actively formulate hypotheses or research questions, conduct investigations, analyze and interpret data, and communicate findings. Teachers provide structured support through inquiry frameworks such as the inquiry cycle, the 5E model, reverse inquiry, and guided online inquiry,	Orosz et al. (2023); Kousloglou et al. (2023); Rodriguez et al. (2020); Tan et al. (2020); Panjaitan et al. (2020); Hairida (2016); Pursitasari et al. (2020); Abaniel (2021); Borrull & Valls (2021); Duran & Dökme (2016); Ouahi et al. (2024);

		gradually decreasing support as students progress. Emphasis is placed on scientific reasoning, argumentation, critical thinking, attitudes toward science, and process skills, often supported by virtual laboratories, simulations, videos, serious games, or AR.	Khasawneh & Khasawneh (2024); Hendratmoko et al. (2023); Streich & Mayer (2020); Pradani et al. (2020); Lameras et al. (2021); Lotter & Ramnarain (2025); Cairns (2019); Aregehagn et al. (2022); Meulenbroeks et al. (2024); Manishimwe et al. (2022)
Higher Education / Teacher Education	Structured Inquiry with Professional Orientation	The syntax of inquiry-based learning follows formal, design-based, or research-oriented instructional models such as DBR-based inquiry, flipped inquiry, technology-enhanced collaborative inquiry, and project-based inquiry. Inquiry activities emphasize disciplinary understanding, epistemic and collaborative practices, instructional design, innovation, creativity, and reflective professional practice, rather than entirely open-ended, student-generated inquiry. Inquiry serves as both a pedagogical exercise and a process for building professional knowledge.	Ong et al. (2020); Wong et al. (2025); Rodríguez et al. (2019); Aidoo et al. (2022); Sapriati et al. (2024); Natale et al. (2021); Langbeheim et al. (2020); Olschewski et al. (2023); Lämsä et al. (2018); Wang & Guo (2021)

distinct patterns in IBL implementation depending on students' age, cognitive readiness, and instructional goals.

Preschool and Elementary School

At this level, Guided Inquiry or Technology-Assisted Guided Inquiry predominates. Inquiry activities are highly structured, with teachers directing the formulation of questions, investigation procedures, and interpretation of findings. The learning process emphasizes foundational scientific skills such as observation, simple experimentation, and conceptual understanding. Technologies such as augmented reality (AR), serious games, prediction–observation–explanation (POE), and simulations are primarily used to scaffold understanding and engagement rather than to grant full epistemic autonomy (Gerhátová et al., 2021; Slim et al., 2022; van Schijndel et al., 2018; Zudaire et al., 2022).

Secondary School (Junior and Senior High School)

At the secondary level, Guided to Semi-Guided Inquiry is dominant. Students are increasingly involved in hypothesis generation, data collection, analysis, and communication of results. Teachers provide structured frameworks (e.g., 5E, inquiry cycles, and flipped or guided online inquiry) and gradually reduce scaffolding as students' skills develop. Inquiry at this stage aims to foster higher-order thinking, scientific reasoning, argumentation, and critical thinking, often supported by virtual laboratories, simulations, videos, and AR (Abaniel, 2021;

Cairns, 2019; Meulenbroeks et al., 2024; Manishimwe et al., 2022).

Higher Education and Teacher Education

In higher education and teacher education, Structured Inquiry with Professional Orientation is prevalent. Inquiry activities are designed using formal instructional or research-based models, such as design-based research (DBR), project-based inquiry, flipped inquiry, and technology-enhanced collaborative inquiry. The focus extends beyond content understanding to include epistemic practices, collaboration, professional reflection, creativity, and instructional design. Inquiry remains structured to align with professional and academic competencies, emphasizing guided but authentic engagement with scientific processes (Wong et al., 2025; Olschewski et al., 2023; Lämsä et al., 2018; Wang & Guo, 2021).

Overall Pattern Across Educational Levels

Overall, the results show that guided and structured forms of inquiry dominate across all educational levels. Student autonomy increases gradually from preschool through higher education, while instructional guidance remains consistent. The absence of fully open inquiry across the reviewed studies indicates that current IBL practices prioritize structured support to ensure conceptual understanding, manage cognitive load, and achieve intended learning outcomes.

These findings highlight that effective implementation of IBL depends not only on the level of openness but also on how well inquiry activities are aligned with students' developmental needs and instructional contexts.

Representation of Distribution of Inquiry-Based Learning (IBL) Research by Region and Type

Based on region and type, the distribution of Inquiry-Based Learning (IBL) research is shown in Table 9.

Based on the article analysis, Europe had the largest number of IBL studies, with 15 articles (36.7%), followed by Southeast Asia with 11

Table 9. Distribution of inquiry-based learning research by region and IBL type

Region	Country	Number of Articles (F)	Persentage (%)	Type IBL (F)
Southeast Asia	Indonesia, Philippines, Thailand, Singapore	11	26.82	Guided Inquiry (6), Guided Online IBL (1), Game-Based Inquiry (1), Guided to Semi-Guided Inquiry (1), Open Inquiry (1), QIMS IBL (1)
East Asia	China, Hong Kong	4	9.75	Structured Inquiry (1), Experimental IBL (1), Guided Inquiry (1), Structured Inquiry (1)
Europe	Netherlands, Spain, Germany, Hungary, Greece, Slovakia, Turkey, Norway, Finland	15	36.71	Guided to Semi-Guided Inquiry (4), Structured Inquiry (2), Guided Inquiry (3), Technology-Infused Active Inquiry (1), 5E Guided Inquiry (2), Pedagogy-Based IBL (2), Scientific Discovery Task IBL (1)
Africa	Morocco, Ghana, South			5E Guided Inquiry (2), Flipped Inquiry-Based Learning (1), Mixed

	Africa, Ethiopia, Rwanda	5	12.20	IBL (1), Video-Based Thematic IBL (1)
Middle East / Arab	Jordan, Israel, Saudi Arabia	4	9.75	Guided Inquiry (2), Technology-Supported Inquiry (1), Hybrid & Online IBL (1)
America	USA, Brazil	2	4.88	Game-Based IBL (1), Online & Hybrid IBL (1)
Total		41	100	

articles (26.8%). This indicates that more research on IBL implementation has been conducted in Europe and Southeast Asia than in other regions. Africa, the Middle East, and the Americas had relatively fewer studies, with 5, 4, and 2 articles, respectively, so data from these regions provides a more limited picture.

After examining frequency, IBL implementation patterns also differed by region. In Southeast Asia, the majority of studies employed Guided Inquiry, including technology-based variants such as Guided Online IBL and QIMS IBL, demonstrating a relatively structured learning approach. In East Asia, the dominant types were Structured Inquiry and Experimental IBL, emphasizing systematic and experiment-based learning designs. Meanwhile, Europe exhibited a wider variety of IBL types, including Pedaste-Based IBL, 5E, Technology-Infused, and Guided and Structured Inquiry, reflecting methodological flexibility and innovation. The Africa and Middle East regions tend to integrate technology-based IBL or local context adaptations, such as 5E Guided Inquiry, Mixed IBL, Technology-Supported IBL, and Hybrid/Online IBL. At the same time, the Americas feature interactive approaches such as Game-Based IBL and Online/Hybrid IBL.

Representation of the Distribution of Research Methods by Level of Education

The distribution of research methods used in IBL studies according to educational level is shown in Figure 6.

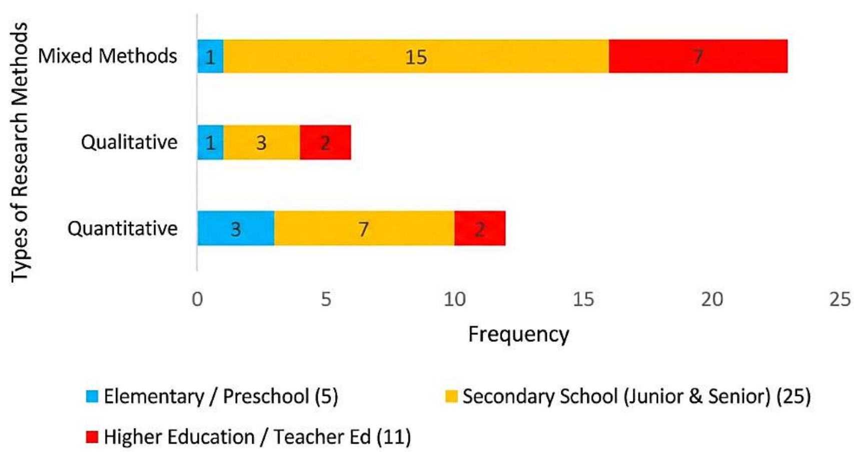

Figure 6. Distribution of research methods by education level

This figure shows how quantitative, qualitative, and mixed-methods approaches are used differently across preschool through higher education. In Elementary/Preschool (5 articles), the majority used Guided/Technology-Assisted Guided Inquiry, with a predominance of simple quantitative methods (pre-post tests, questionnaires), and some used mixed-methods observation. In Secondary School (25 articles), the majority used Guided to Semi-Guided Inquiry, with a higher proportion of mixed methods, combining quantitative (pre-post tests, surveys) and qualitative (observation, interviews, analysis of student products). Meanwhile, in Higher Education/Teacher Education (11 articles), research was more varied, using Structured, Flipped, or Mixed Inquiry, with a relatively high proportion of mixed methods, emphasizing professional skill development, reflection, and complex data analysis.

CONCLUSION

This study shows that Inquiry-Based Learning (IBL) is a flexible and effective approach for developing students' critical and creative thinking skills. Based on a synthesis of 41 studies, a typology of IBL syntax was proposed, grouping learning steps according to frequency of use, learning objectives, and alignment with students' developmental levels. The typology categorizes IBL into three levels: elementary school, focusing on initial engagement and simple exploration; junior high school, emphasizing more complex investigative skills; and high school/college, encompassing elaboration, evaluation, reflection, collaboration, and technology-supported investigations.

This typology not only describes current IBL practices but also provides a practical framework for teachers and curriculum developers to adapt inquiry steps according to classroom context, learning goals, and student characteristics. By linking inquiry syntax to developmental levels, the study contributes theoretically by systematizing IBL practices and practically by offering guidance for classroom implementation.

Future research is recommended to validate this typology in diverse classroom settings, examine underutilized inquiry steps, and explore strategies to enhance teacher preparedness and availability of instructional resources. Additionally, trends related to regional differences and research types (qualitative vs. quantitative) could be further investigated to provide a more comprehensive understanding of IBL implementation worldwide.

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