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Systematic Literature Review

What we already know about Inquiry-Based Learning: A Comprehensive Umbrella Literature Review

Co-funded by the European Union

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Call 2024 Round 1 KA2 KA220-SCH - Cooperation partnerships in school education (KA220-SCH) Form ID KA220-SCH-74515E3B1

Deliverable metadata

Work Package	2
Activity	2 - Identification of best practice and capturing change over time
Lead	Kirchliche Pädagogische Hochschule Wien (kPH)
Co-Lead	National Technical University of Athens (NTUA)
Contributors	BG/BRG Schwechat, BG/BRG Gmünd, Escola A. Aguilera, Institut de Sales, GTVS Dr. Bruno Kreisky
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Reviewers	Manfred Lohr
Deadline	30/10/2025
Submission date	XX/XX/XXX

Editing timeline

Version	Date	Partners involved
Table of Content	05 / 10 / 2025	kPH
First draft version (v0)	30 / 10 / 2025	kPH
Revision of v0	15 / 11 / 2025	NTUA
First revised version (v1)	05 / 12 / 2025	kPH, NTUA
Revision of v1	19 / 12 / 2025	BG/BRG Schwechat
Second revised version (v2)	28 / 12 / 2025	kPH, NTUA
Revision of v2	20 / 01 / 2026	BG/BRG Schwechat, BG/BRG Gmünd, Escola A. Aguilera, Institut de Sales, GTVS Dr. Bruno Kreisky
Final document (v3)	10 / 03 / 2026	kPH, NTUA, all partners

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The inTrust Project

The inTrust project promotes ways of implementing action-oriented, interdisciplinary, and inquiry-based teaching behaviour. The aim is to change students' learning behaviour from one of consumption to one of action through competence-oriented aspects such as critical thinking, communication, collaboration and creativity. Learning, Teaching and Training workshops and inquiry-based learning scenarios provide an insight into different approaches and implementations in primary school and secondary school.

During the implementation activities, partner schools develop scenarios that deal with different aspects of inquiry-based learning (IBL) and are evaluated and implemented internally at each school and then externally by the project partners. 5 learning, teaching and training workshops will be held at the partner schools and universities, with teachers from all partner schools. The workshops deal with individual aspects of IBL, and each hosting partner school deals with the topic in which the school has particular expertise.

Results of the project will reflect three levels: (1) 15 open-source educational learning scenarios for IBL in STEAM subjects, (2) Professional development for teachers of STEAM subjects at primary and secondary school, which is achieved through the workshops and finally, (3) a report detailing the current state of IBL integration in school curricula of the consortium countries (Austria, Spain and Greece).

Abstract

Inquiry-Based Learning (IBL) has been widely recognised for its positive effects on learners' conceptual understanding, critical thinking, and active knowledge construction. Despite a growing body of systematic reviews and meta-analyses, existing research often lacks a coherent synthesis of design principles and practical guidance for classroom implementation. This deliverable presents a systematic literature review (SLR) of review-level studies examining IBL and closely related approaches, including problem-based and design-based learning, in primary and secondary STEM education. Following PRISMA guidelines, 19 peer-reviewed review articles published between 2015 and 2025 were analysed to identify key moderating factors, implementation challenges, and contextual influences shaping the effectiveness of IBL. The review synthesises evidence on success factors, benefits and barriers across different STEAM subject areas and age groups and derives implications for the design, implementation, and support of IBL environments in diverse school settings and education levels. The findings aim to support educators, school heads, and researchers in developing and implementing pedagogically sound and context-sensitive IBL practices for diverse educational settings and subjects by promoting at the same time interdicsciplinarity.

Scope of the Systematic Review

The overarching objective of the SLR is to establish a robust evidence base on the integration of IBL in primary and secondary education, with particular emphasis on science, technology, and design subjects. The work carried out is led by Kirchliche Pädagogische Hochschule Vienna/Lower Austria (kPH) in close collaboration with the National Technical University of Athens (NTUA) and the participating school partners (BG/BRG Schwechat, BG/BRG Gmünd, Escola A. Aguilera, Institut de Sales). The scope of the SLR encompasses the identification and refinement of relevant search terms, the selection of suitable academic databases, and the systematic screening and selection of peer-reviewed studies and relevant grey literature to understand the benefits/barriers associated with IBL.

Building on the outcomes of the SLR, this activity delivers a comprehensive analytical report outlining the current state of IBL in primary and secondary education. The scope encompasses the identification and critical analysis of the benefits and challenges associated with IBL implementation, as well as the generation of subject- and age-group-specific insights that capture variations in effectiveness across diverse educational contexts. Finally, the review underpins the development of evidence-based best practice guidelines, drawing on documented successful IBL initiatives and best practices, to support the design of targeted strategies for the effective adoption of IBL in diverse school settings and science curricula.

Introduction

The field of research into IBL is already full of interesting findings that highlight the positive effects on students' development of critical thinking and conceptual understanding. In this article, we refer to the structure of the inquiry cycle as Pedaste et al. (2015) proposed in their literature review of 32 articles on IBL. The open environment leaves plenty of room for students to investigate independently and build their own knowledge. This is particularly important from a constructivist point of view, in which students develop an understanding of the world and its phenomena through their own experiences. Additionally, apart from IBL, similar approaches as problem-based learning (PBL) and design-based learning (DBL) will be included in this review of literature, given that the focus of this review is on articles that provide an overview of a series of studies. However, despite numerous literature reviews and meta-analyses, these studies rarely synthesize concrete design principles and best practices for classroom implementation. Therefore, we attempted to identify influential factors, moderators, challenges and barriers to derive implications for implementing IBL in school settings. This article should help teachers as well as researchers to develop and design IBL environments.

The following research questions guide the analysis in this review:

1) Which moderating and influencing factors of inquiry-based learning are examined in existing meta-analyses?

2) Which implications for the design and implementation of inquiry-based learning environments in school settings can be derived from the findings of these meta-analyses and literature reviews?

This article will first explain the selection process, then illustrate the results of the included reviews and meta-analyses and finally present implications derived from these results.

Methodology

The literature for this review was selected in accordance with the PRISMA guidelines. The flow diagram of the screening and selection process according to PRISMA can be found in Figure 1. The identification of literature began in August 2025 using the two databases, ERIC and Google Scholar. As search terms, the following were used: i) 'systematic literature review' or 'systematic review' or 'meta-analysis' and ii) 'challenges' or 'difficulties' or 'problems' or 'issues' or 'barriers' or 'limitations' or 'obstacles' or 'constraints' and iii) 'inquiry-based learning' or 'IBL' or 'PBL' or 'enquiry-based learning' or 'problem-based learning' and iv) 'study' or 'education' or 'learning' or 'teaching' or 'instruction' or 'pedagogy' and v) 'effectiveness' or 'impact' or 'evaluation' and vi) 'student*' or 'learner' or 'pupil*' or 'child*' or 'higher education' or 'primary education' or 'secondary education' and vii) and 'pubyear:2015-2025'. The terms from i) were searched in the title only, whereas the terms ii) to vi) were searched in the abstracts. Subsequent to the elimination of duplicates, the titles and abstracts of the 55 articles were reviewed. The guiding criteria for the screening process were:

a) Include only review articles (meta-analysis or systematic or critical literature review) from 2015 to 2025;
b) Include only peer-reviewed articles (no conference proceedings);
c) Include only reviews on studies implementing inquiry-based learning (or related instructional approaches, i.e., problem-based learning) in STEM education;
d) Include only articles reviewing studies with primary and/or secondary student populations or with a focus on teachers implementing IBL.

After the screening process, the remaining 19 articles underwent a full-text analysis. To decide whether articles are eligible for our literature review, we used the PICOS approach, see Table 1. Articles must fulfil the following criteria to progress beyond the eligibility assessment:

a) Full text available in English,
b) The article contains a review of multiple articles,
c) The review article clearly reports inclusion and exclusion criteria for the selected articles, ensuring methodological rigour and reproducibility,
d) The review article refers to IBL (or related instructional approaches i.e., problem-based learning, design-based learning),
e) The review includes articles that implement IBL in school-based settings in primary or secondary level or with a focus on teachers.

Table 1: PICOS approach for the screening process on literature reviews and meta-analyses on IBL.

P	**population**	**Students in primary and secondary schools, teachers**
I	intervention	Implementation of inquiry-based learning, problem-based learning, design-based learning (or similar approaches)
C	comparison	None
O	outcome	Report of implications or challenges, design principles, or moderating effects
S	study design	Systematic literature reviews and meta-analysis

The selected articles were processed to identify challenges and/or design principles for implementing IBL. Included are articles presenting (a) measured influences, or (b) moderating effects on the effectiveness of IBL, or (c) challenges teachers are confronted with, or (d) other barriers in the implementation of IBL.

For the analysis, we conducted a thematic analysis of the findings sections in the eleven included studies. Additionally, the AI notebooklm[1] and perplexity[2] assisted us in gaining an initial overview of the results and similarities between the articles. This saved us time in identifying where and what to look at. The results found, of course, were carefully verified and compared with our findings. From the analysis, we drew conclusions for the implementation of IBL in primary and secondary classrooms.

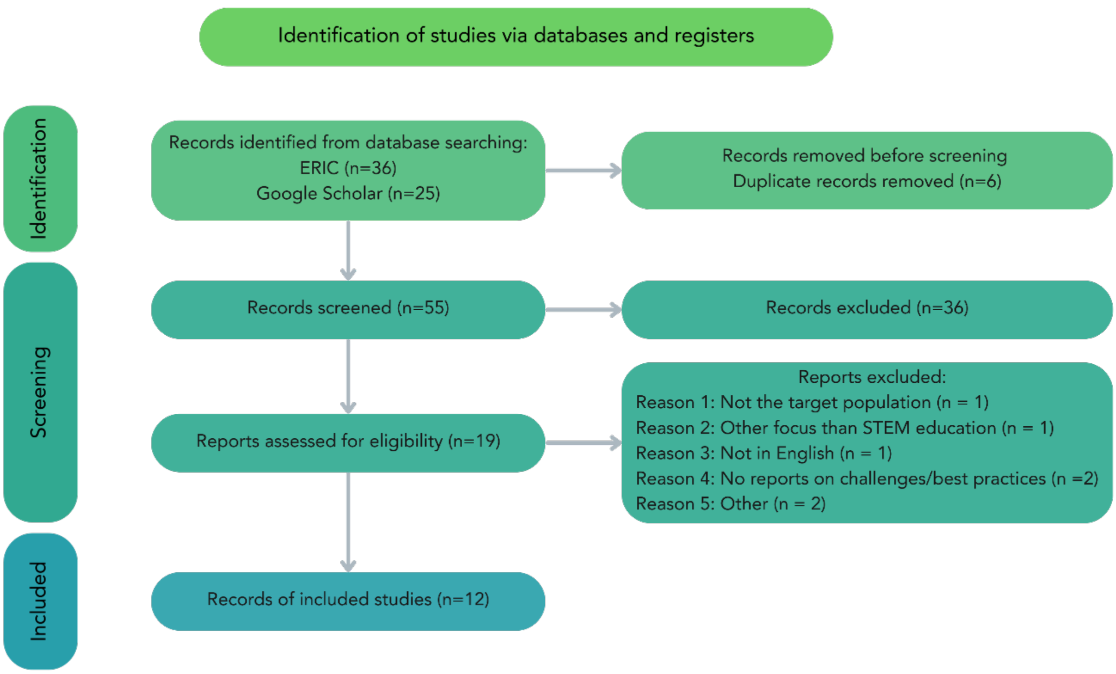

Figure 1: PRISMA flow diagram for screening and selection of studies.

1 You can find the used AI at the following link: https://notebooklm.google/
2 You can find the used AI at the following link: https://www.perplexity.ai/

Results

Descriptives of the included studies

This rapid umbrella literature review includes twelve reviews of IBL, comprising four meta-analyses and seven literature reviews on inquiry-based instruction. While nine of the included studies focused on the strategy IBL, one study focused on Design-Based Learning (DBL), one on Problem-Based-Learning (PBL), and one on Student-Question-Based Inquiry (SQBI). All reviews included studies on science education and/or other disciplines as for example mathematics, see Appendix I: Studies included in the systematic literature review (SLR) for an overview. The reviews found were published in internationally recognised journals. Seven meta-analyses and reviews explicitly stated that they adhered to the PRISMA guidelines. The remaining four clearly documented their inclusion and exclusion criteria. This umbrella review covered a variety of topics and their impacts in IBL settings, ranging from emotions to (mobile) technology, feedback and guidance. The included studies and further information, i.e., the number of analysed studies, are listed in Appendix I: Studies included in the systematic literature review (SLR). In the following sections, we present the findings of our comprehensive review of existing literature on IBL. First, we present influencing factors and reported effects of IBL on different measures as critical thinking skills or conceptual understanding of students. Secondly, we discuss main findings of our thematic analysis. Lastly, we formulate implications for the implementation of IBL in primary and secondary classrooms.

Influencing Factors in Inquiry-Based Learning

Inquiry-based learning appears to have significant positive effects on the students' critical thinking skills (Arifin et al., 2025) and conceptual understanding in science curriculum (Mediana et al., 2025). In order to improve inquiry-based learning in individual classrooms, it is vital to understand which elements contribute to the creation of fruitful inquiry-based learning environments. This chapter will analyse these elements one by one, starting with the level of inquiry and moving on to the role of technology and emotions in IBL.

The Efficacy of different Levels of Inquiry

The impact of the different levels of inquiry in IBL has been examined in numerous studies. Mainly, there are four levels of inquiry in IBL: a) Confirmation Inquiry, b) Structured Inquiry, c) Guided Inquiry and d) Open Inquiry. The level of inquiry is directly linked to the autonomy of the students. Open Inquiry gives students the most freedom, from formulating their own research question to designing an appropriate investigation and analysing and communicating the results. In contrast, Confirmation Inquiry offers the least freedom, as students must imitate a given study design. Mediana et al. (2025) report that students in Open Inquiry settings demonstrate the most significant improvement in conceptual understanding, with an effect size of Hedges g=1.530. Moreover, Guided Inquiry, where students design the procedure matching a given research question, also results in a large positive effect on conceptual understanding (g=0,786), followed by Structured Inquiry (g=0.772) (Mediana et al. 2025). At this point, it must be mentioned that in their sample, only one study reported on Open Inquiry, two on Structured and eleven on Guided Inquiry. Similarly, Arifin et al. (2025) report that Guided Inquiry (SMD=1.46) and Open Inquiry (SMD=1.41) have the largest effects on the students' development of critical thinking skills, while Structured (SMD=0.93) and Confirmation Inquiry (SMD=0.41) have the least effects. Students' autonomy therefore seems to be the most important variable when it comes to IBL. However, the optimal level of inquiry depends on the specific learning goals, as well as the students' ages.

The Effectiveness of IBL in different Age Groups

As previously indicated, greater autonomy in IBL leads to better development of critical thinking skills and conceptual understanding (Arifin et al., 2025; Mediana et al., 2025). However, the effects of IBL on different age groups are worth exploring. Mediana et al. (2025) found the largest effects in senior high school (Hedges' g=1.176), followed by junior high school (g=0.908) and tertiary education (g=0.850). The lowest effects were found in primary education (g=0.289). Similarly, Arifin et al. (2025) suggest that the effectiveness of IBL in developing critical thinking skills varies depending on the grade level. The study found that undergraduates benefited the most (SMD 2.66), followed by middle school students (SMD=1.47). The effects were smallest, but still significant, for preschoolers (SMD=0.86) and high school students (SMD=0.81). Moderate effects were only found on elementary school children (SMD=0.57). The interactive, experience-based approach appears to benefit preschool children. Since undergraduates already possess the necessary skills, such as critical thinking, to solve complex problems, it is logical that they perform better in demanding IBL settings. Elementary school children, on the other hand, cannot be expected to tackle tasks of a similar depth, but they might benefit more in terms of engagement and motivation. Unfortunately, neither study distinguishes between the effectiveness of different levels of inquiry in different age groups. Consequently, it is unclear whether Structured Inquiry is more beneficial than Open Inquiry for primary school children, for example.

Effective Pedagogical Strategies and Models

The literature identifies several key pedagogical strategies and instructional models that amplify the benefits of IBL. First, contextualization, which means linking scientific content to meaningful, real-world problems is a critical success factor. The use of Socio-Scientific Issues (SSI) has been shown to improve secondary and university students' argumentation and problem-solving skills (Hernández-Ramos et al., 2021). Furthermore, ethnoscience-based IBL, which integrates local cultural contexts, has demonstrated a massive effect on critical thinking (SMD = 7.27) (Arifin et al., 2025). Secondly, constructivist frameworks are a prevalent and effective foundation for IBL. The literature highlights the 5E (Engage, Explore, Explain, Elaborate, Evaluate) and OE3R (Orientation-Exploration-Explanation-Elaboration- Reflection) models as successful frameworks for structuring inquiry-based activities and promoting knowledge construction (Mediana et al., 2025). Moreover, collaborative learning is a central and highly effective component of IBL. Collaborative inquiry fosters shared understanding, facilitates reflection on findings, and enhances student enjoyment and engagement in the learning process (Liu et al., 2020; Zhang et al., 2020). At last, integrating deliberate reflection into the inquiry process is a high-impact practice. One meta-analysis found that strategies combining "IBL and reflection" yielded a significant effect size (SMD = 2.81) on the development of critical thinking skills (Arifin et al., 2025).

The Role of Students' Questions in IBL

In the context of inquiry-based learning, the act of posing questions has been demonstrated to play a multitude of significant roles in the learning process, as evidenced by Herranen and Aksela's (2019) insightful literature review. For one, asking questions is an important practice that scientists do and is supposed to be practised by students too. In the literature, numerous positive effects of students' questions are named, i.e. supporting the learning of inquiry skills, increasing thinking skills, improving discussion skills (see also table 3 in Herranen & Aksela, 2019, p. 12). Furthermore, it is motivating for students to first ask their own questions and later find their own answers to the previous questions, keeping them more engaged in the inquiry learning. Thirdly, they point out two approaches of students' questions in inquiry and guiding roles that teachers play: a) questions are a strategy students learn in science education and teachers facilitate the formulation of "scientifically meaningful questions", or b) students' questions are valued as they are, with teachers offering support but allowing students to participate actively in the learning process (Herranen & Aksela, 2019, p. 11).

As a further outcome of the study, the authors propose recommendations concerning the facilitation of inquiry by teachers. They cite a study from Lombard and Schneider (2013, in Herranen & Aksela, 2019, p.13) finding that successful IBL needs: "i) an inquiry process that is long enough, ii) shared knowledge improvement goal amongst the learners and the teacher, iii) student-produced text with question-answer pairs on a single concept, iv) use of authentic resources, iv) peer-discussions, v) teacher feedback on how to elaborate answers and differentiate concepts, vi) fading of teacher guidance to increase student responsibility." Also, the right planning of the group size is a crucial factor. It should be considered whether an activity should be carried out with the whole class or in small groups. It has been hypothesised that teachers may find it more straightforward to guide students in the art of questioning in whole-class settings when they have less experience. Finally, teachers are advised to employ differentiation as students exhibit disparate questioning skills. The implementation of a curriculum designed specifically to guide the creation of questions shows considerable promise for the effective and successful execution of IBL. Other ways of supporting students' questioning included the use of *writing tools*. For example, in one study, students wrote questions about today's lesson in their journals. The teacher then read these questions and selected some of them for follow-up lessons. These questions then formed the basis for further investigations, either in or outside the classroom. Finally, Herranen and Aksela (2019) proposed a model of students-question-based inquiry (SQBI) that could be used to develop and design IBL environments (see Figure B in the appendix).

Guidance in IBL Settings

In the meta-analysis of Lazonder and Harmsen (2016, p. 691), they focus on different types of support (see Table 2) in IBL and measure their effects on i) learning activities (i.e., formulation of hypothesis, analysing data), ii) performance success (i.e., products, assessments), and iii) learning outcomes ("what participant had learned", measured, i.e. through post-tests). Concerning the learning activities, they found that guided inquiry overall had a moderate to large effect in contrast to unguided inquiry. While adolescents (age 12 to 15) profited more from less directive types of guidance, such as process constraints, children (age 5 to 12) benefited more from more specific types of guidance, such as scaffolds. In terms of performance success, guided inquiry produced significantly better results than unguided inquiry. Although the age of the participants had no moderating effect, significant differences in the type of guidance provided were found. Explanations were found to be more effective than all the other, less specific types of guidance combined, followed by heuristics, which were significantly more effective than the other, less specific types. Status overviews and process constraints had the least effect. Interestingly, the type of guidance chosen does not moderate the effect on learning outcomes. Meaning that, any type of guidance is equally effective in terms of learning outcomes. However, studies assessing inquiry skills had effect sizes that were more than twice as high as those found in studies assessing the domain knowledge (Lazonder & Harmsen, 2016, p. 702). Regarding the two moderators, duration and domain, they found no significant effects. As a result, the authors propose that teachers should create learning environments with enough freedom for students to explore phenomena on their own. However, teachers should provide adequate guidance to assist their students in the demanding settings of IBL (p. 706). The type of guidance chosen depends less on the age of the learners, but rather on their topical knowledge, familiarity with inquiry skills, desired learning objectives, and the teacher-student ratio.

In their study, Sun et al. (2020) examined the types of guidance provided during the different phases of the inquiry process in simulation-based learning environments. They found that there is no evidence that guidance was more efficient when provided in certain phases of the inquiry process. They identified three major factors that may shape the effectiveness of guidance, namely: a) Learner factor: explanations and other forms of direct information are more efficient if they match the students' prior knowledge and grade level, due to children's differing developmental statuses. Similarly, providing scaffolds may only be effective for students with the necessary pre-existing inquiry strategies; b) Pedagogical factor: The type and the design of guidance chosen should match the desired learning goals in order to improve learning outcomes. Regarding the cognitive load associated with direct instruction, the literature provides a mixed picture. While some argue that direct instruction improves performance by imposing a high cognitive load, others claim that effective direct instruction reduces the cognitive load to improve performance; c) Technological factor: Incorporating a technological element can enhance learning outcomes. Technology enhances IBL when its features are purposefully integrated with instructional design and learner characteristics, such as coordinated prompts, cognitively appropriate representations, and metacognitive scaffolds.

Table 2: Different Types of Guidance and descriptions, based on Lazonder and Harmsen (2019) and Sun et al. (2020), supplemented with information on target groups.

Type of support	Description	Target group
Process constraints	Restrict the scope or complexity of the task (i.e., fewer variables to discuss)	Learners already being proficient in IBL settings, but have little experience in more complex tasks
Metacognitive Supports	Visualisation of the learning process and status for planning, monitoring and reflecting their own learning	Learners needing support in structuring, planning and monitoring
Prompts	Reminders at critical times, to perform a specific activity (without providing solutions)	Learners who can solve tasks, but need reminders (i.e., students who get easily distracted)
Heuristics	Like prompts but adding hints on to how to solve a certain task	Learners who are unsure of when and how to perform next steps
Scaffolds	Guidelines that structure critical steps to complete a task	Learners who lack the competencies required to perform a specific activity independently (e.g., data analysis)
Explanations	Detailed instructions on how to perform a specific task	Learners who do not yet have the skills to perform an activity

The Role of Technology Integration

Technology serves as a powerful enabler for modern IBL, supporting data collection, analysis, and collaboration in authentic contexts (Liu et al., 2020; Hinostroza et al., 2024; Chen & Chen, 2025). Mobile technologies, in particular, facilitate hands-on scientific inquiry by allowing students to collect, analyse, visualise, and share data seamlessly, both in the classroom and in field settings (Liu et al., 2020). Students mention that using mobile devices for data collection saves them time for completing the experiment. However, the use of mobile devices should be accompanied by reflective and problem-solving discussions (Liu et al., 2020, p. 26). In their study, Liu et al. (2020) highlight various positive effects of the implementation of mobile-IBL, as enhanced students' concentration, enhanced motivation toward science learning, better learning performances, facilitation of group activities, and support in memorizing gained knowledge. Specific technological integrations such as virtual reality (VR), simulations, and gamification are effective for contextualizing abstract scientific concepts, increasing student engagement, and fostering active participation (Suryati et al., 2024). Hinostroza et al. (2024) examined the different phases of IBL and identified seven roles of technology: i) guiding the IBL process, ii) representation of phenomena to be investigated, iii) source of access to contents, iv) information collection tool, v) tool for organising ideas and information, vi) tool for sharing ideas and information, vii) for receiving feedback (p. 6). The seven roles of technology and examples provided by Hinostroza et al. (2024) are summed up in Table 3. Further, emerging Learning Analytics (LA) tools, such as real-time dashboards, show significant potential to support the inquiry process by providing students with data-driven feedback and assisting teachers in orchestrating complex classroom activities (Chen & Chen, 2025). While the evidence clearly outlines these best practices, their successful implementation is often impeded by a range of challenges. Difficult-to-use Applications are time-consuming for students, which in turn leaves less time for other inquiry-based practices. Furthermore, mobile technology must be carefully implemented in new environments, as it can increase cognitive load and overburden students (Liu et al., 2020).

Table 3: Overview of the roles of technology alongside used tools in IBL studies, according to the results of the literature review by Hinostroza et al. (2024).

Roles of Technology	**Dimensions**	**Exemplary tools/systems/software**
Guiding the IBL process	a) "guiding the stages of the research cycle" and b) "guiding the activities carried out in each stage"	a) Learning Management Systems (LMS) in form of web platforms or mobile apps Free access LMS: Moodle, Edmodo, WISE b) "hints and written instructions in different digital formats", open-ended or closed questions;
Representation of phenomena to be investigated	Observe phenomena through devices	Simulations with the possibility to change variable (see i.e., PhET), animations and videos, 3D visualisations through VR headsets or cardboard VR goggles, using mobile devices to investigate augmented reality objects;
Source of access to contents	Providing context, explanations or theories about the phenomenon to be investigated	Plain text, access to multimedia resources (images, videos), audio recordings, complementary information, use of the internet to research information;
Information collection tool	Documenting investigation, compiling data, measuring data	Templates for compiling data provided via LMS, Screenshots i.e., during VS processes, photographs of experiments, stopwatch camera of mobile phone Smart Tool Apps to measure various variables (i.e., Phyphox), videos, written data, audio recordings;
Organising ideas and information	Answering research questions, analysing variables, collaboratively collect notes	Forms with separate boxes for dependent, independent and control variables, digital repertory grid technology (matrix to represent relations between elements), collaborative digital note-taking system, concept-maps, free-access application for identification of observations: Skitch
Sharing ideas and information	Share data, images, text, audios with colleagues and teachers (a)synchronously	Videoblogs, chat, forum systems, free-access: Evernote and Edmodo
Receiving feedback	From classmates or teachers	Open feedback from peers and teachers, feedback from electronic systems after answering mc-questions

The Role of Feedback in IBL

Feedback loops are considered critical in IBL as they provide the opportunity for self-reflection and self-correction, peer-assessment, detailed reports of the learning processes, elaborate answers and differentiated concepts, thereby enhancing students' learning outcomes (Herranen & Aksela, 2019; Chen & Chen, 2025; Zheng et al., 2025). Zheng et al. (2025) highlight the positive and substantial impact of intelligent feedback on students' learning success and their motivation. Intelligent feedback "focuses on using advanced technologies such as artificial intelligence technology to provide information regarding one's understanding or performance" (Zheng et al., 2025, p. 738). The use of modern technology provides customised feedback and suggestions for individual learners. As an outcome of their meta-analysis, they provide the 6W framework, highlighting six crucial questions that should be considered: "why, how, where, when, what, and who" (see Figure A in the appendix). The study concludes with the assertion that intelligent feedback exerts a moderate influence on learning achievements and perceptions, with older students demonstrating a heightened response compared to younger students. Furthermore, it is imperative that learners have a sense of autonomy in determining the timing of receiving feedback. Moreover, the combined utilisation of multiple feedback technologies has been demonstrated to yield a more substantial impact than the deployment of a solitary technology. Finally, the superiority of real-time feedback over delayed feedback has been demonstrated in numerous studies (Zheng et al., 2025; Chen & Chen, 2025). As mentioned before, Chen & Chen (2025) analysed the use of learning analytics in the context of IBL. They find advantages for both students and teachers. Adaptive learning analytics tools are not dependent on specific subjects and can therefore provide individualised feedback for any subject. The individualised feedback fosters the students' understanding and engagement. Furthermore, it helps teachers reflect and revise their designed inquiry activities. Chen & Chen (2025) present two successful learning implementation strategies of learning analytics: The use of dashboards a) helps students to reflect on their own learning, b) may assist teachers in providing guidance and support to their students in a timely manner, and c) facilitates whole-class inquiry practices. Secondly, conversational agents facilitate fruitful discussions in group settings during the inquiry process and peer-feedback.

The Impact of Emotions on Learning

One review examined emotions in the context of inquiry learning; however, it focused on design-based learning (DBL), and no information was found specifically on IBL. In their review, Zhang et al. (2020) investigated studies focusing on emotions and their influence on learning and future activities. They found that positive emotional reactions were linked to high self-efficacy and interest, whereas confusion correlated with a lower interest at the end of longer interventions. Similar results were found regarding students' likelihood of participating in related activities in the future if they displayed happiness during the intervention, whereas anxiety had a negative effect. They provide a full list of guidelines for the various components of DBL (as content, learning activity, materials & resources, teacher's role, grouping and time) that were found in the analysed literature (see Zhang et al., 2020, p. 477 and Figure C in the appendix). For effective DBL, it is crucial for teachers to provide students with qualitative support to help them regulate their emotions, especially to reduce frustration, which may arise at different stages of the project cycle.

Implications for IBL in primary and secondary classrooms

In this section, we provide ten important aspects one should consider when implementing inquiry-based learning in primary and secondary schools. Following the presentation of each aspect, a concise overview of the extant literature pertaining to the respective step is provided.

1 *Just do it!* Studies show that inquiry-based learning has beneficial impacts on the development of students. The first step is to decide to incorporate IBL into your classroom (or outside the classroom).

Example: In Biology, assign a small project where students investigate why biodiversity is declining in a local lake (water sampling, recording and recognizing organisms, and presenting possible causes).

Tip: Start with a small-scale inquiry that promotes critical thinking and increases student participation and interest. Ensure that the objectives of the activity align with the curriculum requirements (e.g., carrying out investigations and analysing data).

Studies show that IBL significantly impacts the development of students' critical thinking skills, particularly in higher education (Arifin et al., 2025) and significantly improves students' conceptual understanding of MINT subjects[3] (Mediana et al., 2025). Therefore, IBL should be considered the primary approach for cultivating critical thinking and conceptual understanding, rather than merely acquiring knowledge, as is the case in traditional science education.

2 *Choose the right level of inquiry!* Studies suggest that more open levels of inquiry result in larger effects on the students' conceptual understanding and critical thinking skills. However, the age of the learners and their experience in IBL must be considered in the choice of the right level of inquiry.

Example: In Physics, assign a pendulum experiment where students choose which variable (length, mass, etc.) they will investigate. This corresponds to an open inquiry approach.

Tip: More open forms of inquiry tend to lead to deeper understanding; however, for younger students (i.e. upper primary school), it is better to provide more guided steps (guided inquiry) so that activities match students' level.

Results on the effects of different levels of inquiry favoured open inquiry and guided inquiry over structured and confirmatory inquiry. Mediana et al. (2025) found that open inquiry followed by guided inquiry has the largest effects on the students' conceptual understanding. However, they analysed two studies on primary education, compared to ten on secondary and tertiary education. Similarly, Arifin et al. (2025) confirm a larger effect of open and guided

[3] MINT is a German acronym for Mathematics, Informatics (Computer Science), Natural Sciences (Physics, Chemistry, Biology), and Technology, serving as the European equivalent to the English STEM (Science, Technology, Engineering, Mathematics) fields.

inquiry on the students' critical thinking skills. Their analysis covered twelve studies on elementary students, compared to twelve on secondary students and nine on undergraduates. However, as the educational level appears to have a substantial influence on the effect of IBL, learning environments have to be carefully tailored to the diverse needs, cognitive readiness of the students and learning objectives. Even at lower levels of education, instructions that resemble recipes, where students merely confirm pre-existing knowledge, should be avoided when students are to develop critical thinking skills and conceptual understanding.

3 *Let them ask!* Student questions can be used as a starting point for inquiry. Nevertheless, they may prove to be advantageous in other stages throughout the investigative process as well. Reflection on the role of questions using the SQIB model may be beneficial in identifying new ways to incorporate student questions into your IBL environment.

Example: In Geography, begin a learning unit on local environmental issues (e.g., analysing temperature differences across our school or across the city) by encouraging students to formulate their own questions, such as: "Why are some areas of our school/city warmer than others?" or "Which factors are causing temperature differences?"

Tip: Encourage students to formulate questions, as this stimulates learning and strengthens critical thinking. Use models (e.g., SQBI) to structure how these questions guide the inquiry process.

Student questions are an essential part of the inquiry process and have a positive impact on the students' motivation and participation. Additionally, students formulating questions is one of the goals in science education, as also presented in the framework for K-12 science education by the National Research Council (2012). Several aspects ought to be considered when designing an IBL with a focus on students' questions. Those aspects can be found in the model of Student-question-based inquiry (SQBI) of Herranen and Aksela (2019), on how students' questions can act as a starting point or a guiding factor within inquiry practices.

4 *Provide guidance for your students!* Research shows that guided inquiry results in more profound learning activities (i.e., asking questions, evaluating data), performance success (products at the end of the inquiry task) and learning outcomes (i.e., better conceptual understanding) than unguided inquiry.

Example: In a sustainability-focused lesson, students investigate the question: "How can we reduce waste in our school canteen?" Facilitate a short brainstorming session to generate initial ideas. Divided students into small groups to explore different aspects of the problem, for example, measuring current waste levels and interviewing cafeteria staff about food preparation and disposal practices.

Tip: While students work independently, monitor group progress and provide targeted guidance when needed, for example, suggesting appropriate methods for data collection, helping students refine their research questions, or prompting them to compare different waste-reduction strategies. This type of scaffolding helps students stay focused.

Guidance plays a crucial role in IBL. It is imperative that any guidance provided is adapted to suit the target group and the objectives of the IBL setting, as suggested in Table 2. Various types, such as scaffolding, process constraints or prompts, can be beneficial in different situations (Sun et al., 2022). The goal is to neither underchallenge nor overwhelm students. It might be sensible to provide guidance that students can choose according to their individual needs. This leads directly to the next implication.

5 *Design challenging tasks, but don't let your students stay stuck in confusion!* Challenging tasks and associated emotions can positively impact student learning. However, students who show confusion should be supported to find a way to solve the respective problem.

Example: In a lower secondary mathematics class, students explore how quickly something can grow over time. For instance, they might investigate how a virus can spread through a population or how the number of followers of a new social media account. Students work in small groups to record the values in a table and create a graph to observe the growth pattern.

Tip: Challenging tasks help students develop deeper understanding and problem-solving skills. Also, contextualization is always a key factor for increasing students' interest. These small scaffolds help students overcome difficulties without taking away the exploratory nature of the activity.

Zhang et al. (2025) examined the role of emotions in IBL. They found that positive emotions in IBL foster interest and excitement toward STEM education. However, while frustration, i.e., due to time pressure or iterative revisions, does not have an immediate negative impact, confusion that is not resolved has a negative effect on the students' interest and learning progress.

6 *Don't bore your students!* Try to avoid giving your students long instructions and let them get started on their own; however, remain accessible if guidance is required.

Example: In Computer Science, instead of explaining a sorting algorithm through a long lecture, give students a small dataset and ask them to design their own sorting method. Tailor some programming examples to real-world problems, for example, demonstrating how integrals can be used to estimate the power produced by a wind turbine.

Tip: Keep instructions short and allow students to start the activity quickly, while remaining available for support if needed. Especially for programming classes, annotated code blocks with clear instructions and explanations are always a key

Furthermore, Zhang et al. (2025) report that other negative emotions such as boredom, fear or nervousness were dominant when students were listening to lengthy instructions, when the content did not match the required tasks, or when students experienced continuous failure. A balance of negative and positive emotions during IBL seems to be crucial for stimulating the students' interest and for active and continuous participation in inquiry practices.

7 *Implement feedback in different occasions and forms!* Use feedback throughout the inquiry process and implement various forms of feedback, i.e., peer-feedback, teacher-feedback, automatic feedback, should be considered in IBL.

Example: In a physics lesson on motion, students design and conduct a simple experiment to measure the speed of a moving object (e.g., a toy car on a ramp). After presenting their results, they receive feedback from classmates (peer review), the teacher, and, where possible, through a digital interactive platform (i.e., PhET) that helps visualise and compare their measurements.

Tip: Integrate feedback throughout the activity (peer, teacher, and automated when possible) to support reflection, encourage collaboration, and help students improve both their investigation process and their interpretation of results.

In IBL, feedback should be used not only for assessment purposes, but also to encourage collaboration and promote self-reflection. Considering the 6W framework developed by Zheng et al. (2025) might result in higher quality of feedback. Their framework relies on the six questions: "why, how, where, when, what, and who". Furthermore, feedback is of greater importance to older learners than to younger ones.

8 *Provide individual feedback!* Individual feedback can foster engagement and motivation. It allows students to self-reflect on their learning process and improve learning outcomes. This can be facilitated by using learning analytics technology.

Example: In Mathematics, use a digital platform (i.e., Phyphox) to analyse the graphs created by each student for monitoring light intensity inside and outside the school building. You may send short individual comments (e.g., suggestions for improving data presentation).

Tip: Use technological tools (learning analytics, dashboards) to monitor individual progress and provide targeted support to your students.

The orchestration of the entire class engenders a situation in which teachers find themselves operating within a highly demanding environment. Consequently, the implementation of technological tools may be advantageous in facilitating individualised feedback from teachers to their students when required. One potential solution to this issue might be the implementation of brief questionnaires throughout the inquiry, which are automatically evaluated and present results to the learner. Another solution might be the use of dashboards that enable educators to monitor individual learners' progress and provide assistance when necessary. This approach may prove particularly advantageous when employed in conjunction with prepared guidance regarding potential obstacles, such as scaffolds.

9 *Provide feedback in a timely manner!* It is more effective to give feedback timely than to delay it.

Example: In Physics, during a lab on electrical circuits, students upload their measurements to a shared digital board. The teacher circulates among groups to give immediate, informal feedback, posts targeted comments directly in shared documents, and uses real-time polling apps (e.g., Socrative or Slido) to check understanding and address misconceptions on the spot.

Tip: Combine "in-the-moment" check-ins with digital tools for real-time assessment. Use a feed-forward approach to guide students' next steps ("How could you test this idea further?" or "Which source could help with that problem?"), ensuring feedback supports learning continuously and keeps students actively engaged.

Digital learning environments may assist teachers in monitoring the students' progress. Chen and Chen (2025), for example, recommend the use of dashboards and other collaborative tools to support feedback from teachers and peers. Additionally, students ought to decide when they receive feedback and what for (Zheng et al., 2025).

10 *Leverage technology – but do so purposefully and thoughtfully!* The utilisation of technology may have several positive effects on students in IBL. Nonetheless, in the event of technology being applied, it should be used for specific tasks and in a reflective manner.

Example: In Geography, students use a simple Geographic Information Systems (GIS) or an online map to identify high flood-risk zones in their area and propose protective measures.

Tip: Select digital tools that enrich inquiry (e.g., data collection apps or simulations) and help students visualise their findings and results. Discuss their advantages and limitations with students so that these tools meaningfully support the learning objectives.

Arifin et al. (2025) report large positive effects of technology on critical thinking. Table 3 provides an overview of the roles of technology and examples of their implementation in IBL environments, based on Hinostroza et al. (2024). Also, Liu et al. (2020) suggest different situations to use mobile technology in the context of IBL, i.e., for data collection or visualisation and highlight many positive effects, such as enhanced student engagement and motivation. However, they emphasise the importance of using these methods reflectively with the students. The careful selection of modern media in IBL, which exploits interactive features and real-time feedback, among other things, should be favoured over traditional media.

Limitations and Future Directions

There are several limitations to this study that must be mentioned. The included studies were only searched for in two databases: ERIC and Google Scholar. Due to time constraints, the literature review was conducted rather quickly and focused on interesting findings that were simple to implement in practice. Additionally, the objective of this review was to identify practical implications tailored specifically to primary and secondary school teachers involved in the inTruST project, which is funded by Erasmus+. In this context, only English literature was included, despite extensive research existing within the German-speaking scientific community.

Future research should therefore consider expanding the scope of the review to include additional academic databases, non-English literature, and a broader range of publication types for capturing a more comprehensive and internationally representative evidence base. An extended review could also place greater emphasis on longitudinal and comparative studies, examining the sustained impacts of IBL across different educational systems, subject domains, and age groups. Finally, future work should explore the systematic alignment of IBL design principles with contemporary and competence-based curricular frameworks.

Conclusions

This deliverable synthesises current evidence from SLR on IBL and related pedagogical approaches, highlighting their documented benefits for students' conceptual understanding, critical thinking, and engagement in science education. Despite the aforementioned methodological limitations, the review provides a focused and practice-oriented synthesis tailored to the needs of primary and secondary school teachers participating in the inTruST project. By concentrating on implementation-relevant findings, the deliverable offers actionable insights into the key enabling factors, challenges, and moderating conditions that shape the effectiveness and the impact of IBL in primary and secondary education.

As a first step, building on these findings, the inTruST consortium has incorporated the review outcomes into curriculum design and pedagogical guidance by aligning them with the Next Generation Science Standards (NGSS)[4]. NGSS conceptualise science learning through three interrelated dimensions, scientific and engineering practices, crosscutting concepts, and disciplinary core ideas, which promote coherent, inquiry-driven learning processes. The emphasis of NGSS on active investigation and real-world problem-solving directly addresses the design principles and implementation challenges identified in the SLR, namely steps 1, 3, 5 – 7 in the boxes above. By adopting the NGSS framework, inTruST seeks to transform evidence from IBL research into a structured, standards-based approach that supports teachers in fostering scientific literacy, integrating inquiry into everyday classroom practices, and equipping students with the competencies required for evolving STEM pathways.

[4] Next Generation Science Standards (NGSS) overview: https://www.nextgenscience.org/

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Appendices

Appendix I: Studies included in the systematic literature review (SLR)

Table A: Information on the included studies in the literature review.

Authors & Year	Journal	Included studies & Research Method	Time range	Population	Subjects	Focus of the study
Arifin et al. (2025)	EURASIA J Math Sci Tech Ed	25 quantitative empirical studies; pre-/quasi-experimental settings; Systematic meta-analysis following PRISMA guidelines	2000-2024	Primary, Secondary, Undergraduate	Science, Biology, Chemistry, Physics	Impact of IBL on critical thinking skills; Analysed moderators: Educational Level, Learning strategy, Level of inquiry, Country, Duration of intervention, Science disciplines, ICT media used, Assessments used, Type of assessments;
Chen & Chen (2025)	Education Tech Research Dev	51 research articles and conference proceedings; Systematic Literature Review following PRISMA guidelines	2012-2024	University students, K-12, Teachers, Others	Physical Science, Life science, Earth Science, Others	Learning analytics and their application in IBL to support teachers and students; Analysed categories: Research trends, Theory, Implementation of LA in IBL phases, and Impacts of LA-support in IBL;
Hernández-Ramoz et al. (2021)	Education Sciences	33 research articles; Literature Review following PRISMA guidelines	2010-2020	High school, Tertiary (mainly tertiary)	Earth science, Engineering, Health, Other	Impact of used technologies in the context of socio-scientific issues (SSI) in PBL scenarios; Analysed categories: Type of SSI, impacts on students (i.e., teamwork, technical skills, problem-solving skills), technologies used, grade level;
Herranan & Aksela (2019)	Studies in Science Education	30 articles; Systematic review; No	2008-2017	Primary (9), Secondary (11), Tertiary	Science, Medical Science,	Student-Question-Based Inquiry (SQBI),

		report following PRISMA guidelines, but transparent report of selection process		(4), Different (5)	Biology, Chemistry	Role of questions in inquiry; Analysed categories: Descriptives of included studies, Nature of inquiry, Significance of questions in the inquiry, Formulation of questions, Questions used in inquiry, Role of the student and teacher;
Hinostroza et al (2024)	Social Sciences & Humanities Open 9	25 experimental or quasi-experimental educational studies; Systematic Literature Review following PRISMA guidelines	2013-2023	Primary, Secondary	Natural Sciences, Physics, Biology, Chemistry, Technology, Social Sciences, Physical Geography	Roles of digital technologies in the implementation of (different phases of) IBL; Analysed categories: Guide to the IBL process, Representation of phenomena, Source of access to content, Data collection tool, Tool for organising, Tool for collaboration, Tool for feedback;
Lazonder & Harmsen (2016)	Review of Educational Research	72 empirical studies with test-control groups receiving different types of guidance; Meta-analysis; No report following PRISMA guidelines, but transparent report of selection process	1993-2013	Primary, Secondary and Tertiary (referred to as age groups)	Science, Mathematics	Effects of different types of guidance for different age categories in IBL; Analysed outcome measures: Learning activities, performance success, learning outcomes; Analysed moderators: Outcome focus, Publication type, Domain, Type of guidance, Age group, Study design, Duration;
Liu et al. (2020)	J Comput Assist Learn	31 empirical studies; Systematic Literature Review following	2000-2019	Secondary	Science, Mathematics, Any discipline	Mobile technologies and their influences on students' engagement in IBL; Analysed categories: Types

		PRISMA guidelines				of mobile IBL, usability and utility, learning experience (i.e., motivation, performance, collaboration), and long-term effects;
Mediana et al. (2025)	IJEMST	12 empirical studies with 14 effect sizes; Meta-analysis following PRISMA guidelines	2014-2024	Primary, Secondary, Tertiary	Science, Mathematics	Impacts of IBL on improving students' conceptual understanding in science and mathematics; Analysed moderators: Grade level, subject, level of inquiry;
Sun et al. (2022)	Journal of Computer Assisted Learning	28 (quasi-)experimental studies; Literature review; No report following PRISMA guidelines, but transparent report of selection process;	2011-2020	Primary, Secondary, Tertiary	Physics, Chemistry, Mathematics, Science	Learning effects of different types of guidance in simulation-based IBL; Analysed categories: Types of guidance;
Zhang et al. (2020)	J Sci Educ Technol	34 empirical studies; Systematic survey of literature following PRISMA guidelines	1998-2019	Primary, Secondary and unidentified	Science, Mathematics	Impacts of emotions in DBL environments; Analysed categories: Academic emotions (Achievement emotions, Epistemic emotions, Topic emotions, Social emotions) and Components in the learning activity (Aims and objective, Assessment, Time, Location, Content, Learning activity, Teacher role, Grouping, Material and resources and Rationale);

Zheng et al. (2025)	Journal of Science Education and Technology	42 (quasi-)experimental studies; Meta-analysis following PRISMA guidelines	2013-2023	Primary, Secondary, Tertiary;	Science	Impacts of intelligent feedback on learning achievements and learning perceptions in IBL; Analysed categories: Sample level and size, Research design, Learning settings, Types of organisation (individual, group), Types of feedback, Feedback timing, Feedback technique, Adaptability of feedback, Feedback generation model, Data source used to provide feedback, Technical ways of providing feedback, Control of feedback, Purpose of feedback;

Appendix II: Frameworks, models and guidelines included and analysed in the SLR

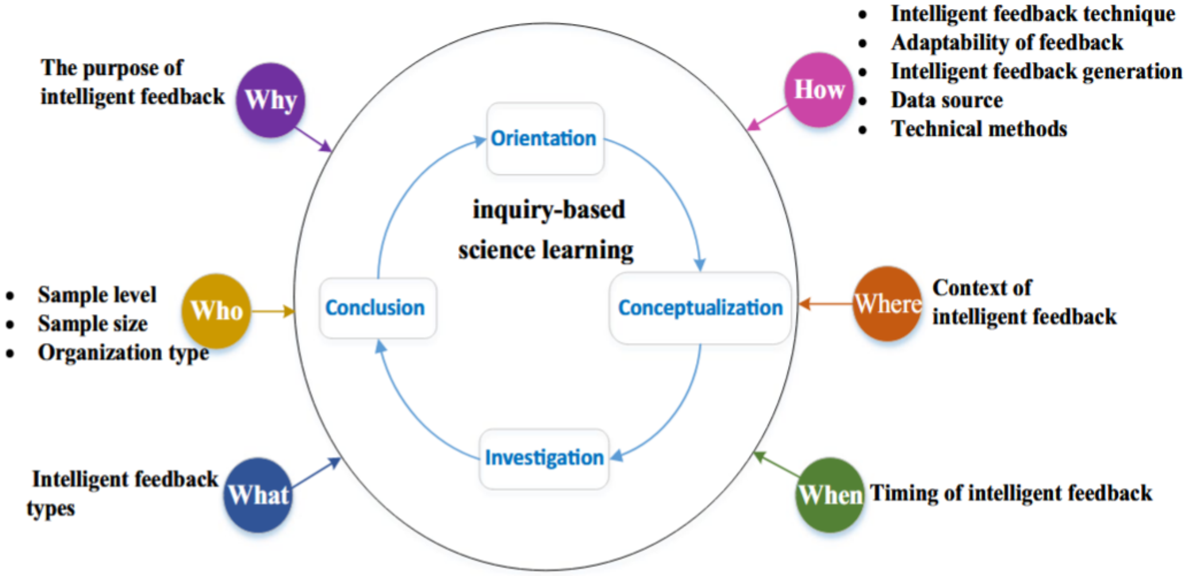

Figure A: 6W framework for intelligent feedback-supported IBL, Zheng et al. (2025)

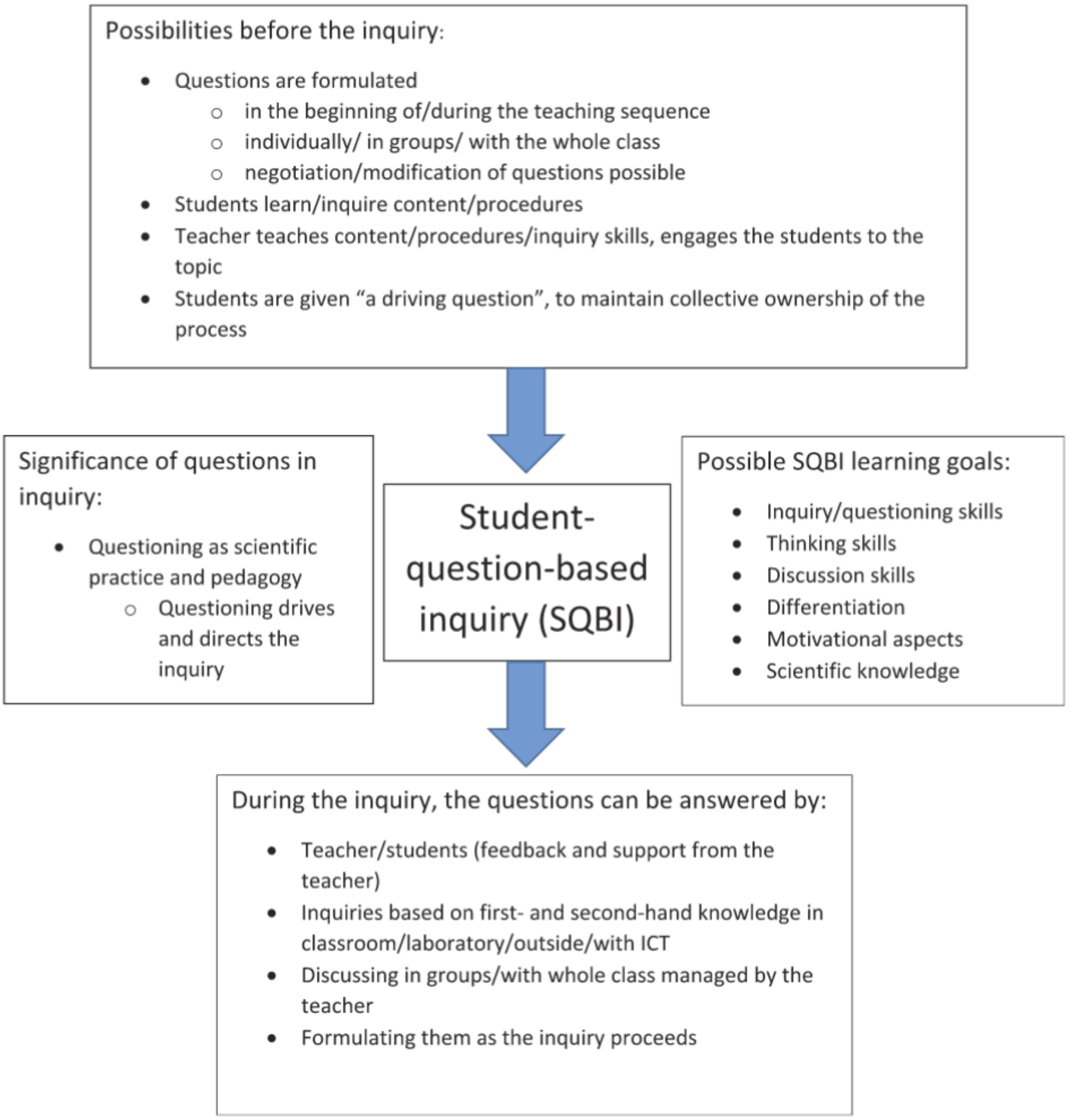

Figure B: Model for student-question-based inquiry SQBI, Herranen & Aksela (2019)

DBL component	Guidelines	Reference source
Content	• Connect learning content to the design challenge and the DBL process to make it more interesting and attractive.	Penuel et al. (2016)
	• Carefully moderate the complexity of the design challenges during iteration.	Vongkulluksn et al. (2018)
Learning Activity	• Combine passive listening and hands-on experimentation activities (e.g., teaching and introducing learning content should not all be provided in one block before hands-on activities).	Carroll et al. (2010)
	• Create a climate in which mistakes and failures are accepted to trigger curiosity in children.	Marks (2017); Marks and Chase (2019)
Materials & Resources	• Prefer appealing modern technologies/kits (e.g., Lego-Logo, Lego NXT kits, Scratch, Raspberry Pi, LilyPad) that engage children, triggering their curiosity and building up their enthusiasm.	Sáez-López and Sevillano-García (2017)
	• DBL should not neglect the need for well-structured materials and resources (e.g., instructional worksheets) to motivate children and trigger their interest and curiosity in the topics covered.	Doppelt and Schunn (2008)
Teacher's Role	• Carefully regulate the amount of support so that children feel independent about their learning	Doppelt and Barak (2002)
	• Show interest in students' achievements (e.g., their design ideas, designs created, and progress in projects).	Hugerat (2016)
	• Actively help children draw links between their tasks and the design challenge.	Penuel et al. (2016)
	• Moderate peer feedback moments, to enable children to listen and accept peer critique and feedback.	Zhang et al. (2019)
	• Provide emotional regulation support for children, especially during iterations.	Vongkulluksn et al. (2018)
Grouping	• Try to create a comfortable atmosphere within mixed-gender groups, especially in cases where they contain a gender minority.	Guo et al. (2016, 2017)
	• Try to cultivate children's sense of responsibility and encourage them to volunteer to offer help to peers.	Chu et al. (2017)
	• Involve various stakeholders (e.g., those with external businesses as clients, involving professionals as experts, and consulting intended users).	Milam et al. (2016); Phusavat et al. (2019)
Time	• Carefully set a feasible project time constraint, considering the complexity of the design challenge and the checkpoints during the project.t	Vongkulluksn et al. (2018)

Figure C: Guidelines for DBL Emotions, Zhang et al., (2020)

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