

The Impact of Inquiry-Based Science Education on the Development of Multidimensional Scientific Literacy

Renata Bellová¹
Eva Culková²

¹ Catholic University of Ružomberok; Hrabovská cesta 1; 03401 Ružomberok; Slovakia; renata.bellova@ku.sk

² Catholic University of Ružomberok, Hrabovská cesta 1; 03401 Ružomberok; Slovakia; email: eva.culkova@ku.sk

Grant: Project No. 5/1a/2026

Name of the Grant: Grant Agency of the Faculty of Education, Catholic University in Ružomberok

Subject: AM - Pedagogy and education

GRANT Journal, MAGNANIMITAS Assn.

Abstract Inquiry-based teaching supports the development of students' scientific literacy across multiple dimensions, including scientific knowledge, experimental skills, motivation, attitudes, the application of knowledge, and collaboration. In this study, third-grade primary school pupils participated in qualitative group interviews conducted before and after a series of inquiry-based learning activities focused on exploring natural phenomena, planning experiments, and applying knowledge in practical contexts. The qualitative analysis revealed improvements across all six investigated dimensions of scientific literacy. Students showed a deeper understanding of scientific concepts, enhanced experimental thinking, increased motivation, greater ability to apply scientific knowledge in everyday situations, and more active collaboration during discussions. The findings indicate that inquiry-based teaching can effectively promote the comprehensive development of scientific literacy and that its principles can be successfully implemented in higher grades, particularly within the *Human and Nature* curriculum, where pupils can build previously acquired inquiry skills to solve more complex scientific problems.

Keywords science education, inquiry-based learning, scientific literacy, experimental skills, knowledge application, collaboration

1. INTRODUCTION

In its contemporary understanding, scientific literacy extends beyond the mere acquisition and reproduction of factual knowledge. It encompasses the ability to think critically, construct and evaluate arguments, solve problems, and apply scientific knowledge in authentic real-life situations. Empirical research has shown that instruction based predominantly on the transmission and reproduction of information is insufficient for developing these competencies and often contributes to the persistence of students' misconceptions.

Current conceptions of the goals of science education go beyond the acquisition of isolated facts and concepts. Contemporary curriculum approaches emphasize the multidimensional nature of science education, whose primary aim is the development of students' scientific literacy (Bybee, 2013; Bellová, 2018; OECD, 2019; Osborne, 2014).

The multidimensional goal of science education encompasses the development of several interrelated domains: scientific knowledge, scientific skills, attitudes, and the ability to apply scientific knowledge in everyday contexts. Scientific literacy is defined as an individual's capacity to engage in discussions of scientific issues, explain natural phenomena using scientific knowledge, design and evaluate scientific investigations, and interpret data and evidence (OECD, 2016; OECD, 2019).

Within this framework, science education focuses on multiple dimensions of learning. The first is the knowledge dimension, which involves understanding fundamental scientific concepts, principles, and laws. The second is the process dimension, which concerns the development of scientific inquiry skills such as asking questions, formulating hypotheses, planning and conducting experiments, collecting and interpreting data, and drawing conclusions. The third is the attitudinal dimension, which includes fostering interest in science, curiosity, and positive attitudes toward understanding the natural world. An equally important component is the application and social dimension, reflected in the ability to use scientific knowledge for problem-solving and to engage in evidence-based discussions of scientific issues (Bybee, 2013; Hodson, 2014; Osborne, 2014).

Research in science education has consistently shown that the development of scientific literacy is more effective when students actively participate in the learning process through Inquiry-Based Science Education (IBSE). This approach enables students to investigate natural phenomena, formulate questions, test hypotheses, and interpret findings, thereby promoting a deeper understanding of scientific concepts (Oliver, McConney & Woods-McConney, 2021; Jegstad, 2023).

Recent studies further indicate that inquiry-based and problem-based instructional approaches make a substantial contribution to the development of scientific literacy, critical thinking, and problem-solving skills. Experimental and quantitative studies confirm that the implementation of inquiry-based strategies leads to improved conceptual understanding of scientific phenomena as well as increased student motivation to learn science (Eymur & Çetin, 2024; Faizin, Susantini & Raharjo, 2024).

The importance of inquiry-based learning is also supported by recent systematic reviews, which highlight its contribution to the

development of 21st-century competencies, including critical thinking, argumentation, collaboration, and the ability to interpret scientific evidence (Vo & Mooney Simmie, 2025; Nahar & Machado, 2025). Furthermore, research suggests that integrating digital tools and emerging technologies into inquiry-based learning can further enhance students' scientific literacy and the development of their scientific identity (Huang & Pei, 2024; Ramli & Borhan, 2024; Perdana, Yulianti & Bertiliya, 2025).

Taken together, these findings indicate that the multidimensional goal of science education is to develop learners who not only possess fundamental scientific knowledge but are also capable of critically evaluating and applying that knowledge in real-world situations and actively engaging in addressing issues related to nature, science, and technology.

2. RESEARCH OBJECTIVES AND HYPOTHESES

The aim of the study was to investigate the impact of implementing inquiry-based activities on the development of multidimensional scientific literacy among primary school pupils. Individual dimensions of scientific literacy – knowledge, scientific skills, attitudes, application of knowledge, and social collaboration - were examined through qualitative analysis of group interviews conducted before and after the educational intervention.

The main research aim was further elaborated into a set of specific objectives that enabled its systematic achievement:

1. **Knowledge Dimension:** To determine whether the implementation of inquiry-based activities contributes to a deeper understanding of fundamental scientific concepts and phenomena, as reflected in more accurate and scientifically sound responses provided by pupils during the interviews.
2. **Process/Skills Dimension:** To examine the extent to which pupils, after participating in inquiry-based activities, can formulate research questions, propose simple hypotheses, plan and conduct experiments, and interpret the data obtained.
3. **Motivational–Attitudinal Dimension:** To investigate whether inquiry-based instruction influences pupils' attitudes toward science education, particularly their motivation, curiosity, and willingness to engage actively in learning activities.
4. **Application Dimension:** To explore pupils' ability to apply scientific knowledge when explaining simple real-life situations, as demonstrated through concrete examples and evidence-based reasoning during the interviews.
5. **Social Dimension:** To examine the extent to which the implementation of inquiry-based activities promotes collaboration, discussion, and evidence-based argumentation among pupils, as reflected in their responses during group interviews.
6. **Assessment of Overall Scientific Literacy Development:** To determine whether inquiry-based instruction contributes to the development of pupils' scientific literacy in its multidimensional conception through a comparison of qualitative data obtained from interviews conducted before and after the intervention.

Based on these objectives, the following research hypotheses were formulated:

H1 (Knowledge Dimension): The implementation of inquiry-based activities in primary science education will contribute to a deeper understanding of fundamental scientific concepts and phenomena, which will be reflected in pupils' interview responses through more accurate and scientifically sound explanations.

H2 (Process Dimension – Scientific Skills): Following participation in inquiry-based activities, pupils will demonstrate a higher level of scientific inquiry skills, particularly in asking questions, formulating simple hypotheses, planning and interpreting experiments, as evidenced by their verbal responses during the interviews.

H3 (Attitudinal Dimension): The implementation of inquiry-based instruction in science education will lead to positive changes in pupils' motivation and attitudes toward learning science, particularly regarding their interest, curiosity, and willingness to engage in learning activities, as reflected in their verbal and reflective interview responses.

H4 (Application Dimension): After participating in inquiry-based activities, pupils will be able to apply scientific knowledge when explaining simple everyday situations, as demonstrated in the interviews through the use of concrete examples and evidence-based reasoning.

H5 (Social Dimension): The implementation of inquiry-based activities will enhance pupils' ability to discuss, collaborate, and construct evidence-based arguments, as reflected in their responses during the group interviews.

H6 (Overall Multidimensional Effect): Inquiry-based instruction contributes to the development of pupils' scientific literacy in its multidimensional conception (knowledge, skills, attitudes, and application of knowledge), which will be identifiable through qualitative analysis of the interview data collected before and after the intervention.

Table 1. Alignment of Scientific Literacy Dimensions, Research Hypotheses, and Interview Questions (Scientific Inquiry Competencies)

Dimension	Hypothesis	Competency Area Assessed
Knowledge Dimension	H1 – Understanding of scientific concepts and phenomena	Level of knowledge; accuracy and scientific correctness of explanations
Process/Skills Dimension	H2 – Development of scientific inquiry skills	Observation, hypothesis formulation, experimentation
Attitudinal (Motivational) Dimension	H3 – Motivation and attitudes toward science	Interest, curiosity, willingness to engage
Application Dimension	H4 – Application of knowledge in everyday life	Practical application of knowledge, evidence-based reasoning
Social Dimension	H5 – Collaboration and argumentation	Communication, teamwork, discussion
Multidimensional Dimension	H6 – Development of scientific literacy	Integrated development across all dimensions

3. RESEARCH METHODOLOGY

The study was conducted with a sample of 30 third-grade primary school pupils. The aim was to examine the effectiveness of Inquiry-Based Science Education (IBSE) in fostering the development of

multidimensional scientific literacy. Participation was voluntary, and informed parental consent was obtained prior to the study.

The first stage of the research involved a pre-intervention group interview conducted prior to the implementation of inquiry-based lessons. Subsequently, the educational intervention was carried out through a series of inquiry-based learning activities in which pupils actively participated. Following the completion of the instructional sequence, the same interview protocol was administered again (post-intervention interview) in order to identify changes across the previously defined dimensions of scientific literacy.

The interviews were conducted in the classroom, audio-recorded, and subsequently transcribed verbatim. Data analysis was carried out using qualitative content analysis. Pupils' responses were categorized according to the individual dimensions of scientific literacy and compared across the pre-intervention and post-intervention phases.

This procedure enabled the identification of changes in pupils' scientific knowledge, inquiry skills, attitudes, ability to apply scientific knowledge, and social collaboration, thereby allowing the effectiveness of inquiry-based instruction to be evaluated.

The interview protocol consisted of 12 questions, which were organized according to the dimensions of scientific literacy and aligned with research hypotheses H1–H6.

4. IMPLEMENTATION OF INQUIRY-BASED ACTIVITIES

As part of the research, five inquiry-based science lessons were implemented with the pupils. These lessons included a variety of activities designed to foster the development of multidimensional scientific literacy:

1. **The World of Insects and Plants** – pupils investigated plants and insects in the school environment, conducting observations and recording data.
2. **Water and Its Properties** – pupils explored the water cycle, evaporation, condensation, and solubility through inquiry-based investigations.
3. **Magnetic and Electrical Interactions** – pupils experimented with magnets and simple electrical circuits, exploring basic physical phenomena.
4. **Colours and Light** – pupils observed the dispersion of white light using a prism, mixed colours, and investigated shadow phenomena.
5. **Soil and Plants** – pupils compared plant growth in different soil types and moisture conditions, recorded observations, and drew conclusions based on the collected evidence.

These activities enabled pupils to observe and explain natural phenomena, plan and conduct experiments, collaborate with peers, construct evidence-based arguments, and apply scientific knowledge in practical contexts. In this way, the effectiveness of Inquiry-Based Science Education (IBSE) in promoting multidimensional scientific literacy was examined.

5. COMPARATIVE ANALYSIS OF RESULTS BEFORE AND AFTER THE EDUCATIONAL INTERVENTION

The collected data were analysed using **thematic analysis**, specifically the procedure of **open coding**, which enabled the

systematic identification of meaningful patterns in pupils' responses before and after the implementation of the inquiry-based activities. The analysis was conducted in several successive stages. First, the group interviews were transcribed verbatim, creating a reliable corpus for qualitative analysis. Subsequently, **meaning units** were identified within the transcripts. These consisted of segments of text containing information relevant to the investigated dimensions of scientific literacy.

In the next phase, **open coding** was applied, whereby individual meaning units were assigned codes that captured their content and significance. This process was inductive in nature, with codes emerging directly from the data rather than being derived from a predetermined coding framework. Subsequently, conceptually related codes were grouped into broader thematic categories representing the principal dimensions and aspects of the phenomenon under investigation (Table 2).

The resulting categories enabled a systematic interpretation of the data and facilitated the identification of changes in pupils' responses between the pre-intervention and post-intervention phases of the study. The results of the analysis were processed separately for each phase and organized into comprehensive analytical tables. Owing to their extent, these tables are not included in the present paper.

The processed data were subsequently synthesized in **Table 2**, which presents the qualitative differences observed between the pre-intervention and post-intervention phases. This procedure made it possible to identify developments within the individual dimensions of scientific literacy resulting from the implementation of Inquiry-Based Science Education (IBSE).

Table 2. Comparison of Categories Emerging from Pupils' Responses Before and After the Implementation of Inquiry-Based Activities

Category	Before the Activities – Characteristics of Pupils' Responses	After the Activities – Characteristics of Pupils' Responses
Understanding of Scientific Experimentation	An experiment is generally seen as a way to find things out or test an idea.	Pupils describe an experiment as a planned test to verify assumptions.
Purpose of Experimentation	Pupils mainly provide general reasons, such as learning something new or finding an answer to a question.	Responses are more precise; experimentation is described as a means of testing ideas and understanding how things work.
Knowledge of Natural Phenomena	Pupils mention basic examples derived from classroom instruction.	More specific knowledge acquired through the activities is evident in their responses.
Ways of Obtaining Information about Nature	Responses include reading books or general observation of nature.	Pupils more frequently mention planning investigations, observing changes, and testing their own ideas.
Experimental Thinking	Pupils only partially describe procedures for testing ideas.	More systematic reasoning includes comparing conditions,

Category	Before the Activities – Characteristics of Pupils' Responses	After the Activities – Characteristics of Pupils' Responses
		controlling variables, and monitoring results.
Understanding of the Concept of Observation	Observation is often understood as “paying attention to the teacher.”	Pupils describe observation as monitoring changes during an investigation and noticing differences.
Understanding of the Concept of Hypothesis	Most pupils are unfamiliar with the term or unable to explain it.	Pupils describe a hypothesis as a prediction that must be tested.
Collaboration During Investigations	Pupils mainly mention difficulties related to cooperation (e.g., problems reaching agreement).	Positive aspects of collaboration emerge, such as task distribution and listening to one another.
Reflection on Experimental Results	Pupils provide general reasons, such as sharing information or describing what they have learned.	Pupils recognize the importance of discussing results and different observations.
Motivation for Inquiry	Most pupils report enjoying investigations, mainly because they learn something new.	Motivation is stronger and linked to direct experience with investigations.

6. VERIFICATION OF THE RESEARCH HYPOTHESES AND DISCUSSION

The qualitative comparison was followed by a quantification of the findings, which resulted in the construction of a summary graph (Figure 1). The graph was based on the identified categories and codes, with the occurrence of relevant pupil responses being recorded for each category in both the pre-intervention and post-intervention interviews. These occurrences were subsequently expressed as frequencies, enabling the representation of the prevalence of individual phenomena across both phases of the study.

Figure 1 thus provides a synthetic overview of changes across the individual dimensions of scientific literacy. Comparing the frequencies observed before and after the intervention makes it possible to identify increases or decreases in the occurrence of the investigated indicators. The graph therefore serves as a basis for testing the proposed hypotheses, as it illustrates the extent of development in pupils' scientific knowledge, inquiry skills, attitudes, ability to apply scientific knowledge, and social competencies.

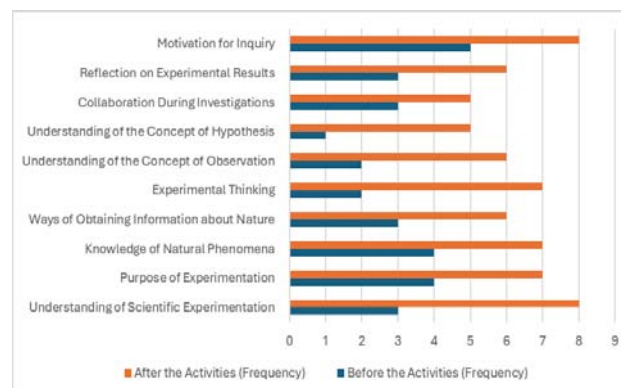


Figure 1. Comparison of the Frequencies of Categories Emerging from Pupils' Responses in the Pre-Intervention and Post-Intervention Interviews.

Based on the data presented in Figure 1, the proposed hypotheses can be evaluated as follows:

H1: Knowledge Dimension

The most substantial increases were observed in the categories **Understanding of Scientific Experimentation** (+5) and **Experimental Thinking** (+5), indicating a significant deepening of pupils' understanding of the principles of scientific inquiry. Considerable improvement was also evident in the categories **Understanding of the Concept of Observation** (+4) and **Understanding of the Concept of Hypothesis** (+4), suggesting a better grasp of fundamental scientific concepts.

The category **Knowledge of Natural Phenomena** increased by +3, indicating that pupils' explanations became more accurate and conceptually sophisticated. A similar increase was observed in the category **Ways of Obtaining Information about Nature** (+3), further supporting the development of scientific reasoning.

Overall, the most pronounced changes occurred in categories related to conceptual understanding and scientific thinking, providing direct evidence in support of **Hypothesis H1**. Following the intervention, pupils' responses were more accurate, scientifically sound, and conceptually deeper. Therefore, **H1 can be considered confirmed**.

H2: Process Dimension – Scientific Inquiry Skills

The evaluation of H2 focused on categories associated with the development of scientific inquiry skills, particularly hypothesis formulation, experiment planning, and interpretation of results.

The largest increase was observed in **Experimental Thinking** (experiment planning) (+5; from 2 to 7), indicating a better understanding of experimental design and a more systematic approach to problem-solving. **Understanding of the Concept of Hypothesis** increased by +4 (from 1 to 5), while **Understanding of the Concept of Observation** increased by +4 (from 2 to 6), suggesting that pupils acquired essential scientific inquiry concepts. The category **Understanding of Scientific Experimentation** increased by +5 (from 3 to 8), demonstrating a more comprehensive understanding of the experimental process and its purpose. Furthermore, the increase in **Reflection on Experimental Results** (+3; from 3 to 6) indicates an enhanced ability to draw conclusions and communicate them verbally.

The overall improvement across all relevant categories indicates a substantial development of pupils' scientific inquiry skills, as reflected in their verbal responses during the interviews. Therefore, **Hypothesis H2 can be considered confirmed**.

H3: Attitudinal Dimension

The evaluation of H3 focused on categories reflecting the affective and value-related aspects of learning.

Following the implementation of the inquiry-based activities, an increase was observed in the category **Purpose of Experimentation** (+3; from 4 to 7), indicating a deeper appreciation of the value of scientific investigation. Similarly, **Reflection on Experimental Results** increased by +3 (from 3 to 6), suggesting a greater willingness among pupils to think about and articulate their own learning experiences. The increase in **Ways of Obtaining Information about Nature** (+3; from 3 to 6) indicates a broader understanding of how knowledge about the natural world can be acquired.

Although the category **Motivation for Inquiry** increased by +3 (from 5 to 8), the key finding is that positive changes were also evident in broader attitudinal indicators, including pupils' appreciation of experimentation and their engagement in the learning process.

These findings confirm that Inquiry-Based Science Education (IBSE) contributed to positive changes in pupils' motivation and attitudes toward science learning. Therefore, **Hypothesis H3 can be considered confirmed**.

H4: Application Dimension

The evaluation of H4 focused on categories reflecting pupils' ability to apply scientific knowledge in real-life contexts and to construct evidence-based explanations.

Following the implementation of the inquiry-based activities, pupils demonstrated an increased ability to:

- **Apply knowledge of natural phenomena** by providing examples from everyday life, indicating a stronger connection between scientific knowledge and practical contexts.
- **Reflect on experimental results and interpret observations.** The increase in the category **Reflection on Experimental Results** (+3; from 3 to 6) suggests an improved ability to draw conclusions and transfer them beyond the immediate experimental setting.
- **Construct evidence-based arguments.** Pupils increasingly referred to observed data and experimental results when explaining phenomena, clearly indicating the development of scientific reasoning and argumentation.

Improvement was also evident in pupils' ability to connect scientific concepts and phenomena with practical situations, as reflected in the category **Ways of Obtaining Information about Nature**.

These findings confirm that Inquiry-Based Science Education (IBSE) supported the development of pupils' application skills. Pupils not only demonstrated an understanding of scientific concepts and phenomena but were also able to apply this knowledge in practical contexts. Therefore, **Hypothesis H4 can be considered confirmed**.

H5: Social Dimension

The evaluation of H5 focused on the social dimension of scientific literacy, namely collaboration, discussion, and evidence-based reasoning.

Following the implementation of the inquiry-based activities, improvements were observed in pupils' abilities to:

- **Collaborate during investigations.** The frequency of relevant responses increased from 4 to 6 (+2), indicating

more active coordination of tasks and greater participation in group work.

- **Construct evidence-based arguments.** The increase in the category **Reflection on Experimental Results** from 3 to 6 (+3) demonstrates more frequent use of observations and experimental evidence to justify conclusions.
- **Engage in discussion and share ideas.** The increase from 3 to 6 (+3) in categories related to reflection and sharing results suggests more active communication, responsiveness to classmates' opinions, and constructive argumentation.

Additional observations confirmed that pupils more frequently asked their peers for opinions, proposed alternative explanations, and discussed experimental outcomes. These behaviours reflect active participation and the collaborative construction of knowledge. These findings indicate that Inquiry-Based Science Education (IBSE) supported the development of pupils' social competencies. Therefore, **Hypothesis H5 can be considered confirmed**.

H6: Overall Multidimensional Effect

In conclusion, **Hypothesis H6 was confirmed**, as positive changes were observed across all investigated dimensions of scientific literacy. The findings indicate an overall improvement in pupils' scientific literacy, encompassing scientific knowledge, inquiry skills, attitudes, application of knowledge, and social competencies.

Taken together, the results suggest that Inquiry-Based Science Education (IBSE) is an effective pedagogical approach for fostering the multidimensional development of scientific literacy in primary school pupils.

7. CONCLUSION

The overall findings of the study indicate that the implementation of Inquiry-Based Science Education (IBSE) in primary science education significantly contributes to the development of pupils' scientific literacy in its multidimensional conception, encompassing scientific knowledge, inquiry skills, attitudes, and the ability to apply knowledge. This conclusion is consistent with previous international research demonstrating that inquiry-based and active-learning approaches enhance learning outcomes, student motivation, and understanding of scientific concepts (Li & Ding, 2023; Strat, Henriksen, & Jegstad, 2023).

Empirical evidence further suggests that the inclusion of inquiry-based activities substantially improves pupils' attitudes toward science subjects, their emotional engagement, and their willingness to participate actively in the learning process (Ganajová, Orosová, Sotáková, & Letošníková, 2025).

Systematic reviews and meta-analyses have also shown that contextualized inquiry tasks, discussion of scientific explanations, and students' independent justification of their responses are crucial for the development of critical thinking and scientific inquiry skills. These approaches enable learners to move beyond the simple acquisition of facts toward deeper, more active, and reflective reasoning in the context of authentic problems (Furtak, Seidel, Iverson, & Briggs, 2012; Crawford, 2014).

The results of the present study revealed improvements across all investigated dimensions, ranging from verbally expressed scientific knowledge and the planning and interpretation of experiments to the application of knowledge in everyday situations and the development of positive attitudes toward science. These changes do not represent isolated or incidental occurrences; rather, they are consistent with the existing body of research on the effectiveness of

inquiry-based approaches in science education. The findings therefore confirm the potential of Inquiry-Based Science Education to foster comprehensive scientific literacy and greater student engagement in science learning. The educational approach presented in this study may be progressively implemented in higher grades within the curriculum area **Human and Nature**. At this stage of schooling, pupils already possess basic experience with inquiry-based activities, enabling them to engage more actively in solving complex tasks and to participate in scientific investigations at more advanced levels of inquiry.

Nevertheless, it should be acknowledged that the findings support the proposed hypotheses only within the context of a single class and a relatively small sample of pupils. Consequently, the generalizability of the results to other schools or larger populations remains limited. Future research should therefore include multiple classes, larger samples, and diverse school contexts to strengthen the validity and generalizability of the findings. We also propose several directions for future research that could deepen the understanding of these effects and enable broader generalization of the findings:

Investigation of interdisciplinary relationships – The aim would be to examine whether an inquiry-based approach to science education also enhances critical thinking, mathematical skills, and language literacy. This would help determine the extent to which the multidimensional goals of science education foster broader student competencies.

Comparative research on different types of inquiry-based activities – The objective would be to compare the effectiveness of various forms of inquiry-based learning activities, such as individual tasks, group work, and digital simulations. The research would employ experimental and quasi-experimental designs, classroom observations, assessment of student outcomes, and qualitative interviews. The expected contribution would be the identification of those types of activities that most effectively promote skill development, positive attitudes toward learning, and the ability to apply acquired knowledge.

Examination of the social dimension and teamwork – The aim would be to investigate in greater detail how students' collaboration, discussion, and argumentation influence the learning process and the development of scientific literacy. The research would utilize recordings of group discussions, sociometric analyses of interactions, and qualitative interviews. The expected contribution would be a better understanding of the social dimension of inquiry-based learning and its effects on motivation and sustainable learning.

References

1. Bellová, R., Melicherčíková, D., & Tomčík, P. (2018). Possible reasons for low scientific literacy of Slovak students in some natural science subjects. *Research in Science & Technological Education*, 36(2), 226–242.
2. Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. Arlington, VA: NSTA Press.
3. Crawford, B. A. (2014). From inquiry to scientific practices in the science classroom. *Studies in Science Education*, 50(2), 135–163.
4. Eymur, G., & Çetin, P. S. (2024). Investigating the role of an inquiry-based science lab on students' scientific literacy. *Instructional Science*, 52.
5. Faizin, A., Susantini, E., & Raharjo, R. (2024). Application of a guided inquiry learning model to improve students' scientific literacy skills. *International Journal of Recent Educational Research*, 5(2).
6. Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research*, 82(3), 300–329.
7. Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*.
8. Huang, L., & Pei, X. (2024). Exploring the impact of web-based inquiry on elementary school students' science identity development. *Humanities and Social Sciences Communications*.
9. Jegstad, K. M. (2023). Inquiry-based chemistry education: A systematic review. *International Journal of Science Education*.
10. Nahar, L., & Machado, C. (2025). Inquiry-based learning and development of 21st-century skills. *Disciplinary and Interdisciplinary Science Education Research*.
11. OECD. (2016). *PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematics and Financial Literacy*. Paris: OECD Publishing.
12. OECD. (2019). *PISA 2018 Assessment and Analytical Framework*. Paris: OECD Publishing.
13. Oliver, M., McConney, A., & Woods-McConney, A. (2021). The efficacy of inquiry-based instruction in science: A comparative analysis of six countries using PISA 2015. *Research in Science Education*.
14. Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*.
15. Perdana, R., Yulianti, D., & Bertiliya, W. A. (2025). Enhancing scientific literacy through AI-integrated inquiry module. *Journal of Educational Management and Instruction*.
16. Ramli, A. A., & Borhan, M. T. (2024). Bridging digital tools and scientific literacy: A systematic review. *International Journal of Modern Education*.
17. Vo, D. V., & Mooney Simmie, G. (2025). Assessing scientific inquiry: A systematic literature review. *International Journal of Science and Mathematics Education*.