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Development of Basic Science Concept Teaching Materials Integrating Project-Based Inquiry Models to Improve Science Process Skills

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Abstract

This research aimed to develop and evaluate Basic Science Concepts instructional materials integrating a project-based inquiry model (BAKDIPA) to improve Science Process Skills among pre-service elementary teachers. The study employed a Research and Development (R&D) design using the Plomp model, consisting of Investigation, Design, and Realization phases. The participants included 33 students in the experimental class and 35 students in the control class enrolled in a Basic Science Concepts course. Data were collected using validation sheets, SPS test instruments, and practicality questionnaires. Experts and practitioners assessed the validity of the developed product, while its practicality and effectiveness were examined through field implementation. The validation results revealed a high level of validity with overall mean scores of 4.10 for the Semester Learning Plan and 4.27 for instructional materials, categorized as "very valid". Practicality assessment also indicated positive user responses, confirming that the material was feasible to implement. The effectiveness test using a paired t-test indicated a significant improvement in SPS, where the t_{count} (14.5) > t_{table} (2.87). The normalized gain analysis further showed an N-Gain of 0.813, categorized as medium effectiveness, while the distribution of SPS levels demonstrated that more students in the experimental class achieved high proficiency compared to the control class. In conclusion, the BAKDIPA instructional material is valid, practical, and effective for enhancing SPS in Basic Science learning for pre-service elementary teachers. This research provides a promising contribution toward strengthening inquiry-oriented science education in teacher preparation programs.

Keywords: Teaching Material; Project-Based Inquiry; Science Process Skills; Science.

Introduction

This study focuses on the development of Basic Science Concept Teaching Materials Integrating Project-Based Inquiry Models to Improve Science Process Skills (SPS). In line with this focus, science education plays a crucial role in developing scientific literacy among young learners, especially at the elementary school level. In an era of rapid technological, environmental, and social change, students are required not only to understand scientific concepts but also to think critically, investigate problems, and apply science in real-life situations. These competencies are closely related to Science process skills (SPS) such as, hypothesizing, classifying, designing experiments, analyzing data, and drawing conclusions Are core competencies that pre-service teachers must master to effectively implement inquiry-based science learning in elementary schools (Darmaji et al., 2022; Maison et al., 2019). These skills represent structured scientific investigative behaviors that enable students to discover new concepts independently (Alatas & Fachrunisa, 2019; Sari S & Fitria, 2021). SPS instruction also supports students in making sense of scientific ideas and communicating their findings to others (Sayekti & Kinasih, 2018). However, when learning processes are dominated by passive knowledge transfer and provide limited investigative experience, students struggle to relate scientific concepts to real-life contexts and fail to develop creative problem-solving skills (Khaeruddin, Mohamad Nur, 2016). Therefore, future elementary school teachers must master SPS so that they are able to design meaningful, inquiry-oriented science learning in schools.

To develop SPS, science learning must be grounded in inquiry. Natural Science studies natural phenomena through systematic observation, experimentation, and reasoning (Parinduri et al., 2022). Consequently, science learning should be organized through inquiry processes that allow students to construct knowledge actively rather than receive it passively through memorization (Sulthon, 2017; Susiana et al., 2017). Inquiry-based learning trains students to ask questions, investigate phenomena, and explain results scientifically.

However, although inquiry is theoretically emphasized, its implementation in teacher education is still weak (Rajagukguk, 2022). In many teacher education programs, science learning is dominated by lecture methods, limited experimentation, and minimal use of real-life contexts (Rajagukguk et al., 2020). As a result, pre-service teachers have few opportunities to practice inquiry activities directly. This condition weakens their scientific reasoning and reduces their readiness to implement inquiry-based learning in elementary schools.

The weak implementation of inquiry has direct consequences for Science Process Skills. SPS are the core of inquiry-based science learning because they enable learners to understand scientific concepts through direct investigation and reasoning (Darmaji et al., 2022; Maison et al., 2019). Learners who are trained in SPS are better able to connect concepts with real phenomena, solve problems creatively, and communicate scientific ideas (Alatas & Fachrunisa, 2019; Sari S & Fitria, 2021). Conversely, when learning is dominated by passive knowledge transfer and lacks investigative experience, students tend to have difficulty applying concepts and show low innovation in problem solving (Khaeruddin, Mohamad Nur, 2016). This problem is also found among pre-service elementary teachers, whose SPS are often underdeveloped because they rarely experience structured inquiry during their training.

These competencies are essential for pre-service teachers to cultivate scientific reasoning and inquiry practices in elementary classrooms. SPS represents structured scientific investigative actions that enable learners to independently construct knowledge (Chengere et al., 2025). However, research indicates that SPS among pre-service elementary teachers remains underdeveloped, with learning still dominated by passive knowledge transmission and limited opportunities for direct inquiry-based investigation. As a result, students often struggle to connect scientific concepts with real-life phenomena and show limited innovation in scientific problem-solving (Rajagukguk et al., 2025).

Many studies have examined inquiry learning and SPS. Research shows that inquiry and project-based approaches can significantly improve SPS, critical thinking, and scientific literacy (Noer et al., 2023; Sayekti & Kinasih, 2018). However, research trends in Indonesia between 2016 and 2022 show that most SPS studies focus on secondary school students and mainly use quantitative approaches (Bilad et al., 2024). Studies that specifically target pre-service elementary teachers are still limited and fragmented. Moreover, many studies only test learning models without developing structured instructional materials that can be directly used in teacher education programs.

One approach that is closely aligned with inquiry is Project-Based Inquiry Learning (PBIL). PBIL integrates inquiry processes with real projects so that students investigate authentic problems and produce concrete products. International studies indicate that PBIL effectively improves SPS and scientific reasoning. However, most of these studies are implemented at the school level. For example, (Santyasa et al., 2020) found significant improvement in SPS among high school students through PBIL, but empirical studies that develop and test PBIL-based instructional materials for pre-service elementary teachers are still very rare. This shows that although inquiry and SPS have been widely discussed, their application in teacher education—especially through structured teaching materials—remains underexplored.

Based on the above discussion, the research gap becomes clear. First, SPS research still rarely focuses on pre-service elementary teachers. Second, few studies develop complete instructional materials that integrate inquiry and project-based learning. Third, limited studies evaluate instructional materials comprehensively in terms of validity, practicality, and effectiveness. The state of the art shows that inquiry-based and project-based learning is effective for improving SPS, but its systematic application in teacher education through validated teaching materials is still lacking. Such instructional design aligns with the demands of 21st-century education, which emphasize creativity, critical thinking, collaboration, and problem-solving skills (Sulistyani et al., 2022).

Therefore, this study is conducted to solve the main problem identified, namely the low SPS of pre-service elementary teachers due to limited inquiry-based learning experiences (Rajagukguk et al., 2022). This research develops Basic Science Concept Teaching Materials Integrating Project-Based Inquiry Models, specifically designed to improve SPS. The novelty of this research lies in producing a structured instructional product and testing it through three aspects: validity, practicality, and effectiveness in improving SPS. Thus, this study not only tests a learning model but also provides a concrete instructional product aimed at solving the problem of low science process skills.

Accordingly, the objectives of this study are directed to answering the problem of low SPS. This study aims to: (1) develop Basic Science Concept Teaching Materials Integrating Project-Based Inquiry Models to Improve Science Process Skills (SPS); (2) examine the practicality of the instructional materials in supporting inquiry activities that train SPS; and (3) evaluate the effectiveness of the instructional materials in increasing the science process skills of pre-service elementary teachers.

The research questions are: (1) To what extent are the developed instructional materials valid for improving SPS in Basic Science learning for pre-service teachers? (2) How practical are the instructional materials in facilitating inquiry activities that train SPS in real learning environments? and (3) How effective are the instructional materials in enhancing the science process skills of pre-service elementary teachers?

This research is expected to contribute to improving the quality of Basic Science education in teacher training programs by providing instructional materials that are valid, practical, and effective in improving SPS. Through this effort, future elementary school teachers are expected to be better prepared to implement inquiry-oriented science learning and to improve students' scientific literacy and problem-solving abilities.

Research Method

This study employed a Research and Development (R&D) approach using the Plomp Development Model (Plomp & Nieveen, 2013) because this model provides a systematic and iterative framework to develop educational products that meet the criteria of validity, practicality, and effectiveness (Rajagukguk, 2019). The Plomp model consists of three main phases, namely Preliminary Investigation, Design and Prototyping, and Assessment. In this study, these phases were adapted into Investigation, Design, and Realization, while maintaining the original logic of the Plomp model, which starts from identifying real educational problems, continues with product design, and ends with testing and revision based on evaluation results. Thus, the use of the Plomp model in this research is not only nominal but structurally aligned with its original development framework (Amelia et al., 2023; Sugiyono, 2019). As shown in Figure 1.

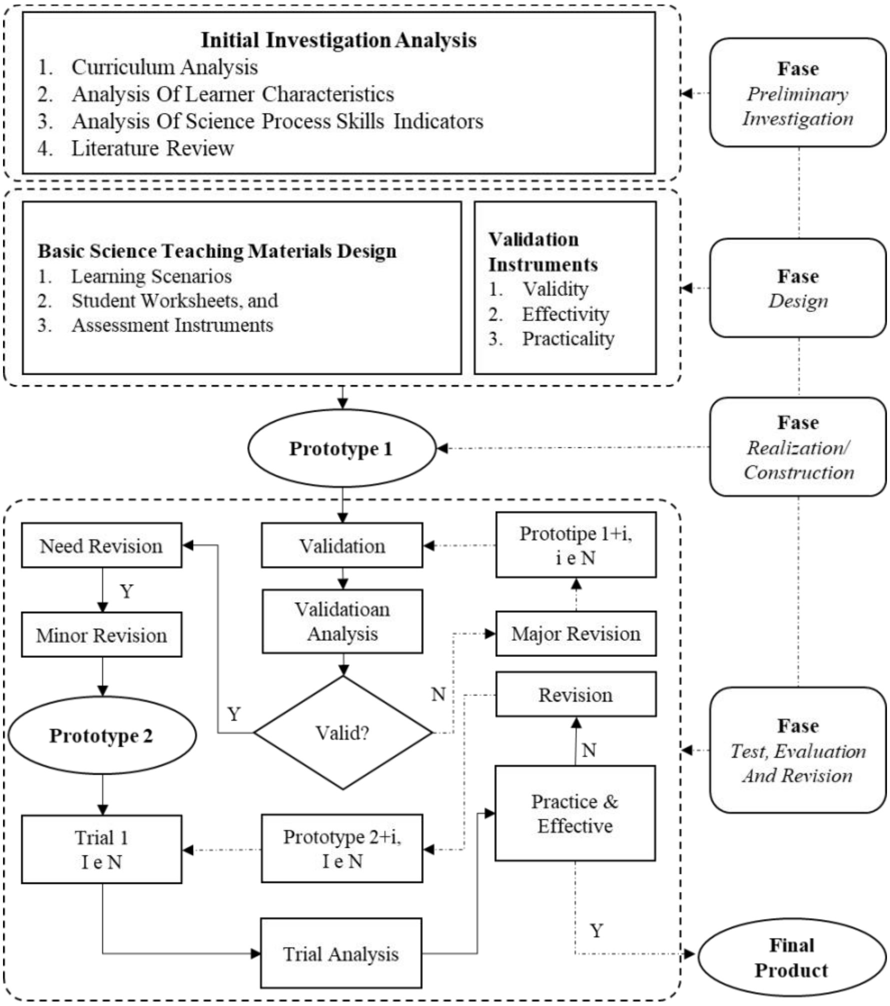

Figure 1. Procedures and Design of Plomp Model Research

The Investigation Phase in this study is an adoption of the Preliminary Investigation phase of the Plomp model. This phase aimed to identify learning problems and needs in Basic Science courses for pre-service elementary teachers. Activities included curriculum analysis to examine learning outcomes and content scope, analysis of learner characteristics, analysis of science process skills indicators, and literature review related to inquiry-based and project-based learning. The results of this phase were used to define learning problems and determine the specifications of the teaching materials to be developed, in accordance with Plomp's principle that development must be grounded in real educational needs.

The Design Phase corresponds to the Design and Prototyping phase in the Plomp model. In this phase, the structure of the Basic Science teaching materials was designed by integrating project-based inquiry components into learning activities. Learning scenarios, student worksheets, and assessment instruments based on science process skills indicators were developed. Validation instruments were also prepared to assess content suitability, language clarity, presentation, and conformity with inquiry-based learning principles. The output of this phase was Prototype I, which represented the initial version of the teaching materials ready for expert validation.

The Realization Phase represents the Assessment phase in the Plomp model. In this phase, Prototype I was validated by experts to examine content accuracy, relevance, language, and design quality. Based on validation results, revisions were made to produce Prototype II. This prototype was then implemented in a limited trial involving pre-service elementary teachers to test its practicality and effectiveness in improving science process skills. Feedback from experts and users was used to revise the product until it met the criteria of validity, practicality, and effectiveness.

Data were collected using observation, questionnaires, tests, and documentation. Observation was used to record the implementation of learning and students' science process skills activities. Questionnaires were used to obtain expert judgments on validity and user responses on practicality. Tests were used to measure science process skills before and after treatment, while documentation was used to collect supporting data such as curriculum documents and learning outcomes.

The instruments used in this study included expert validation sheets covering aspects of content, language, presentation, and inquiry integration; practicality questionnaires for lecturers and students; science process skills test instruments measuring observing, hypothesizing, experimenting, analyzing, concluding, and communicating; and observation sheets of learning implementation. All instruments are attached in the appendix of the manuscript.

Data were analyzed using both quantitative and qualitative techniques. Validation and practicality data were analyzed descriptively by calculating mean scores and percentages and then interpreting them into validity and practicality categories. Effectiveness data were analyzed using pre-test and post-test scores of science process skills. Improvement was measured using N-Gain analysis, and differences between groups were tested using a t-test. Qualitative data from observations and comments were analyzed through data reduction, data display, and conclusion drawing.

Effectiveness testing used a quasi-experimental design embedded in the Realization Phase of the Plomp model. Two groups were involved, namely an experimental class that used the developed Basic Science Concept Teaching Materials integrating project-based inquiry and a control class that used conventional teaching materials. Both groups were given a pre-test and post-test on science process skills. Differences in learning improvement between the two groups were used to determine the effectiveness of the developed teaching materials

Result and Discussion

This research resulted in the development of instructional material for Basic Science concepts integrated with a project-based inquiry model to enhance science process skills. Thus, the developed product consistently uses a Project-Based Inquiry approach, which combines inquiry activities with project-based learning processes. The product fulfilled the criteria of validity, practicality, and effectiveness. The development process began with the preparation of a Semester Learning Plan (RPS) based on Higher Education Standards and aligned with the university curriculum. The RPS was structured according to the Basic Science Concepts course for one academic semester and served as the main reference for designing the teaching materials. Therefore, the RPS did not stand alone, but functioned as the curricular foundation that guided the structure, learning objectives, learning activities, and assessment design in the developed teaching materials.

The instructional material was designed not only as learning content but also as a tool to train and assess students' science process skills through project-based inquiry activities. The final product was arranged as a comprehensive handbook for lecturers and pre-service teachers as primary users, ensuring its applicability in authentic learning environments. All learning activities in the material explicitly reflect the stages of project-based inquiry, including problem identification, hypothesis formulation, project planning, investigation, data analysis, conclusion drawing, and communication of results.

Furthermore, the development and evaluation procedures were directly aligned with the research questions. The validity of the product was examined through expert judgment to answer the first research question. The practicality of the material was assessed through lecturer and student responses during limited implementation to address the second research question. The effectiveness of the instructional material in improving science process skills was evaluated through learning outcome analysis to answer the third research question. Thus, each research stage was systematically designed to ensure that the findings directly correspond to the formulated research questions.

The validation results of the Semester Learning Plan (RPS) are presented in the appendix. These data were used to ensure that the learning objectives, content scope, learning activities, and assessments in the teaching materials were consistent with higher education standards and supported the integration of the project-based inquiry model. Therefore, the RPS validation data functioned as supporting evidence that the developed teaching materials were built on a valid curricular and instructional foundation. Therefore, each stage of the research procedure was systematically designed to ensure that the findings directly correspond to and justify the answers to all formulated research questions. The results of the validation assessment of the Semester Learning Plan (RPS). The average score for each validity aspect of the RPS indicators as evaluated by the practitioners is presented in the following table:

Table 1. Average for Each Aspect of Validity Assessment

No	Assesment Aspect	Average Indicator Score					Total Aspect Mean
1	Core Competencies	4,2	4	4	4	4	4,04
2	Content Indicator	4,6	4,5	4,7	5	5	4,76
3	Language Use	4,4	4,3	4,3	4	4	4,2
4	Learning Steps	4	3,8	4	3	3	3,86
5	Learning Activites	4	4	3,7	3	3	3,54
6	Cloing Components	4,2	4	4,3	4,5	4	4,2
	Overall Aspect Mean						**4,1**

The results of the validation assessment of the Semester Learning Plan (RPS) by the expert validators indicate that the developed RPS achieved a high level of validity. As shown in Table 1, the average score of all assessed aspects was 4.10, which falls within the “Very Valid” category based on the predetermined rating criteria. Among the evaluated components, the Content Indicators aspect obtained the highest score (4.76), suggesting that the material content strongly aligns with the intended learning objectives and competencies. The Language Use and Closing Components also received high validity scores of 4.20, indicating that the instructional language and structural completion of the RPS are appropriate and clearly communicated.

Meanwhile, the aspects of Learning Steps (3.86) and Learning Activities (3.54) received slightly lower scores, although still within the “Valid” category. These results suggest that minor improvements are needed in structuring learning procedures and activities to ensure stronger alignment with the inquiry-based project learning model. Nonetheless, the overall mean score demonstrates that the RPS is feasible and ready to be implemented in the Basic Science course for pre-service elementary teachers.

The validation assessment data for the instructional material on Basic Science Concepts can be found in the appendix. The average indicator scores for each assessment aspect of the instructional material, as evaluated by expert validators and practitioners, are presented in the following table:

Table 2. Average Value of Each Aspect of the Assessment of the Material Book

No	Assesment Aspect	Average Indicator Score						Total Aspect Mean
1	Material Quality and Content Input	4,5	4,4	4,5	4,6	4,5	4,4	4,3
2	Language Quality	4,3	4,2	4,3	4,1	4,1	4,2	4,2
3	Output / Reporting Quality	4,2	4	4,3	4,3	4,0	4,1	4,3
4	Clarity of Content and Objectives	4,3	4,2	4,3	4,3	4,4	4,4	4,3
5	Alignment of Output with Science Indicators	4,2	4	4,3	4,0	4,3	4,4	4,3
Overall Aspect Mean								**4,3**

The results of the expert and practitioner validation toward the instructional material for Basic Science Concepts demonstrate a high degree of feasibility. As presented in Table 2, the overall mean score of 4.27 lies within the "Very Valid" category, indicating that the developed instructional material is appropriate for use in learning activities. The highest scored aspect was Material Quality and Content Input (4.46), suggesting that the content presented is accurate, relevant, and aligned with the scientific concept demands of the Basic Science course. Meanwhile, Clarity of Content and Objectives (4.31) also received a strong rating, confirming that the instructional design clearly communicates learning goals and expectations to users. Other aspects, including Language Quality (4.20), Output/Reporting Quality (4.17), and Alignment with Science Indicators (4.21), were also categorized as very valid, implying that only minor revisions may be needed to further refine clarity, structure, and output consistency. Overall, these results indicate that the instructional material is ready for implementation in the Basic Science learning process and supports the achievement of science process skills among pre-service elementary teachers.

The results of the t-test analysis indicate a statistically significant improvement in science process skills (SPS) abilities among pre-service teachers after participating in the Basic Science Concept course using the developed instructional material. Based on the normalized gain calculation, students' creative thinking skills demonstrated an average N-Gain score of 0.813, which falls into the medium effectiveness category. Furthermore, the t-test results show that the obtained value of t_{count} = 14.5 is considerably higher than t_{table} = 2.87, confirming that the improvement is significant at a high level of confidence. This corresponds with the meta-analytic review by (Biswal Biswajit Behera, 2023), which concluded that inquiry-based learning methods exert a considerable positive impact on learners' SPS.

Moreover, the integration of project-based learning (PjBL) within the inquiry framework appears to deepen student engagement and facilitate higher-level skill development (e.g., hypothesizing, experimenting, analyzing, concluding). Studies show that inquiry-based approaches yield large effect sizes for higher-order thinking and SPS (Antonio & Prudente, 2024, found g = 0.893) (Antonio & Effects, 2024). The present study's result that 57.57% of the experimental group reached the "high" SPS category—compared to 34.28% in the control group—supports that claim. Additionally, literature on open inquiry and resource design confirms that when students undertake authentic investigative tasks and project work, their SPS improve significantly (Ederon, 2024). The analysis results of the science process skills (SPS) are presented in Table 3 below.

Table 3. Distribution of Science Process Skills (SPS) Categories

Science Process Skills (SPS)	F	Fr (%)
High	12	34,28
Moderate	19	54,28
Low	4	11,44
Total	**35**	**100**

The effectiveness demonstrated in the testing phase is the result of a systematically structured learning process, which was carefully designed through the development of the project-based inquiry–integrated instructional material for Basic Science Concepts (Biswal Biswajit Behera, 2023; Juniar et al., 2020). This indicates that the developed instructional material enhances both the effectiveness and meaningfulness of learning, as it engages students in active knowledge construction throughout every inquiry stage. By participating in project-based inquiry activities, students become more creative, independent, and capable of improving their science process skills. Thus, the integration of inquiry and project-based learning within the instructional material significantly contributes to better learning outcomes in the Basic Science Concepts course for pre-service elementary teachers.

The findings of this study indicate that the integration of project-based inquiry into Basic Science teaching materials meaningfully improves the science process skills (SPS) of pre-service elementary teachers. This improvement can be interpreted as evidence that SPS develop most effectively when students are actively involved in investigating real problems, rather than merely receiving information. Inquiry activities require learners to observe, question, test, and explain phenomena, while project-based learning provides a concrete context that makes these inquiry processes meaningful and purposeful. Therefore, the effectiveness of the developed materials is not merely the result of new content, but of a learning structure that positions students as active constructors of knowledge.

From a theoretical perspective, these results are consistent with constructivist learning theory, which states that knowledge is built through active engagement with experiences. Inquiry-based learning aligns with this view by allowing students to generate understanding through investigation and reflection. The addition of project-based learning strengthens this process by situating inquiry within authentic and goal-oriented tasks. Previous studies have shown that inquiry alone improves SPS, but when combined with projects, students become more motivated, responsible, and reflective because they see the tangible outcomes of their learning. This explains why students in this study demonstrated stronger abilities in hypothesizing, experimenting, analyzing data, and drawing conclusions.

The acceptance of the research hypothesis—that project-based inquiry teaching materials improve science process skills—is logically supported by the learning mechanisms embedded in the materials. The materials guide students through systematic stages: identifying problems, formulating hypotheses, planning and conducting investigations, analyzing findings, and communicating results. Each of these stages directly trains specific SPS indicators. Therefore, the observed improvement in SPS is not incidental, but a logical consequence of repeated engagement in structured inquiry and project activities. If learning had remained expository, students would have had fewer opportunities to practice these skills, and the hypothesis would likely not have been supported.

When compared with previous studies, the findings are generally consistent with research showing that inquiry-based and project-based approaches positively affect higher-order thinking and scientific skills. However, the relatively high improvement in this study may be influenced by the fact that the instructional material was specifically designed, validated, and refined for the context of pre-service elementary teachers. Many previous studies applied inquiry or PjBL as teaching strategies without developing complete instructional materials. This difference suggests that not only the model, but also the quality and structure of the learning resources, play an important role in determining learning outcomes.

The meaning of these results is significant for teacher education. Improving SPS at the pre-service level means future teachers will be more capable of implementing inquiry-oriented science learning in elementary schools. This has long-term implications for improving students' scientific literacy, which has been a persistent weakness in Indonesia. If teachers themselves are trained through inquiry and project-based learning, they are more likely to transfer these approaches into their own classrooms.

Differences between this study and some previous findings may be caused by variations in learning context, duration of implementation, student characteristics, and the level of scaffolding provided. In this study, inquiry activities were carefully structured and supported by teaching materials that guided both lecturers and students. In other studies where inquiry was less structured, students may have experienced confusion or cognitive overload, resulting in weaker outcomes. This indicates that inquiry and project-based learning must be well-designed and well-supported to be effective.

Overall, the findings show that integrating inquiry with project-based learning in well-developed teaching materials is a powerful strategy for enhancing science process skills. The results not only confirm existing theories about inquiry and constructivist learning, but also extend them by demonstrating the importance of product-oriented instructional design in teacher education.

Conclusion

This study confirms that the proposed hypothesis is accepted, namely that the developed science instructional material integrating inquiry and project activities is able to improve the science process skills of pre-service elementary teachers compared to conventional instruction. The main strength of the material lies in its systematic learning structure, which encourages students to actively observe, investigate, analyze, and communicate learning outcomes independently, in line with the research objective of producing feasible and impactful instructional material. However, this study is limited by the small scale of the trial and the relatively short implementation period, so the generalization of the findings should be made with caution. Despite these limitations, the developed material has strong potential to be refined and applied in broader contexts, at different educational levels, and in combination with digital learning to further strengthen science process skills and the quality of science education.

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