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Metacognitive Inquiry-Based Science Modules: A Need Analysis of Elementary Pre-Service Teachers' Science Process Skills

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Abstract

Science Process Skills (SPS) are essential competencies for prospective elementary school teachers, yet PGSD students often have limited opportunities to develop these skills through inquiry-based learning. This study analyzed students' needs for developing an inquiry-based science module with a metacognitive orientation to enhance SPS. A quantitative descriptive survey was conducted with 60 PGSD students who had completed a science course. Data were collected using a needs analysis questionnaire covering five student characteristics and three SPS need dimensions. Descriptive statistics, Pearson correlation, item-level correlation, and the Mann–Whitney U test were employed. Learning styles and preferences showed the highest mean score ($M = 3.031$), whereas learning experience had the lowest ($M = 2.292$), indicating limited exposure to laboratory and inquiry-based learning. All SPS need dimensions were rated very high, with module requirements obtaining the highest mean score ($M = 3.654$). Although no significant relationships were found between overall student characteristics and SPS needs, item-level analysis revealed a positive correlation between the ability to relate science concepts to everyday life and awareness of SPS gaps ($r = 0.319$, $p = 0.027$), and a negative correlation between difficulties in understanding abstract concepts and module requirements ($r = -0.397$, $p = 0.005$). Students with lower academic ability reported significantly greater module needs ($p = 0.012$). These findings support the development of a differentiated inquiry-based science module integrated with metacognitive strategies to improve SPS among prospective elementary school teachers.

Keywords: Metacognitive; Inquiry-based learning; Science process skills; Needs analysis; Pre-service elementary school teachers

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INTRODUCTION

Science learning in the Elementary School Teacher Education Program plays a strategic role in preparing pre-service teachers to respond to the challenges of 21st-century education. Prospective elementary school teachers are expected not only to master scientific concepts but also to possess scientific skills that support critical thinking, analytical reasoning, and problem-solving abilities (Fitria et al., 2018; Öztürk, 2023). In the context of modern education, science learning should be directed toward meaningful learning experiences that integrate conceptual understanding with scientific skills in a balanced manner (Bidarra & Rusman, 2017; Prykhodkina et al., 2025). Therefore, science instruction in higher education needs to be systematically designed to facilitate the development of both conceptual mastery and scientific competencies among students (Idris et al., 2022; Nouri et al., 2021).

One of the essential competencies that should be developed through science learning is science process skills. Science process skills include the abilities to observe, classify, measure, formulate hypotheses, conduct experiments, interpret data, and draw scientific conclusions (Gizaw & Sota, 2023; Nurjumiati et al., 2025; Widyaningsih, 2020). These skills are important because they enable students to actively construct scientific knowledge through direct investigation and experimentation (Constantinou et al., 2018; Falloon, 2019). For pre-service elementary school teachers, science process skills are not only necessary for mastering scientific concepts during university studies but also for preparing them to design and facilitate inquiry-oriented science learning in primary schools. Therefore, inadequate science process skills may limit prospective teachers' ability to create meaningful learning experiences that foster scientific literacy and critical thinking among elementary students. However, several previous studies have indicated that the science process skills of pre-service elementary school teachers remain relatively low. This condition may be associated with science learning practices in higher education that are still predominantly characterized by lecture-based instruction and teacher-centered approaches, limiting students' opportunities to engage directly in scientific inquiry activities (Murphy et al., 2021).

In addition to science process skills, metacognitive ability is considered another important factor that influences students' success in science learning. Metacognitive ability refers to an individual's awareness and control over their own thinking processes, including planning, monitoring, and evaluating learning strategies (Drigas & Mitsea, 2020; Ozturk, 2017; Rivas et al., 2022). Students with strong metacognitive abilities are generally more capable of regulating their learning processes, identifying learning difficulties, and selecting appropriate strategies for solving problems (Mastrothanais et al., 2018). Metacognitive ability also contributes to the development of independent and reflective learning habits among students (Tachie, 2019). Nevertheless, current science learning practices have not fully integrated metacognitive activities into the learning process (Avargil et al., 2018; Geng & Su, 2025). As a result, students often learn mechanically without reflecting on their understanding and learning strategies, which may lead to less meaningful learning experiences and insufficient development of higher-order thinking skills.

To overcome these challenges, the inquiry approach is considered relevant for implementation in science learning. Inquiry-based learning positions students as active participants in constructing knowledge through scientific investigation and exploration (Prayogi et al., 2023; Yulianci et al., 2018). Through inquiry activities, students are encouraged to observe phenomena, formulate problems, develop hypotheses, conduct experiments, analyze data, and draw conclusions based on evidence (Asriyadin et al., 2021; Yulianci et al., 2021). Inquiry-based learning has been widely recognized as an effective approach for improving science process skills and promoting critical and analytical thinking abilities. Furthermore, integrating inquiry learning with metacognitive orientation is believed to provide more meaningful learning experiences because students are not only involved in scientific activities but are also encouraged to reflect on, monitor, and evaluate their thinking processes during learning activities.

Several previous studies have demonstrated that inquiry-based learning effectively enhances students' science process skills, conceptual understanding, and scientific reasoning by actively engaging learners in scientific investigations and problem-solving activities (Arantika et al., 2019; Masithah et al., 2022; Nurjumiati et al., 2022). Likewise, studies on metacognitive strategies have consistently reported positive effects on students' reflective thinking, self-regulated learning, and learning independence by encouraging learners to plan, monitor, and evaluate their own cognitive processes (Hamzah et al., 2022; Sitaresmi et al., 2024; Tina et al., 2020). Other studies have also developed inquiry-oriented instructional modules to improve students' learning outcomes and scientific competencies. These findings collectively indicate that both inquiry-based learning and metacognitive approaches contribute significantly to the development of higher-order thinking skills and science learning. However, most previous studies have investigated these approaches separately or have primarily focused on evaluating their effectiveness after instructional interventions, while relatively little attention has been given to systematically identifying learners' actual needs prior to module development.

This limitation highlights an important research gap. Although inquiry-based instruction and metacognitive learning strategies have been widely investigated, few studies have comprehensively examined the characteristics and instructional needs of pre-service elementary school teachers as the empirical foundation for developing inquiry-based science modules with a metacognitive orientation. Existing instructional modules are generally designed based on theoretical assumptions or curriculum requirements without sufficiently considering students' science academic ability, prior learning experiences, initial science process skills, metacognitive readiness, and learning preferences. Consequently, the resulting instructional materials may not adequately address the actual learning difficulties experienced by students or optimally facilitate the development of science process skills. Considering that pre-service elementary school teachers will later become facilitators of inquiry-oriented science learning in primary schools, understanding their learning needs represents an essential prerequisite for designing effective instructional materials.

Addressing this gap, the present study offers a novel contribution by conducting a comprehensive needs analysis that simultaneously examines students' science academic ability, learning experiences, initial science process skills, metacognitive ability, and learning preferences as the basis for developing an inquiry-based science module with a metacognitive orientation. Unlike previous studies that primarily emphasized the effectiveness of inquiry learning or metacognitive strategies independently, this study provides empirical evidence to guide the systematic design of instructional modules that are responsive to students' actual characteristics and learning needs. Conducting a needs analysis before instructional development is particularly important because learning materials developed without sufficient understanding of learners' profiles may fail to provide appropriate scaffolding for meaningful scientific inquiry and reflective learning. Therefore, the findings of this study are expected to provide both theoretical and practical foundations for developing inquiry-based science modules that effectively support the improvement of science process skills among pre-service elementary school teachers. Based on these considerations, this study aims to analyze the instructional needs of pre-service elementary school teachers regarding the development of an inquiry-based science module with a metacognitive orientation to enhance their science process skills.

METHOD

This study employed a quantitative descriptive research design using a survey approach to identify the instructional needs of pre-service elementary school teachers as the foundation for developing an inquiry-based science module with a metacognitive orientation. The study represents the analysis phase of a Research and Development (R&D) project, in which the primary objective was to obtain comprehensive information regarding students' characteristics, learning experiences, science process skills, metacognitive ability, learning preferences, and expectations for the proposed instructional module.

The research was conducted in the Primary School Teacher Education (PGSD) Study Program at STKIP Taman Siswa Bima, Indonesia, during the even semester of the 2025/2026 academic year. The participants consisted of 48 undergraduate students who had completed the Basic Science Concepts course. Purposive sampling was employed because these students had prior learning experience in science courses and were therefore considered capable of providing relevant information regarding their learning experiences, science process skills, metacognitive ability, and instructional needs related to the development of an inquiry-based science module.

Data were collected using a needs assessment questionnaire developed based on relevant theoretical frameworks and previous studies concerning science process skills, metacognitive ability, learning preferences, and instructional material development. Since the purpose of the questionnaire was to identify students' learning characteristics and instructional needs rather than to measure psychological constructs or test causal relationships, the instrument was designed to provide descriptive information for the module development process. The questionnaire consisted of six dimensions, namely: (1) science academic ability, (2) learning experience, (3) initial science process skills, (4) metacognitive ability, (5) learning preferences, and (6) expectations regarding the characteristics of the inquiry-based science module with a metacognitive orientation. Responses were recorded using a four-point Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree).

To enrich the survey findings, classroom observations and document analysis of course learning materials were also conducted. These qualitative data were used to support the interpretation of the questionnaire results and to obtain a broader understanding of the existing science learning practices in the study program.

The collected data were analyzed using descriptive statistics to determine the mean score and category of each indicator. Pearson product-moment correlation analysis was employed to examine the relationship between students' characteristics and their instructional needs for module development. Furthermore, the Mann–Whitney U test was applied to compare differences in instructional needs between student groups because several variables did not fully satisfy the assumptions of parametric analysis. The findings from these analyses were subsequently used as the empirical basis for designing an inquiry-based science module with a metacognitive orientation that aligns with students' instructional needs.

RESULTS AND DISCUSSION

Student Characteristics

The analysis of student characteristics was conducted to identify the initial profile of pre-service elementary school teachers students as the basis for developing an inquiry-based science module with a metacognitive orientation. Understanding students' characteristics is important to ensure that the developed learning module is aligned with students' academic conditions, learning experiences, and learning needs. In this study, five dimensions were measured to provide a comprehensive overview of students' characteristics related to science learning and science process skills. The results of the analysis are presented in Table 1.

Table 1. Five dimensions were measured to profile student characteristics

No.	Dimension	Indicators (items)	n
1	Academic Ability (Science)	Understanding concepts, explaining phenomena, abstract concepts, connecting to daily life.	4
2	Learning Experience	Practicum, experiment-based learning, lecture-heavy background, scientific inquiry.	4
3	Initial Science Process Skills	Observation, classification, hypothesis, simple experiment, drawing conclusions.	5
4	Metacognitive	Planning, monitoring, awareness, reflection, strategy improvement.	5
5	Learning Style & Preference	Hands-on practice, visual/graphical, discussion, problem-based learning.	4

Table 1 presents the instrument used to measure student characteristics, which consists of five main dimensions: Academic Ability in Science, Learning Experience, Initial Science Process Skills, Metacognitive Skills, and Learning Style & Preference. Each dimension is operationalized into several specific indicators that serve as Likert-scale questionnaire items. The Academic Ability in Science dimension comprises four indicators focusing on conceptual understanding and the ability to relate science concepts to everyday life. The Learning Experience dimension also includes four indicators reflecting students' prior experiences with practicum activities and inquiry-based learning. The Initial Science Process Skills dimension consists of five indicators covering observation, classification, and hypothesis formulation skills. The Metacognitive dimension includes five indicators measuring students' abilities in planning, monitoring, and self-reflection during the learning process. Meanwhile, the Learning Style & Preference dimension contains four indicators describing students' preferences for hands-on, visual, discussion-based, and problem-based learning approaches. This instrument framework was designed to obtain a comprehensive profile of students' initial conditions as the basis for analyzing their science process skills needs.

Science Process Skills Needs

The analysis of Science Process Skills needs was conducted to identify the extent to which pre-service elementary school teachers students require the development of scientific skills in science learning. Identifying these needs is essential to support the design of learning modules that facilitate students in developing scientific investigation abilities and meaningful learning experiences. In this study, the needs for Science Process Skills were categorized into three dimensions. Each dimension consisted of several indicators used to describe students' needs related to science process skills development. The number of indicators in each dimension is presented in Table 2.

Table 2. Dimensions of Science Process Skills Needs

No.	Dimension	Indicators (items)	n
1	Science Process Skills Training Needs	Observing, classifying, measuring, hypothesis, experiment, data interpretation, drawing conclusion	7
2	Science Process Skills Gaps	Difficulty observing, unfamiliarity with hypothesis, difficulty experimenting, analyzing, concluding	5
3	Module Requirements	Inquiry-based module, experiment steps, metacognitive activities, thinking-trigger questions, reflection	5

Table 2 illustrates the instrument used to measure students' Science Process Skills needs, which is organized into three main dimensions. The first dimension, Science Process Skills Training Needs, consists of seven indicators representing essential science process skills, including observation, classification, measurement, hypothesis formulation, conducting experiments, data interpretation, and drawing conclusions. The second dimension, Science Process Skills Gaps, comprises five indicators that identify specific areas in which students experience difficulties, namely scientific observation, hypothesis formulation, independent experimentation, data analysis, and drawing accurate conclusions. The third dimension, Module Requirements, contains five indicators describing the characteristics of the instructional modules needed by students, including inquiry-based modules, experimental procedures, metacognitive activities, thinking-trigger questions, and learning reflection activities. Overall, Table 2 demonstrates that the Science Process Skills needs assessment was comprehensively designed to address aspects of training needs, gap identification, and preferences for instructional module designs that support science process-oriented learning.

Student Characteristics Profile

Across the five dimensions of student characteristics, learning style and preference obtained the highest mean score (M = 3.031), followed by metacognitive awareness (M = 2.829) and academic ability (M = 2.771). Learning experience had the lowest mean score (M = 2.292), indicating that most students had limited practicum or inquiry-based learning experience prior to this study.

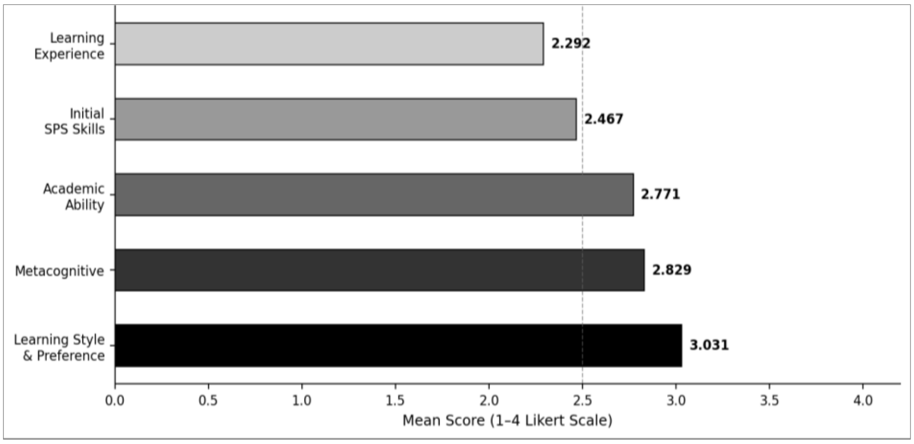

Figure 1. Mean Scores of Student Characteristics Dimensions

Profile of Science Process Skills Needs

All Science Process Skills items showed consistently high mean scores ranging from 3.29 to 3.69, indicating a universally strong perception of Science Process Skills training needs. Module requirement items (M = 3.65) ranked highest among the three Science Process Skills dimensions, followed by SPS gaps (M = 3.45) and SPS training needs (M = 3.47).

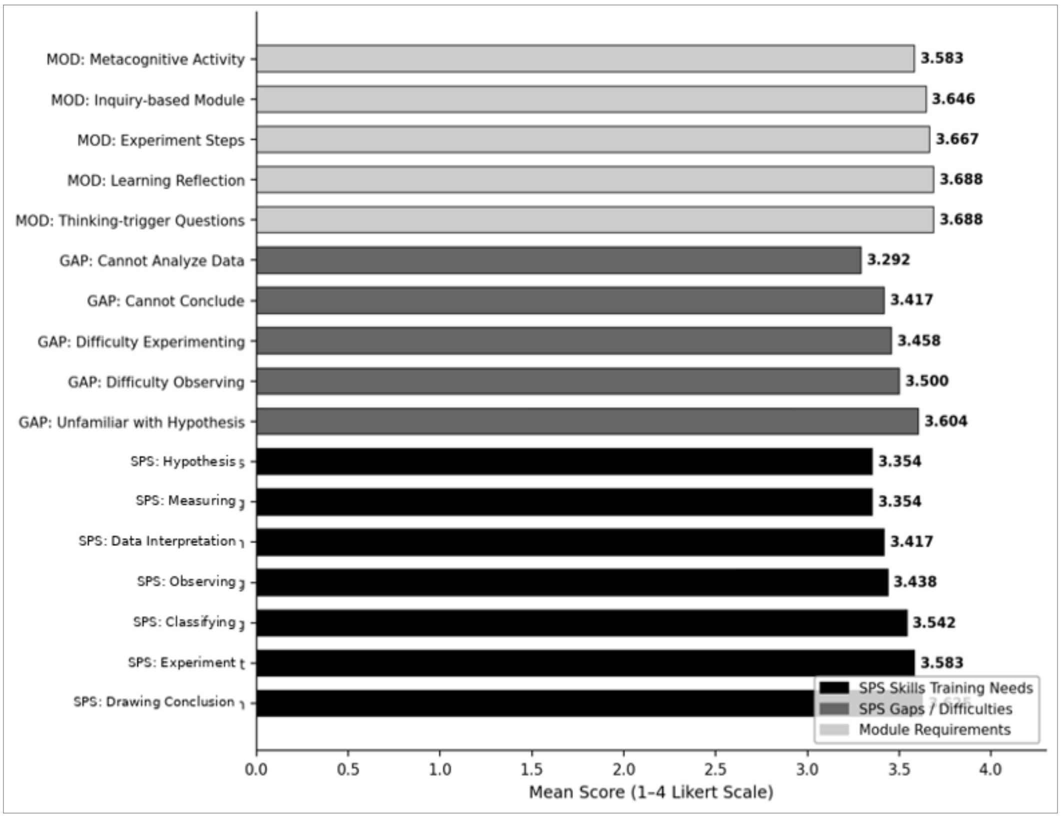

Figure 2. Science Process Skills Needs, Gaps, and Module Requirements per Item

The descriptive statistical results of the eight dimensions measured in this study, comprising five dimensions of student characteristics and three dimensions of Science Process Skills needs, are presented in Table 3.

Table 3. Descriptive Statistical Results of Student Characteristic Dimensions and Science Process Skills Needs

Dimension	Mean	SD	Min–Max	Category
Academic Ability	2.771	0.505	1.25 – 3.75	Moderate
Learning Experience	2.292	0.563	1.00 – 3.50	Low–Moderate

Dimension	Mean	SD	Min–Max	Category
Initial SPS Skills	2.467	0.524	1.40 – 3.60	Moderate
Metacognitive	2.829	0.502	1.60 – 3.80	Moderate–High
Learning Style & Preference	3.031	0.618	1.25 – 4.00	High
SPS Training Needs	3.473	0.223	3.00 – 4.00	Very High
SPS Gaps	3.454	0.267	2.80 – 4.00	Very High
Module Requirements	3.654	0.263	3.00 – 4.00	Very High

Table 3 summarizes the descriptive statistics of the eight dimensions measured in this study, comprising five dimensions of student characteristics and three dimensions of Science Process Skills needs. Among the student characteristic dimensions, Learning Style & Preference showed the highest mean score (M = 3.031) and was categorized as high, indicating that students demonstrated strong preferences for active and diverse learning approaches. The Metacognitive dimension (M = 2.829) and Academic Ability in Science (M = 2.771) were categorized as moderate–high and moderate, respectively. In contrast, the Learning Experience dimension obtained the lowest mean score (M = 2.292) and was categorized as low–moderate, reflecting students' limited prior exposure to practicum activities and scientific inquiry before this study. Regarding Science Process Skills needs, all three dimensions demonstrated very high mean scores, with Module Requirements ranking highest (M = 3.654), followed by SPS Training Needs (M = 3.473) and SPS Gaps (M = 3.454). The relatively low standard deviation values across the SPS dimensions (SD = 0.223–0.267) indicate a consistent perception among students regarding the high need for Science Process Skills development. Overall, this table demonstrates that although students' characteristic profiles varied, their needs for Science Process Skills development consistently remained at a very high level.

Correlation Analysis

Pearson Correlation Matrix

A Pearson correlation analysis was conducted between five dimensions of student characteristics and three dimensions of science process skill needs. Pearson Product Moment correlation analysis was used to determine whether there is a linear relationship between student characteristics and the need for Science Process Skills (SPS) development. In the context of this study, Pearson correlation was used not to prove a causal relationship, but to identify patterns of relationships between variables that can be used as a basis for developing module design. The correlation results help determine the student characteristics most closely related to learning needs so that the developed module is more targeted. The results are summarized in Figure 3 and Table 4.

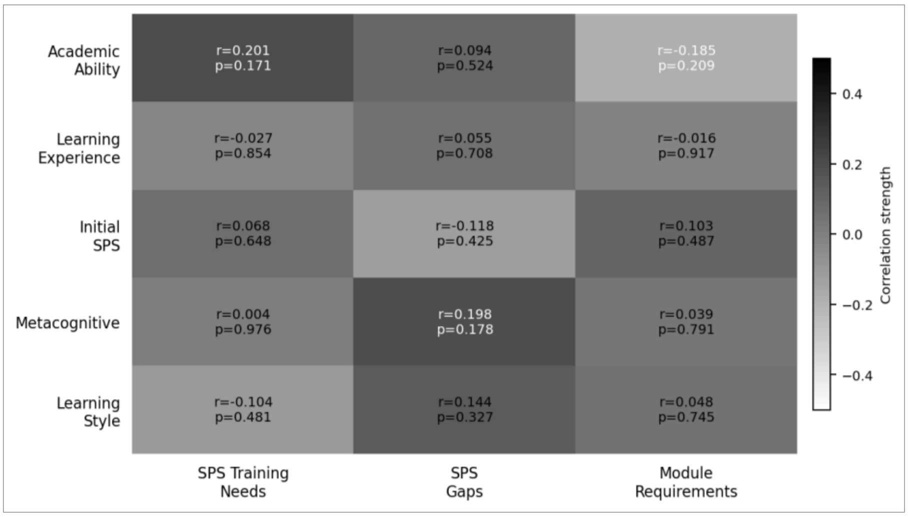

Figure 3. Correlation Heatmap: Student Characteristics vs. Science Process skills Needs (* p < 0.05; darker cells indicate stronger positive correlation)

The results of the Pearson correlation analysis between the five dimensions of student characteristics and the three dimensions of Science Process Skills needs are presented in Table 4 below.

Table 4. Correlation Analysis of Student Characteristic Dimensions and Science Process Skills Needs

Characteristic Dimension	r (A)	p (A)	r (B)	p (B)	r (C)	p (C)	Sig.
Academic Ability	0.201	0.171	0.094	0.524	-0.185	0.209	—
Learning Experience	-0.027	0.854	0.055	0.708	-0.016	0.917	—
Initial SPS Skills	0.068	0.648	-0.118	0.425	0.103	0.487	—
Metacognitive	0.004	0.976	0.198	0.178	0.039	0.791	—
Learning Style & Pref.	-0.104	0.481	0.144	0.327	0.048	0.745	—

A = SPS Training Needs; B = SPS Gaps; C = Module Requirements. Sig. = * $p < .05$; ** $p < .01$

Table 4 presents the results of the Pearson correlation analysis between the five dimensions of student characteristics and the three dimensions of SPS needs. The correlation coefficients (r) and corresponding p-values for each variable pair are reported comprehensively. The analysis revealed that none of the dimensional correlations reached statistical significance at the $p < 0.05$ level. The Academic Ability in Science dimension showed a weak positive correlation with Science Process Skills Training Needs ($r = 0.201$, $p = 0.171$), although the relationship was not statistically significant. The Learning Experience dimension demonstrated correlations close to zero across all Science Process Skills dimensions, indicating the absence of meaningful linear relationships. The Metacognitive dimension exhibited a weak positive correlation with Science Process Skills Gaps ($r = 0.198$, $p = 0.178$), although this relationship was also not statistically significant. In contrast, the Academic Ability in Science dimension showed a weak negative correlation with Module Requirements ($r = -0.185$), suggesting that students with higher academic ability tended to perceive slightly lower needs for instructional modules. Overall, the findings presented in Table 4 indicate that, at the aggregated dimensional level, no statistically significant relationships were identified between student characteristics and their Science Process Skills needs. Therefore, further analysis at the item level is necessary to identify more specific relationship patterns.

Item Level Significant Correlations

This analysis aims to obtain more detailed information regarding the relationships between indicators within each dimension. Inter-item correlations are conducted to identify specific indicators that exhibit significant relationships. At the item level, two statistically significant correlations were identified.

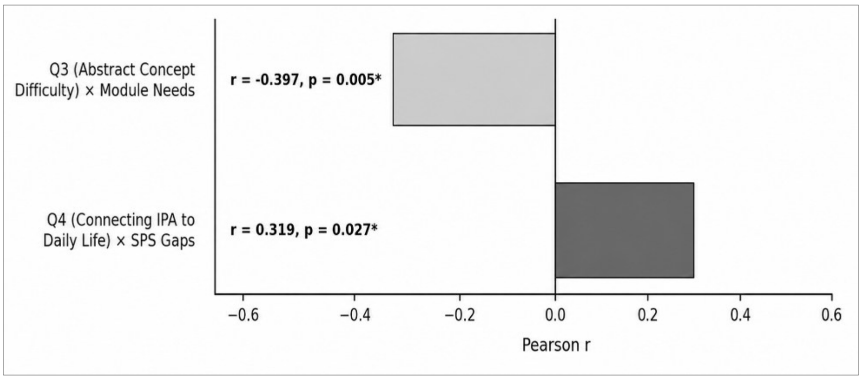

Figure 4. Statistically Significant Item-Level Correlations (*$p < 0.05$)

Q4 (Connecting IPA Concepts to Daily Life) × SPS Gaps: $r = 0.319$, $p = 0.027$. Students who are more capable of relating science to real-world contexts showed greater awareness of existing Science Process Skills gaps, reflecting higher metacognitive awareness. Q3 (Difficulty with Abstract Concepts) × Module Requirements: $r = -0.397$, $p = 0.005$. Students experiencing more difficulty with abstract concepts consistently showed greater perceived need for comprehensive learning modules.

Group Comparison Analysis

The Mann–Whitney U test was used to compare the Science Process Skills needs between two groups of students based on their academic ability (low and high). This test can determine whether students with different academic abilities have different module needs. This information is important to support the development of differentiated inquiry modules, ensuring they can accommodate students with diverse academic abilities. Students were divided into two groups based on the median score of academic ability: low group (n = 40, score ≤ 3.00) and high group (n = 8, score > 3.00). Mann-Whitney U test was applied to compare SPS needs between groups.

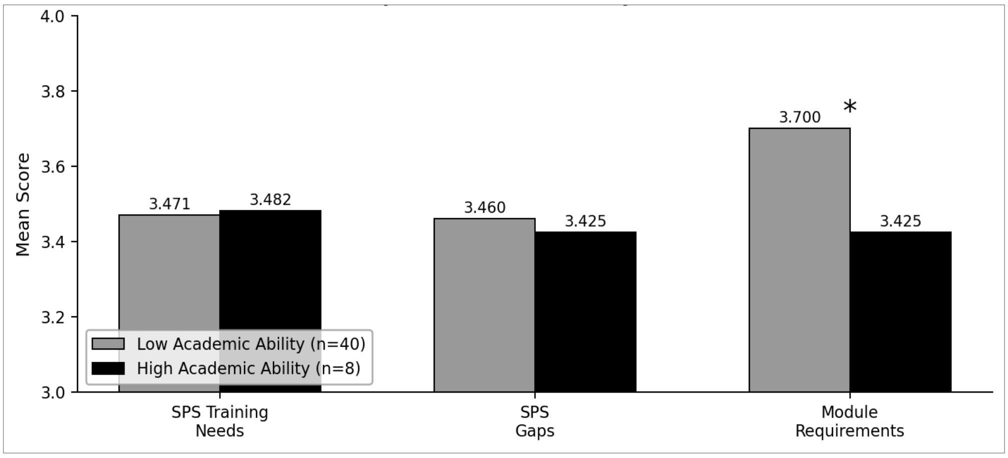

Figure 5. Science Process Skills Need Scores by Academic Ability Group (*p<0.05, Mann-Whitney)

The following are the results of the group comparison analysis using the Mann–Whitney U Test between students with low academic ability (n = 40) and high academic ability (n = 8) across the three dimensions of Science Process Skills needs, as presented in Table 5.

Table 5. Comparison Test Between Students with Low and High Academic Ability Across Three Dimensions of Science Process Skills Needs

SPS Dimension	Low Group (n=40)	High Group (n=8)	p-value (MWU)	Significance
SPS Training Needs	3.471	3.482	0.743	not significant
SPS Gaps	3.460	3.425	0.327	not significant
Module Requirements	3.700	3.425	0.012	*Significant

* p < 0.05 (Mann-Whitney U Test)

Table 5 presents the results of the group comparison analysis using the Mann–Whitney U Test between students with low academic ability (n = 40) and high academic ability (n = 8) across the three dimensions of Science Process Skills needs. Among the three dimensions examined, only the Module Requirements dimension demonstrated a statistically significant difference (p = 0.012). Students in the low academic ability group showed a higher mean score for module requirements (M = 3.700) compared to those in the high academic ability group (M = 3.425), indicating that students with lower academic ability perceived a greater need for structured and comprehensive instructional module support. Meanwhile, no significant differences were identified between the two groups in terms of Science Process Skills Training Needs (p = 0.743) and SPS Gaps (p = 0.327), suggesting that perceptions regarding the importance of science process skills training and awareness of skill gaps were relatively consistent among students regardless of their academic ability levels. These findings emphasize that instructional module design should incorporate differentiated approaches based on students' academic ability, particularly by providing adequate scaffolding for students with lower initial competencies.

Discussion

The findings revealed that the need for Science Process Skills was categorized as very high across all indicators, with scores ranging from 3.29 to 3.69. This finding suggests that pre-service elementary school teacher students perceive a need for further reinforcement in fundamental scientific skills, including observing, classifying, measuring, formulating hypotheses, conducting experiments, interpreting data, and drawing conclusions (García-Carmona et al., 2017; Özer & Sarıbaş, 2023). The consistently high Science Process Skills needs across all student profiles may suggest that students perceive their current learning experiences as providing insufficient opportunities to develop science process skills. However, because instructional practices were not directly examined in this study, this interpretation should be considered with caution (Ngozi, 2021). Theoretically, science process skills develop through scientific inquiry activities involving direct experience, observation, experimentation, and reflection (Ekici & Erdem, 2020; Labouta et al., 2018). Previous studies have reported that lecture-oriented instructional practices are often associated with more limited opportunities for students to develop investigative skills (Shah, 2025). The present study did not directly evaluate instructional practices; however, the relatively low mean score for learning experience ($M = 2.292$) is consistent with students' perceptions of limited exposure to practicum and inquiry-based learning. This finding is consistent with previous studies reporting that teacher-centered instruction limits the development of students' scientific thinking skills because students are rarely engaged in independent inquiry processes (Kang & Keinonen, 2018; Asilevi et al., 2024; Woods & Copur-Gencturk, 2024).

Furthermore, the results demonstrated that module requirements obtained the highest mean score among all SPS dimensions ($M = 3.654$). This finding suggests that students require instructional materials capable of facilitating systematic, contextual, and investigative learning experiences. The high demand for inquiry-based modules can be explained by students' difficulties in understanding abstract scientific concepts. In science education, abstract concepts require visualization, experimentation, and concrete experiences in order to be meaningfully understood (Erduran & Kaya, 2018; Soysal, 2025). Consequently, students tend to require modules that not only provide conceptual explanations, but also incorporate experimental procedures, thinking-trigger questions, reflective activities, and opportunities for scientific reasoning practice. This phenomenon is further supported by the item-level correlation analysis, which revealed that difficulty in understanding abstract concepts was significantly associated with the need for instructional modules ($r = -0.397$, $p = 0.005$). Scientifically, this relationship indicates that the greater the students' difficulty in comprehending abstract concepts, the greater their need for structured learning modules. This finding is highly relevant to constructivist learning theory, which emphasizes that conceptual understanding becomes more effective when students construct knowledge through concrete experiences and exploratory activities (Chengere et al., 2025). The present finding also supports previous studies reporting that inquiry-based modules effectively enhance conceptual understanding and science process skills by providing active and meaningful learning experiences (Arantika et al., 2019; Morokuhi et al., 2025).

Another important finding of this study was the significant relationship between students' ability to connect science concepts to everyday life and their awareness of SPS gaps ($r = 0.319$, $p = 0.027$). This result indicates that students with stronger contextual thinking abilities tend to possess better reflective and evaluative capacities regarding their own competencies. Scientifically, this condition is closely related to students' metacognitive ability to conduct self-assessment of their thinking processes and scientific competencies (Andromeda et al., 2019). Students who are capable of relating scientific concepts to real-life phenomena are more likely to recognize the limitations of their scientific skills because they can compare conceptual knowledge with its practical application in everyday contexts. This finding reinforces constructivist learning theory, which highlights the importance of contextual experiences in fostering meaningful understanding and learning awareness (Gannar & Kilani, 2025). In addition, the findings are consistent with previous research demonstrating that contextual thinking ability positively correlates with metacognitive awareness and scientific problem-solving skills.

This study also found that students with lower academic ability demonstrated significantly higher needs for instructional modules compared to students with higher academic ability ($p = 0.012$). This finding indicates that academic ability influences the extent to which students require instructional support. Scientifically, students with lower academic ability generally experience greater difficulties in organizing information, understanding abstract concepts, and developing independent learning strategies (Cukurova et al., 2017). Therefore, they require stronger scaffolding through systematic and structured learning modules. From Vygotsky's Zone of Proximal Development (ZPD) perspective, students with lower ability levels require external support to achieve higher levels of understanding. Inquiry-based modules equipped with experimental procedures, guided thinking activities, and reflective tasks can function as scaffolding mechanisms that assist students in constructing knowledge progressively (Nurjumiati et al., 2022). This finding supports previous studies indicating that differentiated instruction and structured modules are effective in improving conceptual understanding and science process skills among students with lower academic ability.

In addition, the findings revealed that hypothesis formulation and measurement skills obtained the lowest SPS training need scores ($M = 3.354$), while simultaneously showing high levels of perceived gaps, particularly regarding unfamiliarity with hypothesis formulation ($M = 3.604$). This phenomenon indicates a discrepancy between students' perceived needs and their actual competencies in scientific thinking processes. Scientifically, hypothesis formulation represents a higher-order thinking skill that requires analytical reasoning, prediction, and understanding of variable relationships (Saar et al., 2026). Students' limited ability to formulate hypotheses may stem from instructional practices that emphasize final answers rather than scientific reasoning processes. As a result, students become less accustomed to making scientific predictions or independently designing investigations. This finding highlights the importance of providing more intensive inquiry-based activities to familiarize students with scientific thinking processes involving observation, prediction, experimentation, and evaluation.

In addition, the integration of metacognitive orientation within inquiry-based modules is expected to support students in becoming more reflective and self-regulated learners. Through reflective activities such as self-monitoring, learning evaluation, and strategy adjustment, students may develop greater awareness of their scientific reasoning processes and learning progress (Ghanizadeh, 2016; Hawe et al., 2017). Metacognitive-oriented inquiry learning also provides opportunities for students to evaluate errors, reconsider investigation procedures, and improve problem-solving strategies independently. Therefore, the combination of inquiry activities and metacognitive reflection can create more meaningful and sustainable science learning experiences for pre-service elementary school teachers students.

The findings of this study also provide important implications for the development of science learning modules for pre-service elementary school teachers. The modules should be designed not only to deliver scientific content, but also to facilitate inquiry activities that actively engage students in scientific investigations. In addition, metacognitive components such as reflective questions, self-evaluation sheets, learning journals, and guided reasoning activities should be integrated into the module structure to support students in monitoring and evaluating their own learning processes (Martirosov & Moser, 2021). Such learning experiences are expected to encourage students to become more independent, reflective, and scientifically literate learners.

For pre-service elementary school teachers, the improvement of science process skills is highly important because these competencies will influence their future teaching practices in elementary classrooms. Teachers with adequate science process skills are more likely to implement student-centered and inquiry-oriented science learning in schools (Williams et al., 2017) . Therefore, strengthening Science Process Skills during teacher education programs may contribute not only to students' academic development at the university level but also to the quality of science learning in elementary education in the future.

Overall, the findings of this study demonstrate that the development of inquiry-based instructional modules is essential for improving the science process skills of pre-service science teacher students. The modules developed should not merely focus on content delivery, but should also facilitate experimentation, problem-solving, metacognitive reflection, and the development of scientific reasoning skills. These findings further emphasize that improving SPS cannot be achieved solely through conventional instructional approaches; rather, it requires active, contextual, investigative, and differentiated learning experiences tailored to students' characteristics.

CONCLUSION

This study demonstrated that students enrolled in the Elementary School Teacher Education (PGSD) Program exhibited a very high need for the development of an inquiry-based science module with a metacognitive orientation to enhance their Science Process Skills (SPS). The findings revealed that Module Requirements achieved the highest mean score ($M = 3.654$), whereas Learning Experience recorded the lowest mean score ($M = 2.292$), indicating students' limited exposure to inquiry-based learning experiences. Although no significant relationships were identified between student characteristics and SPS needs at the dimensional level, item-level analysis revealed that students' ability to relate science concepts to everyday life was significantly associated with their awareness of SPS gaps ($r = 0.319$, $p = 0.027$), while difficulties in understanding abstract concepts were significantly associated with an increased need for instructional modules ($r = -0.397$, $p = 0.005$). Furthermore, students with lower academic ability reported significantly greater module requirements than those with higher academic ability ($p = 0.012$). Therefore, the proposed module should systematically integrate inquiry learning syntax, metacognitive activities, structured experimental procedures, contextual science problems, visual representations to support the understanding of abstract concepts, thinking-trigger questions, and differentiated scaffolding tailored to students' academic abilities. These design features are expected to promote more active, reflective, and meaningful learning experiences while effectively enhancing the Science Process Skills of PGSD students.

RECOMMENDATION

Based on the findings of this study, the development of an inquiry-based science module with a metacognitive orientation is recommended for implementation in science learning for pre-service elementary school teachers students in order to improve science process skills through more active, reflective, and meaningful learning experiences. Future studies are recommended to continue the module development process through validity, practicality, and effectiveness testing on a broader scale, as well as to integrate digital media to support students' inquiry and metacognitive activities. However, a limitation of this study is the use of questionnaires as the primary research instrument, which may lead to subjectivity in participants' responses. Therefore, future research should employ more diverse data collection methods to obtain more comprehensive and accurate findings.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Syahriani Yulianci	√	√	√	√	√	√		√	√	√			√	√
Nurjumiati		√	√					√	√		√			
Baiq Dina Hardianti				√			√			√				

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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