Journal of Natural Science and Integration
P-ISSN: 2620-4967|E-ISSN: 2620-5092
Vol. 9, No. 1, April 2026, pp 25-37

Available online at:
http://ejournal.uin-suska.ac.id/index.php/JNSI
DOI: 10.24014/jnsi.v9i1.39232

Mapping Science Process Skills in Biology: A Study on Digestive System Learning

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ABSTRACT
Science process skills (SPS) play a crucial role in fostering students' scientific reasoning, inquiry abilities, and conceptual understanding in biology. However, SPS development can be inconsistent across indicators, largely due to variations in instructional practices and learning environments. This study examined students' SPS within the context of the digestive system topic and identified the factors that influence their development. The researchers used a cross-sectional survey design involving 114 Grade 11 science students from three public schools in South Tangerang City, Indonesia, selected through purposive sampling. The researchers collect data through SPS tests and teacher interviews and analyze it descriptively using percentage scores and performance categories. The results showed that overall SPS achievement was in the good category (77%). Performance varies across indicators: predicting (89%), questioning (88%), and hypothesizing (85%) fall into the very good category; classifying (68%) and interpreting (71%) fall into the good category; and communicating (60%) emerges as the weakest indicator. Interviews with teachers indicated that the limited application of inquiry-based learning, coupled with restricted instructional time, has led to inconsistent development of students' Scientific Process Skills (SPS). These findings underscore the considerable impact that instructional design and classroom practices have on SPS outcomes. Therefore, educators need to apply more structured inquiry-based learning and provide explicit training in scientific communication and data interpretation to achieve balanced SPS development.

Keywords: *science process skills; biology learning; inquiry-based learning, digestive system.*

INTRODUCTION

As science and technology rapidly advance in the twenty-first century, students need to develop higher-order thinking skills and scientific competencies to address complex real-world problems. Education should enhance students' ability to engage in scientific practices by using science process skills (SPS). Additionally, students must build a strong foundation in factual, conceptual, and procedural knowledge in science, particularly in biology, during their secondary school education. Science process skills (SPS) underpin critical thinking and problem-solving in science education and include observing, predicting, hypothesizing, interpreting data, and communicating scientific findings (Damopolii et al., 2018; Maryanto et al., 2026).

From a theoretical perspective, constructivist and inquiry-oriented approaches to science education highlight the significance of science process skills (SPS). These approaches empower students to actively construct knowledge by participating in authentic inquiry activities that include questioning, investigating, interpreting data, and drawing evidence-based conclusions. Contemporary research in science education indicates that these practices are crucial for fostering a deep understanding of concepts and enhancing scientific reasoning (Alarcon et al., 2023). Inquiry-based and student-centered instructional strategies are empirically linked to enhanced SPS development, as these approaches provide structured opportunities for learners to engage in scientific thinking and practice (Kassaye et al., 2025). At the international policy level, the Organization for Economic Co-operation and Development (OECD)'s PISA 2025 Science Framework emphasizes science competencies that involve constructing and evaluating scientific inquiry and interpreting evidence for informed decision-making, positioning these skills as essential educational outcomes rather than peripheral objectives (OECD, 2025). Together, these theoretical and policy perspectives underscore that SPS are not merely supplemental cognitive activities but central outcomes of modern science education that prepare students for complex problem-solving and scientific literacy in the 21st century (Kassaye et al., 2025).

As a result, it is essential that any effective science curriculum includes structured opportunities for inquiry-based and investigative learning experiences that specifically focus on training. Researchers have demonstrated that a variety of teaching strategies, including inquiry-based learning, guided inquiry, and problem-based learning, aid in the development of SPS in biology and general science contexts (Damopolii et al., 2018; Handayani et al., 2016; Sinta & Agustina, 2024). In addition, accurately measuring SPS achievement also depends on the development of valid and trustworthy assessment tools, especially for biology subjects such as the digestive system (Habibah & Fuadiyah, 2025), because assessment practices directly influence how students engage with scientific competencies.

Though many studies show that certain learning models can raise SPS, most focus on the efficacy of interventions rather than on mapping students' preexisting SPS profiles in specific biology subject areas. For instance, structured laboratory exercises support gains in students' observation and data analysis abilities (Atikah & Haryanto, 2025), and guided inquiry and problem-based learning have been found to improve SPS performance (Hartati et al., 2022; Sinta & Agustina, 2024). However, empirical data still do not adequately describe the baseline distribution of students' SPS and the specific strengths and weaknesses of students' SPS across biology topics at the senior high school level, despite evidence that pedagogical innovation can improve SPS.

Despite growing research on Science Process Skills (SPS), a significant gap remains in understanding students' SPS achievement in specific biological contexts. This gap is important because designing focused instructional interventions requires knowing which SPS indicators are strong and which remain weak. Without this insight, efforts to improve instruction risk being generic and less effective. Moreover, few studies have contextualized SPS within complex biological systems, such as the digestive system, where conceptual understanding and process skills are closely intertwined. Most existing research treats SPS as a general construct across science subjects, rather than examining how SPS manifests in specific content areas. Addressing this gap is essential for developing targeted strategies that effectively enhance both conceptual knowledge and scientific skills.

Because the digestive system involves the observation of organ structures, the interpretation of functional mechanisms, the study of biological processes, and the explanation of cause-and-effect relationships supported by empirical evidence, it provides a strong and relevant context for SPS analysis. Its integrative nature enables researchers to examine multiple SPS indicators simultaneously. Thus, the choice of this subject is conceptually justified, as it is a field of study in which scientific methods and conceptual reasoning must work together in an integrated manner.

This study does not intend to evaluate the efficacy of a certain teaching model based on the detected gap. Rather, it aims to offer an empirical analysis of senior high school students' achievement of science process skills in the digestive system topic. Creating a comprehensive SPS achievement profile across specific skill indicators, recognizing patterns of strengths and weaknesses within a biological content area, and offering evidence-based suggestions for more focused instructional design in biology learning are the three main contributions of this study. This study provides the fundamental information required for upcoming intervention-based research and curriculum improvement initiatives by clarifying the current status of students' SPS.

In addition to instructional approaches, the development of science process skills (SPS) is also closely related to how these skills are assessed and explicitly integrated into classroom practice. Assessment plays a critical role in shaping students' engagement with scientific processes, as it signals which competencies educators value in learning (Habibah & Fuadiyah, 2025). When assessment focuses primarily on factual recall and conceptual understanding, students may have limited opportunities to demonstrate and develop higher-order SPS such as interpreting data and communicating scientific arguments. Conversely, well-designed SPS assessments particularly those that require explanation, reasoning, and evidence-based responses can encourage deeper engagement with scientific inquiry processes. Educators must align assessment practices with instructional goals to ensure that they not only teach SPS but also consistently evaluate them. Previous research emphasizes that valid and reliable SPS instruments are essential for accurately capturing students' competencies and guiding instructional improvement (Habibah & Fuadiyah, 2025).

Furthermore, educators cannot separate the integration of SPS into biology learning from laboratory activities and hands-on experiences. Practical work provides authentic contexts for students to observe, classify, predict, and interpret phenomena, thereby strengthening the connection between conceptual knowledge and scientific practice (Atikah & Haryanto, 2025). However, the effectiveness of laboratory activities depends on how well they are structured and guided. Without clear inquiry-oriented objectives, laboratory work may become procedural rather than investigative, limiting its contribution to SPS development. Research shows that structured laboratory experiences and guided inquiry activities significantly enhance students' ability to analyze data and draw conclusions (Chengere et al., 2025). These findings suggest that the quality of implementation, rather than the mere presence of practical activities, determines the impact of laboratory and inquiry activities on students' SPS.

Another important factor influencing SPS development is the alignment between students' cognitive abilities and the complexity of learning tasks. Scientific reasoning, reading comprehension, and analytical thinking are crucial for enabling students to engage effectively in scientific inquiry (Schlatter et al., 2021). When learning tasks exceed students' cognitive readiness, they may struggle to interpret data or construct scientific explanations, even if they can perform basic observational tasks. This pattern indicates that SPS development requires not only appropriate instructional strategies but also careful consideration of students' cognitive levels. Differentiated instruction, which adapts learning tasks to students' readiness, has been shown to improve both critical thinking and SPS by providing more accessible and meaningful learning experiences (Ramlawati et al., 2025). Therefore, understanding students' baseline SPS is essential for designing instruction that is both challenging and achievable.

In the context of biology education, particularly in topics such as the digestive system, integrating SPS becomes even more critical given the complexity of the concepts involved. The digestive system requires students to understand dynamic processes, interactions among organs, and cause-and-effect relationships supported by scientific evidence. These characteristics demand not only conceptual understanding but also the ability to interpret data, construct explanations, and communicate findings effectively. However, as previous studies indicate, students often struggle to connect abstract biological concepts with empirical evidence, especially when instruction does not explicitly emphasize SPS (Novitasari et al., 2023). These findings highlight the importance of examining how SPS distribute across indicators within specific biological contexts.

Moreover, teacher-related factors play a significant role in shaping SPS development. Teachers act as facilitators of scientific inquiry, and their ability to design learning activities, guide discussions, and model scientific reasoning directly influences students' engagement with SPS. Studies show that teacher professionalism and competence in scientific communication significantly affect students' SPS outcomes (Qodriyani et al., 2020). When teachers lack confidence or experience in facilitating inquiry-based learning or scientific argumentation, students may receive limited opportunities to develop these skills. These conditions suggest that improving SPS is not solely a matter of student ability but also requires strengthening teachers' pedagogical and professional competencies.

Taken together, these considerations highlight that multiple interconnected factors, including assessment practices, instructional design, laboratory implementation, cognitive readiness, and teacher competence, influence SPS development. Despite the growing body of research on SPS, there remains a need for empirical studies that map students' SPS profiles across specific biological topics and classroom contexts. Such studies can provide valuable baseline data to inform more targeted instructional interventions and support the development of balanced and comprehensive scientific competencies. Therefore, this study seeks to address this need by providing a detailed analysis of students' SPS in the digestive system topic, contributing to a more context-sensitive understanding of science learning in secondary education.

METHODOLOGY

This study employed a quantitative descriptive design using a cross-sectional survey approach to examine students' science process skills (SPS) in the digestive system topic. Cross-sectional surveys capture data from a defined population at a single point in time without manipulation, providing a snapshot of current achievement. Data were collected once during the odd semester of the 2024/2025 academic year, after students had completed the digestive system unit. No instructional intervention or follow-up measurement was conducted, so the focus was solely on describing existing SPS levels and distribution.

The population consisted of all Grade 11 science-track students in 12 public senior high schools in South Tangerang City with accreditation A, totaling approximately 1,248 students. All schools implement the Merdeka Curriculum, follow the same nationally standardized biology syllabus, and allocate similar instructional time for the digestive system topic, minimizing curricular differences. Inclusion criteria required that students be enrolled in Grade 11 science-track classes, have completed the digestive system unit, be present during data collection, and provide informed consent. Students absent during data collection or who had not studied the topic were excluded.

A purposive sampling technique selected three schools and one intact class per school based on curriculum implementation, laboratory facilities, demographic similarity, and accessibility for research approval. The final sample consisted of 114 students: 38 from SMAN 1, 36 from SMAN 8, and 40 from SMAN 11. Although purposive sampling enhances contextual representativeness, it limits statistical generalizability; therefore, findings primarily reflect schools with similar characteristics. Three schools were considered sufficient for a descriptive cross-sectional survey, as the study aimed to profile SPS achievement rather than make population-level inferences or conduct group comparisons.

Data were collected using an essay-based SPS test covering six indicators: grouping, predicting, questioning, hypothesizing, communicating, and interpreting. Content validity was assessed by three biology education experts using Aiken's V index ($V > 0.80$), and construct validity was evaluated through item discrimination analysis using ANATES software (minimum discrimination index ≥ 0.30). Internal consistency reliability, measured with Cronbach's Alpha, was $\alpha = 0.79$, indicating acceptable reliability.

To complement the survey, three biology teachers (one per school) were interviewed using a semi-structured protocol. Interviews explored classroom implementation of SPS, instructional constraints, and contextual factors influencing student achievement. Interview data were analyzed descriptively and used for triangulation to provide contextual interpretation rather than comparative analysis.

Quantitative data were analyzed descriptively. Student responses were scored with an analytic rubric aligned with SPS indicators, converted to percentages (obtained score ÷ maximum score × 100), and the mean percentage per indicator was calculated. SPS achievement was categorized as: 81–100% (very good), 61–80% (good), 41–60% (sufficient), 21–40% (poor), and 0–20% (very poor). No inferential statistics were conducted, consistent with the study's aim of profiling SPS achievement. Data processing was performed in Microsoft Excel 2021, with ANATES software used for item analysis.

This study conforms to the characteristics of a cross-sectional survey, as it collected data at a single time point without intervention, focused on profiling existing conditions, and employed descriptive analysis. By integrating quantitative SPS measurement with teacher interviews, the research provides a concise yet comprehensive snapshot of students' science process skills and the classroom context, offering foundational data for future instructional improvement or experimental research.

RESULT AND DISCUSSION

This study aimed to describe the achievement of science process skills (SPS) among Grade 11 science students of public senior high schools in South Tangerang City on the topic of the digestive system. The primary data were obtained through an essay-based science process skills test, while teacher interviews were used as supporting data to strengthen the interpretation of the findings.

Science Process Skills Achievement Based on Score Categories

The results of the science process skills test were categorized into three levels: high, moderate, and low. The distribution of SPS score categories in each school is presented in Table 1.

Table 1. Distribution of Students' Science Process Skills Score Categories

School	High (80–100)	Moderate (60–79)	Low (0–59)	Mean Score
	Percentage	Percentage	Percentage	Percentage
SMAN 1	37	63	0	79,52
SMAN 8	19	69	12	67,16
SMAN 11	45	48	7	76,89
Total	34	60	6	74.52

Based on Table 1, the majority of students were in the moderate category (60% of the total sample). The highest proportion of students in the high category was found at SMAN 11 (45%), while the highest proportion in the low category was at SMAN 8 (12%). Overall, the mean science process skills score of students from the three schools was 74.52, which falls into the good category.

Science Process Skills Achievement Based on Indicators in Each School

Further analysis was conducted based on the achievement of each SPS indicator in each school in Table 2.

Table 2. Science Process Skills Achievement of Students at SMAN 1 South Tangerang

SPS Indicator	Mean (%)	Category
Classifying	75	Good
Predicting	89	Very Good
Questioning	91	Very Good
Hypothesizing	83	Very Good
Communicating	65	Good
Interpreting	75	Good
Overall Mean	80	Good

At SMAN 1 South Tangerang, questioning showed the highest achievement (91%), while communicating had the lowest (65%). The overall average was categorized as good.

Table 3. Science Process Skills Achievement of Students at SMAN 8 South Tangerang

SPS Indicator	Mean	Category
Classifying	64	Good
Predicting	81	Very Good
Questioning	79	Good
Hypothesizing	77	Good
Communicating	51	Sufficient
Interpreting	59	Sufficient
Overall Mean	69	Good

Based on Table 3, at SMAN 8 South Tangerang, predicting had the highest achievement (81%), while communicating was the lowest (51%). Nevertheless, the overall mean remained in the good category.

Table 4. Science Process Skills Achievement of Students at SMAN 11 South Tangerang

SPS Indicator	Mean (%)	Category
Classifying	66	Good
Predicting	98	Very Good
Questioning	93	Very Good
Hypothesizing	96	Very Good
Communicating	64	Good
Interpreting	79	Good
Overall Mean	83	Very Good

Based on Table 4, SMAN 11 South Tangerang demonstrated the highest SPS achievement among the three schools, with an overall mean of 83% (very good). Predicting had the highest score (98%), while communicating had the lowest (64%).

Overall Science Process Skills Achievement Based on Indicators

A comparison of SPS achievement across all schools is presented in Table 5.

Table 5. Average Students' Science Process Skills Based on Indicators

SPS Indicator	SMAN 1 (%)	SMAN 8 (%)	SMAN 11 (%)	Mean (%)	Category
Classifying	75	64	66	68	Good
Predicting	89	81	98	89	Very Good
Questioning	91	79	93	88	Very Good
Hypothesizing	83	77	96	85	Very Good
Communicating	65	51	64	60	Sufficient
Interpreting	75	59	79	71	Good
Overall Mean	80	69	83	77	Good

Based on Table 5, predicting, questioning, and hypothesizing achieved the highest level (very good). In contrast, communicating had the lowest achievement (fair category). Overall, students' science process skills in the digestive system topic were categorized as good, with an average of 77%.

To provide a more detailed understanding of students' science process skills (SPS), Table 6 presents the mean achievement, relative strengths and weaknesses, and pedagogical implications of each SPS indicator.

Table 6. Indicator-specific Science Process Skills (SPS) Achievement and Implications

SPS Indicator	Mean Achievement (%)	Strength / Weakness	Pedagogical Implication
Predicting	89	Strong	Students can use patterns and prior knowledge to anticipate outcomes; aligns with inquiry-based learning.
Questioning	88	Strong	High curiosity and engagement; foundation for exploration and problem-solving.
Hypothesizing	85	Strong	Ability to generate evidence-based predictions; reflects active reasoning.
Interpreting	71	Moderate	Students can draw conclusions but struggle with integrating complex data; requires scaffolded data analysis exercises.
Classifying	68	Moderate	Able to identify similarities and differences but sometimes misinterpret features; more exploratory tasks needed.
Communicating	60	Weak	Difficulty in expressing scientific findings; highlights need for structured argumentation and data presentation activities.

Teacher Interview Results as Supporting Data

Interviews with biology teachers indicate that the three schools have implemented student-oriented learning models, such as problem-based and inquiry-based learning, as well as discussion methods. Teachers stated that they have attempted to implement science process skills in their lessons, particularly the indicators of observing, questioning, communicating, and interpreting. However, not all science process skill indicators are optimally demonstrated in every learning session. This finding aligns with test results, which showed that communication indicators had the lowest achievement compared to other indicators.

Discussion

The findings show that students generally demonstrate good science process skills (SPS) in the digestive system topic (M = 77%), yet considerable variation emerges across indicators. Such variation shows that SPS does not function as a single, unified construct; instead, SPS operates as a multidimensional set of competencies that develop at different rates depending on instructional exposure and task demands. Previous studies report a similar pattern and highlight variability in SPS achievement across skill domains despite overall satisfactory performance (Jannah et al., 2024; Tanti et al., 2020). This finding aligns with evidence that SPS varies across indicators such as predicting, interpreting, and communicating, even when overall performance remains moderate (Qodriyani et al., 2020).

Variations in SPS across indicators also reflect differences in students' cognitive readiness, which influences how effectively students engage in different types of scientific tasks. Differentiated inquiry learning improves SPS when teachers align instructional tasks with students' cognitive levels and learning readiness (Ramlawati et al., 2025). Students demonstrate basic scientific abilities, yet they have not achieved integrated mastery across SPS components. Cognitive factors such as reading comprehension and reasoning likely contribute to this condition because these skills support scientific problem-solving (Schlatter et al., 2021). Teacher interview data support this interpretation, as students can follow experimental procedures but struggle to articulate scientific reasoning. This condition aligns with findings that students develop inquiry skills gradually and strongly depend on lesson design and instructional sequencing (Chaerunisa et al., 2023).

Predicting, questioning, and hypothesizing emerge as the strongest SPS indicators across schools. These competencies closely align with inquiry-based learning environments that emphasize active knowledge construction. Inquiry-based Learning consistently acts as a catalyst for SPS development when teachers implement structured guidance and ensure active engagement (Muzafar & Ahmad, 2025). Teachers report that inquiry activities increase students' confidence in generating predictions and formulating questions during discussions. Project-Based Learning (PjBL) strengthens SPS when it engages students in authentic inquiry processes that require knowledge construction and contextual problem-solving (Susilawati et al., 2024). Guided inquiry, combined with instructional media, significantly improves SPS by providing structured scaffolding that supports conceptual understanding and experimental reasoning (Syafrilianto et al., 2024). Sufriyah et al. (2025) further demonstrate that guided inquiry significantly improves SPS in biotechnology learning, and they find that communication reaches its highest level when teachers consistently apply structured inquiry stages. Open inquiry approaches also enhance SPS when they give students greater autonomy, although success depends on learner readiness and balanced instructional support (Romadhona & Suyanto, 2020). In addition, experimental evidence indicates that guided inquiry-based laboratory instruction significantly enhances SPS by actively engaging students in hypothesizing, experimenting, and drawing conclusions, compared to traditional instruction (Chengere et al., 2025).

Classifying skills show moderate achievement, indicating that students group objects based on observable characteristics but struggle when classification requires deeper conceptual reasoning. Teachers report that students classify based on obvious features but struggle when the conceptual criteria become more complex. Previous studies show that classification skills improve when teachers explicitly integrate conceptual reasoning rather than relying solely on surface features (Pakaya et al., 2023). Guided inquiry supports this development by structuring learning steps that help students organize scientific information more systematically (Syafrilianto et al., 2024). Project-Based Learning also strengthens classification skills by engaging students in sustained problem-solving and knowledge organization (Susilawati et al., 2024). Chaerunisa et al. (2023) further emphasize that inquiry-based lesson design plays a central role in shaping students' progression of inquiry skills across different cognitive levels.

Interpreting skills develop at a moderate level but remain weaker than predicting and questioning skills. Students identify patterns in data but struggle to integrate observations with biological concepts to construct meaning. Teacher interviews indicate that students often need step-by-step guidance when they interpret graphs or experimental results. Prior research confirms that students require structured scaffolding and repeated analytical practice to develop interpretation skills effectively (Fikriyah & Ahied, 2020; Novitasari et al., 2023). Guided inquiry strengthens interpretation skills by guiding students to analyze, reflect, and connect data with conceptual understanding through structured learning sequences (Syafrilianto et al., 2024)). Chaerunisa et al. (2023) also highlight that inquiry-based laboratory design supports gradual improvement in students' inquiry skills, particularly in data analysis and interpretation.

Communication skills represent the weakest SPS indicator across all schools. Teachers report that students understand the material but struggle to express it clearly in written reports and oral discussions. Students construct tables and graphs at a sufficient level. However, Akbar et al. (2023) show that the relationship between table construction and graphing remains weak, which indicates limited integration between data representation and conceptual explanation. Their findings also show that table-making accounts for only a small proportion of the variation in graph-construction ability, confirming that teachers must teach scientific communication explicitly rather than assume it develops naturally. Sufriyah et al. (2025) demonstrate that guided inquiry significantly improves communication when teachers implement structured scaffolding, although communication remains weak without systematic instructional design. Romadhona & Suyanto (2020) further show that open inquiry improves communication more effectively when students receive sufficient autonomy, although outcomes depend on readiness and instructional balance. Inquiry-based learning functions as a catalyst for SPS development when teachers implement it systematically (Muzafar & Ahmad, 2025). Chengere et al. (2025) further confirm that guided inquiry laboratory activities significantly enhance students' ability to communicate scientific findings through explanation, argumentation, and conclusion drawing. Qodriyani et al. (2020) also report that communication tends to be among the stronger SPS aspects when teachers demonstrate high professionalism and explicitly facilitate students' scientific expression.

The uneven distribution of SPS across indicators reflects instructional design and classroom implementation practices. Science instruction emphasizes basic skills, such as observing and questioning, more strongly, while higher-order skills, such as interpreting and communicating, receive less systematic attention (Pakaya et al., 2023). Teacher interviews indicate that time limitations and lesson structure restrict SPS integration because teachers cannot address all indicators in every learning session. Differentiated inquiry learning improves SPS when teachers adapt tasks to student readiness (Ramlawati et al., 2025), while guided inquiry strengthens SPS when teachers use structured media and consistent scaffolding (Syafrilianto et al., 2024). These findings show that SPS development depends not only on instructional approach but also on implementation consistency.

Inquiry- and problem-based learning approaches provide effective strategies for SPS development, but teachers must implement them consistently and systematically. Teachers report that they use inquiry-based learning, but classroom constraints often prevent full implementation. Empirical evidence confirms that structured inquiry learning and practical activities significantly improve SPS when teachers apply them consistently (Apeadido et al., 2024; Kassaye et al., 2025; Pozuelo-Muñoz et al., 2023). Guided inquiry significantly improves SPS compared to conventional instruction when teachers implement it effectively (Syafrilianto et al., 2024). In contrast, Inquiry-based Learning catalyzes SPS development when teachers design learning systematically (Muzafar & Ahmad, 2025). Chengere et al. (2025) further support the claim that structured, laboratory-based inquiry produces strong empirical gains in SPS compared to traditional instruction.

From a broader perspective, SPS development closely aligns with scientific literacy because it integrates knowledge, reasoning, and inquiry. Scientific literacy-based learning improves students' conceptual understanding and critical thinking skills (Rizalia et al., 2025). OECD (2025) frameworks emphasize scientific reasoning and inquiry as core competencies for 21st-century learners. Project-Based Learning strengthens scientific literacy by integrating inquiry, reasoning, and collaborative problem-solving (Susilawati et al., 2024). Therefore, SPS functions not only as isolated learning outcomes but also as a foundation of scientific literacy development.

Teacher-related factors also influence SPS development, especially in scientific communication. Previous studies show that many teachers struggle with scientific writing and academic communication (Admoko et al., 2021), which, in turn, affects how students develop these competencies. Qodriyani et al. (2020) confirm that teacher professionalism significantly influences students' SPS achievement, particularly in communication and data interpretation skills. Teachers shape students' communication and reasoning skills by modeling scientific discourse in classroom practice.

Overall, students demonstrate generally good SPS, but their development remains uneven across indicators. Students show stronger performance in predicting, questioning, and hypothesizing, while communication and interpretation remain weaker. However, evidence from guided inquiry, open inquiry, differentiated instruction, laboratory-based inquiry, and Project-Based Learning shows that SPS improves significantly when teachers design instruction systematically, provide scaffolding, and align tasks with student readiness (Chengere et al., 2025; Muzafar & Ahmad, 2025; Ramlawati et al., 2025; Romadhona & Suyanto, 2020; Sufriyah et al., 2025; Syafrilianto et al., 2024). This finding reinforces that SPS outcomes depend strongly on instructional design quality and require integrated development rather than fragmented skill instruction.

This study contributes to the existing literature by offering a context-specific mapping of science process skills (SPS) within a particular biological topic, namely the digestive system, rather than treating SPS as a general construct across science subjects. Unlike prior studies that primarily focus on the effectiveness of instructional interventions, this research provides a baseline empirical profile of SPS distribution across indicators in a real classroom setting. The novelty lies in integrating indicator-level analysis with contextual biological content, revealing how specific scientific skills manifest differently within complex conceptual domains. This approach allows for a more nuanced understanding of SPS development. It highlights that students' competencies are shaped not only by pedagogical models but also by the cognitive demands of specific subject matter.

The findings of this study have important implications for both instructional practice and science education theory. In practice, identifying communication and interpretation as the weakest SPS indicators suggests that teachers need to design more targeted learning activities, such as structured scientific writing tasks, argumentation exercises, and scaffolding for data interpretation. Integrating these elements into inquiry-based learning helps ensure that teachers develop all SPS components more evenly. Theoretically, the study reinforces the view that SPS is a multidimensional construct influenced by instructional design, cognitive readiness, and content complexity. It supports the argument that effective SPS development requires not only inquiry-based approaches but also deliberate alignment between learning objectives, assessment strategies, and classroom practices.

Although this study provides valuable insights, it has several limitations that we should acknowledge. First, purposive sampling limits the generalizability of the findings, as the sample comprises only three public senior high schools with relatively similar characteristics. Second, the cross-sectional design captures SPS at a single point in time, preventing analysis of students' skill development over time or causal relationships between instructional practices and SPS outcomes. Third, the reliance on essay-based assessments may not fully capture all dimensions of SPS, particularly practical and performance-based skills that emerge during laboratory activities. Additionally, the study used teacher interview data primarily for descriptive support rather than for in-depth qualitative analysis, which may limit the depth of contextual interpretation.

Future research should extend this work by employing longitudinal or experimental designs to examine how different instructional interventions influence the development of SPS over time. Studies could also explore integrating performance-based assessments, such as laboratory observations and project-based evaluations, to provide a more comprehensive measure of SPS. Expanding the research to diverse school contexts, including private schools or schools with varying accreditation levels, would enhance the generalizability of findings. Furthermore, future studies may investigate the relationship between SPS and other variables, such as scientific literacy, critical thinking, and metacognitive skills, to better understand how these competencies interact in biology learning. Finally, intervention-based research focusing specifically on improving communication and interpretation skills would be particularly valuable, given that these indicators consistently emerge as areas of weakness.

CONCLUSION

This study concludes that students' science process skills (SPS) in the digestive system topic are generally in the good category, but remain unevenly developed across indicators. Skills related to inquiry processes, such as predicting (89%), questioning (88%), and hypothesizing (85%), are relatively well developed, while communication (60%) and interpretation (71%) represent the weakest components. This imbalance reflects the influence of instructional practices and the partial implementation of inquiry-based learning, as supported by teacher interview data indicating limitations in time allocation and incomplete coverage of SPS indicators in classroom practice. The overall mean SPS score of 77% further confirms that although students demonstrate adequate scientific competence, there is a substantial gap of nearly 29 percentage points between the strongest and weakest indicators. These findings emphasize the need for more systematic, structured inquiry-based instruction, explicit scaffolding in scientific communication and data interpretation, and better alignment between learning activities and SPS indicators to achieve more balanced, integrated skill development in biology learning.

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