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PROFILING GRADE STUDENTS' SCIENCE PROCESS SKILLS IN LEARNING INHERITANCE OF TRAITS

Alfiatun Nikmah*, Endah Rita Sulistya Dewi, M. Syaipul Hayat
Program Studi Magister Pendidikan IPA, Program Pascasarjana, Universitas PGRI Semarang Jl. Sidodadi Timur Nomor 24 – Dr. Cipto, Karangtempel, Semarang Timur, Jawa Tengah
**Corresponding author:alfiumuhakiim@gmail.com*

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ABSTRACT

This study aims to investigate and comprehensively describe the profile of Science Process Skills (SPS) among grade XII students in the biology material on Inheritance of Traits at SMA Negeri 1 Ngawen. The study uses a quantitative approach, employing the Research and Development (R&D) method and adapting the ADDIE development model. Quantitative data collection was carried out through tests using SPS assessment instruments in the form of structured essay questions that include 6 main indicators: observing, classifying, predicting, measuring and using numbers, concluding, and communicating. The results of data analysis show a very uneven distribution of students' SPS abilities: only 1.47% of students are included in the "good" category, 19.12% are categorized as "sufficient", 20.59% are categorized as "less", and the absolute majority of 58.82% are in the "very less" category. Cumulatively, the average student KPS score was 41.67% (very poor). This finding underscores the need for a radical reconstruction of biology learning strategies by shifting toward a scientific approach integrated with the STEAM framework to boost students' scientific investigation skills.

INTRODUCTION

Science education, particularly biology at the senior high school level, should ideally transcend the mere transmission of factual knowledge, rote memorization of Latin terminology, and passive acceptance of theoretical laws (Siwi, 2019). Authentic science learning must be design-driven to embody the genuine nature of scientific inquiry, which fundamentally integrates three interconnected dimensions: scientific attitudes, core conceptual understanding, and Science Process Skills (SPS) (Trianto, 2014). Within the current Merdeka Curriculum framework, the pedagogical paradigm has fundamentally shifted toward student-centered learning. Students are no longer positioned as passive consumers of scientific information but rather as active discoverers of concepts. Through a well-structured scientific approach, the learning process must be anchored in real-world phenomena that can be logically reasoned. This stimulates intensive educational interactions, fosters analytical thinking, and nurtures objective, rational thought processes among learners (Nuzulia et al., 2017).

Science Process Skills represent the core cognitive and psychomotor competencies that bridge theoretical principles and empirical verification (Supratman & Ramdhayani, 2022). SPS can be defined as a set of transferable, intellectual abilities and practical tools that scientists use to conduct systematic investigations, construct valid concepts, and formulate scientific laws based on empirical evidence (Sulistiyono, 2020). Cultivating SPS in students is tantamount to providing them with the opportunity to experience science firsthand through experimental engagement—learning by doing—rather than simply listening to abstract verbal explanations (Ahmad Syafi'i & Darnaningsih, 2025). Scientific activities such as observing anomalies, classifying natural objects, predicting outcomes, manipulating experimental variables, and drawing conclusions are vital to establishing meaningful biology education. When students are explicitly trained in SPS, their critical thinking capacities and real-world problem-solving skills are accelerated, preparing them to navigate socio-scientific issues in modern society (Verawati et al., 2021).

The Science Skills (SPS) encompasses cognitive and investigative skills, as well as an understanding of the methods and procedures used in scientific research. These skills must be used to gather information, conduct experiments, write observation notes, analyze data, and interpret research results (Hariandi, Sahala Sitompul, et al., 2023). SPS is a competency that students must master and implement through physical and mental activities to achieve more effective science learning (Maison et al., 2019).

Despite its theoretical and curricular significance, a stark discrepancy is frequently observed between the normative goals of the national curriculum and the actual classroom practices. A preliminary study and systematic observation conducted at SMA Negeri 1

Ngawen revealed that biology instruction remains predominantly traditional and teacher-centered. Instructional delivery primarily focuses on covering textual content to meet high-stakes examination standards. Although the school has provided digital infrastructure, including liquid crystal display (LCD) projectors, and has permitted the educational use of smartphones, these technologies are limited to projecting static PowerPoint presentations or displaying textbook passages on digital screens. Learning activities are rarely designed to stimulate or scaffold students' SPS indicators. Consequently, students exhibit passive classroom behavior, low responsiveness to conceptual prompts, and a noticeable lack of initiative in asking critical questions. When tasked with completing student worksheets, they require highly detailed, repetitive instructions to formulate simple hypotheses, process basic quantitative data, or present their group findings.

One of the most cognitively demanding topics in the Grade XII biology curriculum is the concept of the Inheritance of Traits, which encompasses Mendelian genetics, non-Mendelian extensions, and chromosomal anomalies. This topic is inherently abstract, dense with allelic symbolism, probabilistic calculations, and microscopic mechanisms of cellular division. Ironically, the topic of trait inheritance offers vast opportunities for students to engage in scientific inquiry. It allows them to observe phenotypic variations in their surrounding environment, formulate predictive genotypes, model mock genetic crosses, compute phenotypic ratios, and deduce hereditary laws. If this highly investigative topic is delivered through conventional, verbalistic, and passive methods, students' cognitive potential and interest are constrained. Low SPS in genetics learning not only impairs conceptual understanding but also induces systemic stagnation in students' overall scientific competencies, ultimately diminishing their ability to solve real-world science-based problems.

Recognizing the severity of this educational issue, an empirical investigation is vital to map the precise SPS profile of students before designing curricular interventions. Following an initial data dissemination meeting at SMA Negeri 1 Ngawen, a professional learning community comprising five biology teachers established a shared awareness. The low performance of students was not attributed to an inherent cognitive deficit, but to a direct outcome of an instructional ecosystem that fails to provide sufficient avenues for active scientific exploration. In this forum, four biology teachers strongly agreed that an immediate, radical restructuring of instruction was imperative. Furthermore, three of these four teachers explicitly emphasized that the primary focus of educational remediation must be to shift classroom delivery from informative lecturing to an inquiry-based model.

The proposed pedagogical alternative to address this problem is to integrate a scientific approach into the Science, Technology, Engineering, Art, and Mathematics (STEAM) framework. The scientific approach establishes a chronological sequence of inquiry—observing, questioning, gathering information, associating, and communicating—which directly aligns with the operational indicators of SPS (Dewi et al., 2023; Hariandi, Sitompul, et al., 2023). To enrich this inquiry process within a modern educational context, the scientific approach can be enhanced by the interdisciplinary dimensions of STEAM. The distinguishing feature of this integration is the purposeful incorporation of Technology (utilizing computational models or virtual genetic simulators), Engineering (designing physical models of genetic crosses), and Art (employing creative visual design for scientific communication). This interdisciplinary combination holds a robust philosophical foundation for transforming abstract genetic laws into tangible, contextual, and hands-on learning experiences.

While numerous studies have separately investigated the general implementation of inquiry models, a specific research gap remains regarding the empirical diagnostic mapping of detailed SPS profiles for the abstract topic of trait inheritance in rural or semi-urban public schools, such as SMA Negeri 1 Ngawen. Furthermore, explicitly connecting this baseline profiling as a foundational needs analysis for developing a customized scientific-STEAM instructional module represents a distinct pedagogical novelty. Therefore, the primary objective of this study was to investigate, analyze, and describe the current Science Process Skills profile of Grade XII students at SMA Negeri 1 Ngawen on the concept of Inheritance of Traits, establishing an empirical baseline for targeted instructional interventions.

MATERIALS AND METHODS

This study employed a descriptive quantitative design as the needs analysis stage of an ADDIE-based development study. The descriptive quantitative approach was selected to provide an objective, empirical, and statistically precise portrait of students' current scientific competencies. By deliberately focusing on the Analyze phase of the five-stage ADDIE framework (Analyze, Design, Develop, Implement, Evaluate), this research serves as a diagnostic foundation to justify and guide the subsequent structural design of scientific learning modules in subsequent research cycles (Cahyadi, 2019; Molenda, 2023).

The research was conducted at SMA Negeri 1 Ngawen, located in Blora Regency, Central Java Province, Indonesia. Data collection was conducted systematically over two months during the odd semester of the 2024/2025 academic year, specifically from August to September 2024. The target population of this study comprised all Grade XII students who had selected the advanced biology academic track. Using a total sampling technique, in which the entire accessible population meeting the academic criteria was included to maximize statistical representation, a sample of 68 students was selected as the primary research respondents.

The primary data collection instrument consisted of a structured, objective essay test containing 18 items. The essay format was intentionally chosen over multiple-choice variants to allow a comprehensive trace of students' scientific reasoning paths, detect logical misconceptions in biological principles, and accurately evaluate the depth of their procedural skills. The instrument was developed by aligning the items with six core SPS indicators: observing, classifying, predicting, measuring and using numbers, inferring, and communicating. Before field administration, the instrument underwent rigorous evaluation. It was validated by a panel of three expert validators specializing in science education and evaluation instrument design. The expert validation yielded a Content Validity Index (CVI) of 0.89, falling into the highly valid category. Subsequent field testing for reliability with a non-sample group produced a Cronbach's alpha coefficient of $\alpha = 0.78$, confirming high internal consistency and instrument reliability.

To ensure objectivity and minimize grader bias in evaluating students' essay responses, a structured analytical scoring rubric was established. Each of the 18 items was scored on a scale from 0 to 3 according to specific operational criteria. The operational framework of the scoring rubric for the six evaluated SPS indicators is presented in Table 1.

Table 2. Analytical scoring rubric for the evaluation of students' Science Process Skills

SPS Indicator	Score 3 (Excellent)	Score 2 (Partial/Sufficient)	Score 1 (Poor)	Score 0 (No Response)
Observing	Identifies and records all relevant qualitative and quantitative physical traits accurately from the given biological phenomenon.	Identifies major physical traits but misses subtle phenotypic details or displays minor observational inaccuracies.	Mentions vague, superficial observations that are largely disconnected from the core genetic phenomenon	Fails to provide any observational data or leaves the answer space blank.
Classifying	Groups genetic traits or data into correct taxonomic categories based on a clear, logically consistent scientific criterion.	Places most items into appropriate categories but exhibits minor inconsistencies or lacks explicit grouping criteria.	Incorrectly categorizes genetic data, showing confusion regarding basic contrasting traits.	Fails to categorize or exhibits completely arbitrary grouping.
Predicting	Formulates a highly logical prediction of genetic outcomes based on empirical trends and sound hereditary laws.	Proposes a plausible prediction but provides incomplete, weak, or partially flawed scientific reasoning.	Offers an illogical guess or prediction that contradicts established Mendelian principles.	Provides no predictive statement whatsoever.
Measuring & Using Numbers	Calculates exact genotypic and phenotypic ratios using appropriate mathematical probability formulas.	Performs correct basic calculations but commits minor arithmetic errors or fails to simplify ratios.	Uses completely incorrect mathematical procedures or values, showing severe numeracy gaps.	Fails to execute any mathematical calculation or numerical representation.
Inferring	Formulates a valid, data-driven conclusion that establishes a logical relationship between genetic variables.	Draws a general conclusion that is correct but merely repeats data without synthesizing relationships.	Writes an invalid inference that is unsupported by or directly contradicts the provided experimental data.	Fails to write an inferential statement.
Communicating	Presents scientific arguments and genetic data clearly and accurately using appropriate technical terminology and	Conveys genetic information adequately but displays unstructured formatting or	Exhibits highly disorganized presentation, making the scientific argument	Fails to communicate any relevant data or explanation.

SPS Indicator	Score 3 (Excellent)	Score 2 (Partial/Sufficient)	Score 1 (Poor)	Score 0 (No Response)
	structured tables/diagrams.	minor misuse of biological terms.	ambiguous or unintelligible.	

Quantitative data from student work results were analyzed using descriptive and percentage statistical techniques (Sukarelawa et al., 2024). The first step was to calculate the percentage distribution of students in each general KPS criteria category using the following equation:

$$x_i = \frac{N_i}{N} x\ 100\%$$

Where Xi is the percentage of students' KPS ability in a certain category, Ni is the number of students whose total score falls into that category. At the same time, N is the total number of research respondents (N = 68) (Arikunto, 2015).

The second step is to measure the percentage of achievement for each KPS indicator, to determine which indicator is most critical. The calculation is carried out using the following equation

$$L_i = \frac{\bar{x_i}}{x_i\ max} x\ 100\%$$

here Li is the percentage of science process skills ability on a particular indicator, Xi is the average score obtained by all students on that indicator, and Ximax is the ideal maximum score that may be obtained on that indicator (Arikunto, 2015; Ramdhan, 2021).

The percentage scores obtained were then converted into qualitative predicates using a 0-100 rating scale with adapted criteria from Kusumayuni et al. (2023) and Suryaningsih et al. (2021). The division of the KPS assessment criteria intervals is presented in detail in Table 2.

Table 3. Assessment Criteria for SPS Students at Secondary Education Level

Interval (%)	Criteria	Code
85-100	Very Good	VG
70-84	Good	G
55-69	Adequate	A
50-54	Poor	P
0-49	Very poor	VP

(Source: Kusumayuni et al., 2023; Mu'minah et al., 2020;Rachman et al., 2024)

RESULTS AND DISCUSSION

The quantitative data analysis provided a clear assessment of the current Science Process Skills profile among Grade XII students at SMA Negeri 1 Ngawen. Based on the cumulative calculation of the essay test scores, the general distribution of students' SPS capabilities across the five established proficiency categories is summarized in Table 3.

Table 4. Frequency Distribution of KPS Categories of Class XII Students of SMAN 1 Ngawen

Student SPS Category	Student Count	Percentage
Very Good	0	0 %
Good	1	1,47 %
Adequate	13	19,12 %
Poor	14	20,59 %
Very Poor	40	58,82 %
Total	68	100%

The empirical data presented in Table 4 reveal a critical situation regarding the quality of students' SPS. Notably, 0.00% of the students reached the "Very Good" category, and only a minimal 1.47% (1 student) achieved the "Good" category. The remaining students were distributed among the lower tiers: 19.12% in the "Sufficient" category, 20.59% in the "Poor" category, and a clear majority of 58.82% (40 students) in the "Very Poor" category. These results demonstrate that most Grade XII students at the school have not yet developed proficient science process skills.

To identify the specific operational areas driving these low scores, the data were analyzed across individual SPS indicators. The recapitulation of the percentage scores and their corresponding qualitative categories for each of the six indicators is detailed in Table 4.

Table 4. Recapitulation of Percentage Scores and Categories for Each Student KPS Indicator

Indicator	**Question Number**	**Average**	**Category**
1. Observing	6, 11	30,88	VP
2. Classifying	2, 12	57,35	P
3. Predicting	5, 8	38,24	VP
4. Measuring and Using of Numbers	3, 7	25,00	VP
5. Inferring	9, 10	46,32	VP
6. Communicating	1, 4	52,21	P
Average		41,67	VP

The cumulative average score across all six SPS indicators for the Grade XII students at SMA Negeri 1 Ngawen was 41.67%. According to Sudjono's (2006) evaluative criteria, this cumulative average falls into the "Very Poor" category. This finding indicates that low scientific competency is a systemic issue across almost all evaluated dimensions of inquiry. To illustrate the performance gaps across these skills, a comparative visualization is shown in Figure 1.

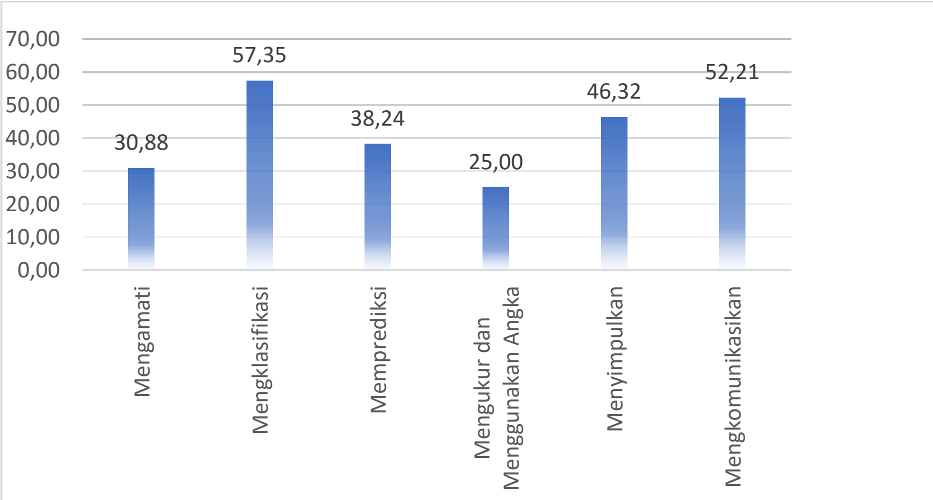

Figure 1. SPS Chart for Grade XII Students at SMAN 1 Ngawen

Based on the data in Table 5 and the graphical visualization, four SPS indicators are trapped in the "Very Poor" category: measuring and using numbers, observing, predicting, and concluding. The Measuring and Using Numbers indicator (25.00% - Very Poor) recorded the lowest score among all the indicators tested. In the Inheritance of Traits material, the ability to measure and use numbers is very necessary when students have to calculate the phenotype and genotype ratios of the results of Mendel's Law crosses, apply combinatorics formulas, and conduct Chi-Square (chi2) harmony tests to detect apparent deviations from Mendel's Law. This low score is triggered by students' unfamiliarity with integrating mathematical logic into biological phenomena. Students tend to experience mathematical anxiety when encountering numbers and formulas in biology problems, so they fail to convert cross-sectional data into valid percentages or ratios.

Observation is the most fundamental pillar in SPS (Manalu et al., 2023). However, students' scores in this aspect were very low, namely 30.88% (Very Poor). This low observational ability was evident in students' inability to record and identify physical phenotypic characteristics presented in pictures or narratives of crossbreeding cases (for example, differences in chicken wattle characteristics, pea seed shape, or hereditary disease genealogy). Students are accustomed to reading conclusions immediately without conducting in-depth, systematic sensory observations, due to classroom learning patterns that rarely present real objects or biological preparations.

Predictive skills require students to identify patterns or trends in existing data and then predict events that have not yet occurred using logical, scientific reasoning. Table 3 shows that this indicator received a score of 38.24% (Very Poor). In the context of genetics, students struggled to predict the probability of a child who has hemophilia or color blindness from a parent's marriage with a specific genotype. Students speculated without a sound understanding of the law of independent segregation or sex linkage.

The indicator showed a score of 46.32% (Very Poor), indicating students' weaknesses in interpreting the relationships between variables resulting from simulation experiments on crosses. When asked to conclude from a table of data on Drosophila crosses, students rewrote the data in the table rather than synthesizing a logical conclusion and addressing the hypothesis.

The poor performance of these four fundamental indicators strongly suggests that students at SMAN 1 Ngawen are not yet accustomed to a climate of investigation, experimentation, and in-depth analysis of scientific research findings. The one-way learning process has stifled their curiosity and scientific acumen. On the other hand, two indicators showed relatively better performance, although still far from ideal: classification and communication.

The Classifying indicator achieved the highest percentage score in this study, at 57.35%, and was the only indicator that fell into the Sufficient category. This score indicates that most grade XII students at SMAN 1 Ngawen have adequate basic skills for grouping or classifying biological quantities. In the inheritance material, students were able to distinguish and group dominant versus recessive traits, homozygous versus heterozygous, and autosomes versus gonosomes. This prominent classification ability is due to the conventional learning pattern in the classroom, which often emphasizes grouping definitions and classification charts of material.

The communication indicator fell within the upper limit of the "Poor" category, at 52.21%. Students possessed basic skills in reading graphs or presenting cross-sectional data in simple tables. However, they remained very weak when asked to communicate these scientific arguments verbally in class presentations or to construct coherent explanatory narratives using appropriate genetic terminology. Therefore, improving this aspect of scientific communication remains a crucial area of focus.

Given the current critical SPS of SMAN 1 Ngawen students, improvements simply by replacing visual media or increasing the intensity of cognitive exercises are likely to be ineffective. A comprehensive, structured, and agreed-upon instructional paradigm shift is needed, shared by all teachers. The fundamental solution proposed, based on collaborative reflection with the biology teacher community, is to implement a STEAM-based Scientific Approach.

The scientific approach will reconstruct the syntax of classroom learning into five scientific steps: observing the phenomenon of human trait variation, asking why the variation occurs, collecting cross-breeding data through genetic buttons, reasoning about the mathematical ratios of the cross-breeding, and communicating the findings (Sari et al., 2024). Through this process, the main focus of learning shifts from an orientation towards the final result (exam scores) to strengthening students' critical, logical, analytical, and investigative thinking skills, as in true scientists (Ramadan et al., 2025).

The STEAM framework catalyzes the enhancement of this scientific approach. The interdisciplinary synergy within STEAM will stimulate students' Key Performance Indicators (KPI) (Dewi et al., 2023; Mu'minah et al., 2020). The Science indicator guides students in a deeper exploration of the essential concepts of heredity, mutation, and cell division through guided inquiry (Lepiyanto & Pratiwi, 2023). The Technology indicator addresses the time constraints of observing cross-breeding, which can take months. Students are encouraged to use genetic simulation software (such as StarGenetics or virtual labs) to conduct digital crossbreeding instantly. This activity directly trains the "Observing" and "Predicting" SPS indicators. In the Engineering & Mathematics indicator, students are challenged to design a three-dimensional DNA mock-up project from recycled materials or to design their own cross-breeding demonstration tools. This process requires mathematical precision in calculating scale, chemical bond angles, and the probability of genotype occurrence. These engineering and mathematical activities will significantly enhance the "Measuring and Using Numbers" SPS indicator. Art elements are integrated into the Art indicator, in which students are asked to present a pedigree chart illustrating the transmission of genetic diseases (such as color blindness or thalassemia) with an aesthetic, creative, yet scientifically accurate graphic design. This step trains the "Communication" SPS indicator.

This holistic scientific-STEAM integration is believed to transform the face of biology learning at SMAN 1 Ngawen from abstract, dry, and boring to a scientific adventure that is concrete, meaningful, contextual, and rich in hands-on (physical activities) and minds-on (higher-order thinking activities). Intensive, continuous stimulation through this scientific-STEAM syntax is expected to be the key to recovering and boosting all student SPS indicators that were previously in the very poor category.

CONCLUSION

Based on the results of data analysis and discussion, it can be concluded that the profile of Science Process Skills (SPS) of grade XII students of SMA Negeri 1 Ngawen on the concept of Inheritance of Traits is generally at a very worrying level, with an accumulative average score of 41.67%, which is included in the Very Poor category. Of the six SPC indicators tested, there is only 1 indicator that successfully reaches the "Enough" category, namely classifying (57.35%), while 1 indicator is in the "Poor" category, namely communicating (52.21%). The remaining 4 indicators are stuck in the "Very Poor" category, with the measuring and using numbers indicator occupying the lowest position (25.00%).

The implications of this study emphasize the need for concrete curriculum interventions at the school level. As a concrete recommendation, the biology teacher community at SMAN 1 Ngawen must immediately migrate from conventional teaching models to the consistent implementation of learning tools with a Scientific Approach integrated with the STEAM framework. Because this study only captures the profile of *Science-Based Learning* (SBL) in the inheritance of traits material at the 12th grade level, it is recommended for future researchers and other biology teachers to conduct similar investigations on different biology topics and school characteristics, so that the national student SBL profile map can be documented for the continuous improvement of the quality of science education.

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