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Assessment of Science Process Skills in Physics Education: A Case Study on Electrostatics Among Grade 11 Students

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Abstract

Empirical evidence on students' science process skills (SPS) proficiency within specific physics content areas remains limited in Thai secondary education, particularly in the context of electrostatics. This study is a survey research aimed at assessing the fundamental science process skills (SPS) of Grade 11 students in the context of electrostatics. A validated 30-item multiple-choice test covering eight SPS dimensions -observing, measuring, classifying, using space/time relationships, using numbers, organizing data and communicating, inferring, and predicting - was administered to 36 students enrolled in the Science-Mathematics-Technology-Environment (SMTE) Program at Sarakham Pittayakhom School Thailand, and analyzed using descriptive statistics and quartile distribution. The results revealed an overall mean score of 12.30 out of 30 (41.01%), reflecting a below-average level of SPS proficiency. Classifying was the strongest skill (mean = 2.53, 63.19%), with the majority of students reaching the third quartile (Q3), while using numbers (mean = 0.64, 21.30%) and predicting (mean = 0.97, 24.31%) were the weakest, with most students falling in the first quartile (Q1). The five remaining skills - observing, measuring, using space/time relationships, organizing data and communicating, and inferring-clustered at a moderate level in the second quartile (Q2). The pronounced difficulty in numerical and predictive skills is attributed not solely to general mathematical weakness, but to the abstract and invisible nature of electrostatic phenomena, which requires students to simultaneously apply scientific notation, interpret charge signs, and execute multi-step proportional reasoning without the support of direct sensory experience. These findings suggest that targeted instructional interventions-including problem-based learning, predict-observe-explain strategies, digital simulations, and adaptive learning technologies-are needed to explicitly scaffold the integration of quantitative procedures with conceptual understanding in electrostatics instruction.

How to Cite

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INTRODUCTION

Science education serves as a cornerstone for developing students' analytical and problem-solving competencies through systematic scientific inquiry. In the contemporary educational landscape, science process skills (SPS) have emerged as fundamental cognitive abilities that enable students to effectively analyze, interpret, and understand complex scientific phenomena (NARST, 2024). These skills are particularly crucial in physics education, where students must apply systematic methodologies to comprehend abstract concepts and solve multifaceted problems. The growing importance of SPS is further reflected in the broader academic landscape; a scientometric analysis of 8,110 Scopus publications between 2000 and 2024 revealed a steady rise in SPS research output, reaching a peak of 730 articles in 2024, underscoring the field's expanding global significance (Lalthlamuanpuii et al., 2025).

Science process skills encompass a comprehensive set of cognitive abilities categorized into basic and integrated skills. Basic science process skills include observing, measuring, classifying, using space/time relationships, using numbers, organizing data and communicating, inferring, and predicting (American Association for the Advancement of Science, n.d.). These foundational skills serve as prerequisites for more advanced integrated science process skills, which include controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting, and formulating models Research has consistently demonstrated that mastery of science process skills enhances students' conceptual understanding and their ability to engage in scientific reasoning and experimentation (Darmaji et al., 2019).

Recent studies have revealed that students often demonstrate varying levels of proficiency across different dimensions of science process skills. Physics education students typically exhibit stronger performance in observation and classification skills, while predictive reasoning and numerical analysis often require additional instructional support (Darmaji et al., 2019; Maison et al., 2019). This variation in skill mastery highlights the need for targeted assessment strategies that can identify specific areas where students require additional guidance.

The development of science process skills is intrinsically linked to the cultivation of critical thinking abilities and 21st-century competencies. Research has shown a strong positive correlation between students' science process skills and their critical thinking capabilities (Pathoni et al., 2020). Furthermore, the alignment between science process skills and 21st-century competencies, including complex communication, adaptability, and problem-solving abilities - makes physics education an ideal context for fostering comprehensive skill development (National Research Council, 2012).

In the Thai educational context, recent assessments have revealed concerning gaps in foundational skills among students at all levels of education (World Bank, 2024). Studies on science process skills in secondary school contexts reveal that while students generally perform adequately on knowledge-recall tasks, their ability to apply higher-order process skills - particularly those involving inferring, predicting, and quantitative analysis - remain underdeveloped (Rauf et al., 2013). This disparity suggests that traditional instructional approaches emphasizing rote learning may prioritize content delivery over the cultivation of scientific thinking. Recent educational reforms promoting inquiry-based approaches offer promising opportunities for more effective integration of process skill development into physics instruction, yet targeted evidence of skill gaps within specific content areas is still needed to guide these efforts. Within physics education specifically, this challenge is compounded by the abstract and mathematical nature of the subject, which demands not only content knowledge but also the ability to apply process skills such as inferring, predicting, and quantitative reasoning - skills that Thai secondary students have been shown to find particularly difficult (Rauf et al., 2013; Maison et al., 2019).

Despite the recognized importance of science process skills, there remains a significant gap in understanding how students in diverse educational contexts develop these competencies within specific physics content areas. This gap is particularly pronounced in the assessment of fundamental science process skills related to electricity and magnetism concepts, which are central to the physics curriculum but often challenging for students to grasp. Furthermore, while SPS research has grown substantially at the global level, empirical studies remain concentrated in Western and East Asian contexts, with Southeast Asian countries - including Thailand - remaining notably underrepresented in the literature (Kurniahtunnisa et al., 2024).

Electrostatics, as a foundational topic in secondary-level physics, presents unique pedagogical challenges due to the abstract and invisible nature of electric charges and forces. Students are required to visualize and reason about phenomena that cannot be directly observed, demanding a high level of both conceptual understanding and process skill application. Within this content domain, science process skills such as inferring, predicting, and using numbers become especially critical, as students must apply quantitative reasoning and logical deduction to interpret electrostatic phenomena (Darmaji et al., 2019; Maison et al., 2019). However, despite its central place in the physics curriculum, studies specifically examining students' science process skills within the context of electrostatics remain scarce, representing a notable gap in the existing literature.

The role of assessment in identifying and addressing learning gaps in science education cannot be overstated. Formative and diagnostic assessments of science process skills enable educators to pinpoint specific competency weaknesses among students, thereby guiding the design of targeted instructional interventions (Gizaw & Sota, 2023). Furthermore, standardized instruments for measuring science process skills provide a reliable basis for comparing student performance across different learning environments, grade levels, and content areas. Among the various assessment formats available, multiple-choice instruments remain widely used in SPS assessments due to their objectivity, scoring consistency, and capacity to measure discrete cognitive skills across multiple dimensions within a single administration (Sarıoglu, 2023; Kurniahtunnisa et al., 2024). By applying a validated assessment tool within the domain of electrostatics, this study contributes to the broader effort of building an evidence base for science education reform in Thailand and similar educational contexts in developing nations.

Therefore, this study aimed to assess the science process skills of 36 Grade 11 students at Sarakham Pittayakhom School, Thailand, focusing on fundamental SPS within the context of static electricity. Using a validated 30-item test instrument based on static electricity concepts, this research seeks to identify students' strengths and weaknesses across different dimensions of science process skills. The findings will provide refined teaching strategies that support students' scientific skill development, ultimately fostering deeper comprehension of physics concepts and better preparing students for the demands of 21st-century scientific literacy.

METHOD

This study employed a survey research design to assess the fundamental science process skills of Grade 11 students in the context of electrostatics. Data were collected using a validated 30-item multiple-choice test covering eight dimensions of science process skills, administered to students enrolled in the Science - Mathematics -Technology - Environment (SMTE) Program at Sarakham Pittayakhom School, Thailand. The following subsections.

Research Design

This study employed a survey research design to assess the science process skills of Grade 11 students in Thailand. The research focused on evaluating students' proficiency in fundamental science process skills related to electrostatics in physics through a structured multiple-choice test.

Participants

The participants consisted of 36 Grade 11 students, SMTE Program, Sarakham Pittayakhom School, Maha Sarakham Province, Thailand. The sample was selected using convenience sampling, as access was granted by the subject teacher for one class only among the three available SMTE classes during the data collection period in January 2025. Although this sampling approach limits the generalizability of the findings, the selected class was considered representative of the broader SMTE student population at this school, as all three classes follow the same curriculum and instructional conditions.

Research Instrument

The research instrument used in this study was a 30-item multiple-choice test designed to assess students' science process skills. This test was adapted from a previous study by Kittisak Chamai, titled "Development of Science Process Skills on Electrostatics Using the 7E Learning Cycle and Concept Mapping for Grade 11 Students." This instrument was selected for three reasons. First, its content aligns directly with the electrostatics unit prescribed in the Thai national science curriculum for Grade 11, which has remained unchanged since the instrument's original development. Second, the test's 30-item format is designed to be completed within a single class period, allowing data collection to proceed without disrupting regular instruction or requiring additional logistical arrangements. Third, the instrument covers all eight fundamental science process skills targeted in this study, providing comprehensive coverage within a single, manageable assessment tool. Prior to administration, the instrument was reviewed by the subject teacher responsible for the Grade 11 physics course to confirm that its content remained consistent with the current curriculum and learning objectives.

The instrument comprised 30 items covering all eight fundamental science process skills, with a minimum of three items per dimension. All items were multiple-choice with four options and scored dichotomously (1 = correct, 0 = incorrect). To illustrate the nature of the assessment, one representative item per dimension is presented below, together with a brief explanation of how each item operationalizes the target skill.

[Skill: Observing (OB)] A plastic rod is rubbed with a wool cloth, then brought close to small pieces of paper resting on a table. Which of the following represents a direct observational statement, free from interpretation or inference?

A. The plastic rod carries a negative charge and therefore attracts the pieces of paper. B. The pieces of paper move toward the plastic rod as the rod is brought near. C. The plastic rod generates an electric field that causes the paper to move. D. The paper experiences a force due to electrons transferred from the wool cloth to the rod. (Answer: B)

This item assesses whether students can distinguish a direct sensory observation from an interpretation or theoretical inference. A student who selects option B demonstrates the ability to describe only what is physically observable without attributing a cause.

[Skill: Classifying (CL)] Given the following materials (glass, copper, rubber, silver, PVC plastic, aluminum, ceramic tile, and iron) a student wishes to classify them according to their electrostatic properties. Which grouping and criterion are most scientifically accurate?

A. Conductors: glass, copper, silver / Insulators: rubber, plastic, ceramic, aluminum, iron B. Conductors: copper, silver, aluminum, iron / Insulators: glass, rubber, PVC plastic, ceramic tile C. Conductors: copper, silver, aluminum / Insulators: rubber, PVC plastic / Semiconductors: glass, ceramic tile, iron D. Conductors: copper, silver, iron / Insulators: rubber, glass, ceramictile / Semiconductors: PVC plastic, aluminum (Answer: C)

This item assesses the ability to apply consistent, scientifically accurate criterion when sorting materials into categories. Correct classification requires distinguishing conductors, insulators, and intermediate materials based on their electrical properties.

[Skill: Measuring (ME)] A student places a test charge $q_0 = +1\times10^{-6}$ C at distances r = 0.1, 0.3, and 0.9 m from a point charge $Q = +9\times10^{-9}$ C and records the electrostatic force F using a force meter ($k = 9\times10^9$ N.m²/C²). Based on a graph of E versus $1/r^2$ constructed from the data, what value of the electric field E should be read at r = 0.3 m, and which conclusion is most scientifically justified?

A. E = 900 N/C; the graph is a straight line through the origin, indicating $E \propto 1/r^2$ B. E = 900 N/C; the graph is curved, indicating $E \propto r^2$ C. E = 300 N/C; the graph is a straight line, indicating $E \propto 1/r$ D. E = 100 N/C; the graph is non-linear, indicating no definable relationship (Answer: A)

This item assesses the ability to compute a derived quantity from measured data ($E = F/q_0$) and correctly interpret a graphical relationship. Full credit requires both an accurate numerical result and a valid interpretation of the graph's shape.

[Skill: Using Space/Time Relationships (ST)] Two identical metallic spheres, A and B, are placed 30 cm apart and both carry positive charges. Which statement correctly describes both the spatial configuration of the electric field lines between the spheres and the subsequent motion of the spheres if they are free to move?

A. The electric field lines point toward each other; the spheres move toward each other. B. The electric field lines point toward each other; the spheres move away from each other. C. The electric field lines point away from each other; the spheres move toward each other. D. The electric field lines curve outward and away from each other (repulsive); the spheres continuously accelerate away from each other over time. (Answer: D)

This item requires students to reason about both spatial arrangement (field line geometry) and temporal change (motion over time). A correct response must integrate both dimensions simultaneously.

[Skill: Using Numbers (UN)] Two-point charges $q_1 = +4\times10^{-6}$ C and $q_2 = -2\times10^{-6}$ C are placed in air at a separation of 0.2 m. Given $k = 9\times10^9$ N.m²/C², calculate the magnitude of the electrostatic force between the two charges and identify the nature of this force.

A. F = 1.8 N; repulsive B. F = 3.6 N; repulsive C. F = 1.8 N; attractive D. F = 0.9 N; attractive (Answer: C)

This item assesses numerical computation using Coulomb's Law and the ability to determine the nature of the force from the signs of the charges. Full credit requires both a correct calculated value and a correct identification of the attractive force.

[Skill: Organizing Data and Communicating (OD)] A student measures the electrostatic force between two fixed point charges at varying separations r, recording the following data: r = 0.1 m $\longrightarrow$ F = 9.0 N; r = 0.2 m $\longrightarrow$ F = 2.25 N; r = 0.3 m $\longrightarrow$ F = 1.0 N; r = 0.4 m $\longrightarrow$ F = 0.56 N. Which form of data representation most clearly reveals the mathematical relationship between F and r?

A. A linear graph (F vs. r) B. A log-log graph (log F vs. log r) to linearize the power-law relationship C. A bar chart comparing F values at each separation D. A pie chart showing the proportional distribution of force values (Answer: B)

This item assesses the ability to select the most appropriate representation for communicating a power-law relationship. The log-log graph is the correct choice because it linearizes the $F \propto 1/r^2$ relationship, yielding a straight line with slope -2.

[Skill: Inferring (IN)] A student observes that when a glass rod rubbed with silk is brought near the leaves of a gold-leaf electroscope, the leaves diverge. When a rubber rod rubbed with wool is brought near the same electroscope, the leaves also diverge. Based solely on these observations, which inference is most logically justified?

A. The glass rod and the rubber rod carry the same type of charge, since both produce identical results. B. The leaves carry the same type of change as the object brought near, causing them to repel each other. C. Regardless of the sign of the charge on the object, electrostatic induction causes the leaves to acquire like charges and therefore diverge. D. The electroscope can detect only positive charges. (Answer: C)

This item assesses the ability to construct a logical inference from two consistent observations without overgeneralizing or assuming information not stated. The correct response identifies electrostatic induction as the mechanism, which accounts for both observations regardless of charge sign.

[Skill: Predicting (PR)] According to Coulomb's Law, $F = k(q_1q_2)/r^2$, two point charges $q_1 = q_2 = 1\times10^{-6}$ C separated by a distance of 1 m exert a repulsive force of 9×10^{-3} N on each other. If the separation is reduced to 0.5 m and the magnitude of q_1 is doubled, what is the predicted value of the new electrostatic force?

A. $F_{new} = 7.2\times1^{0-2}$ N (an 8-fold increase) B. Fnew = 3.6×10^{-2} N (a 4-fold increase) C. $F_{new} = 1.8\times10^{-2}$ N (a 2-fold increase) D. Fnew = 9×10^{-3} N (unchanged) (Answer: A)

This item assesses the ability to apply known quantitative relationships to predict an outcome under changed conditions. Full credit requires correctly combining both the inverse-square effect of halving the distance (×4) and the linear effect of doubling the charge (×2), yielding an 8-fold increase.

Validity and Reliability of the Test

1. Content Validity

The test was reviewed by experts to ensure alignment with the research objectives and The Index of Item-Objective Congruence (IOC) was ≥ 0.50, confirming its content validity, overall IOC value was in the range of 0.5 - 1.00, indicating high content validity.

2. Item Analysis

The test was piloted with 36 non-sample students from Grade 12/1, Lao Kham Pittayakhom Ratchamangkhalaphisek School, Bueng Kan Province, Thailand, during the second semester of the 2018 academic year. The difficulty index (p) ranged from 0.20 to 0.80, and the discrimination index (r) was ≥ 0.2. And The test's reliability was measured using Kuder-Richardson Formula 20 (KR-20), yielding a value of 0.9 to 1, indicating high reliability. Although this pilot study was conducted in 2018, the psychometric properties established at that time were considered applicable to the present study. This is because the electrostatics content in the Thai national science curriculum for Grade 11 has not been revised since the instrument's original development and validation, ensuring continued content relevance. It should be acknowledged, however, that a formal re-validation with a current student sample was not conducted for this study, which represents a limitation. The content appropriateness of the instrument for the 2025 administration was confirmed through a review by the subject teacher of the Grade 11 physics course.

Data Collection Procedures

1. Administration of the Test

The test was distributed via Google Forms to the participants from SMTE Program (Enrichment Program of Science, Mathematics, Technology, and Environment), Sarakham Pittayakhom School. Students were given one hour to complete the test.

2. Data Management

Responses were checked for completeness. The collected data was structured into a database for statistical analysis.

Data Analysis

1. Descriptive Statistics

The overall mean score and percentage of science process skills were calculated.

2. Analysis of Individual Science Process Skills

Student performance was analyzed across eight dimensions of fundamental science process skills: observing (OB), measuring (ME), classifying (CL), using space/time relationships (ST), using numbers (UN), organizing data and communicating (OD), inferring (IN), and predicting (PR).

3 Quartile Analysis

Student scores were categorized into quartiles to determine distribution trends. The analysis focused on identifying the quartile distribution for each science process skill. Comparisons were made to highlight which skills required further development.

RESULT AND DISCUSSION

Overall Performance of Science Process Skills

The assessment results indicate that students exhibit varying levels of proficiency across different science process skills. The mean score across all eight fundamental science process skills was 12.30 out of 30, with an overall performance percentage of 41.01%.

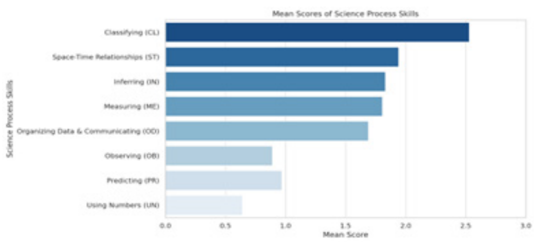

Figure 1. Bar Chart-Mean Scores of Science Process Skills

From the bar chart analysis, it is evident that students performed best in Classifying (CL) with a mean score of 2.53 (63.19%), while the lowest performance was observed in Using Numbers (UN) with a mean score of 0.64 (21.30%).

Performance by Science Process Skill

The percentage of correctness for each science process skill is shown in Table 1, ranked from highest to lowest performance.

Table 1. Show ranked from highest to lowest performance

Science Process Skill	Mean Score	Percentage (%)
Classifying (CL)	2.53	63.19
Using Space-Time Relationships (ST)	1.94	48.61
Inferring (IN)	1.83	45.83
Measuring (ME)	1.81	45.14
Organizing Data & Communicating (OD)	1.69	42.36
Observing (OB)	0.89	29.63
Predicting (PR)	0.97	24.31
Using Numbers (UN)	0.64	21.30

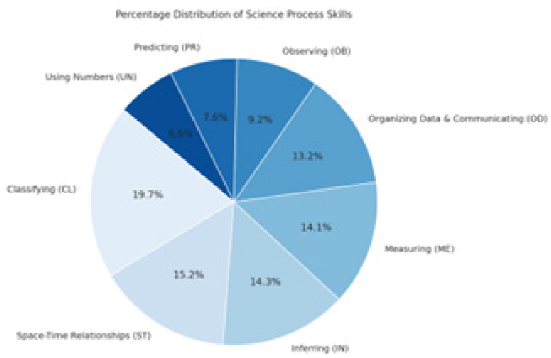

Figure 2. Percentage Distribution of Science Process Skills

The pie chart highlights that the highest proportion of correct responses was in Classifying (CL) (19.7%), whereas the lowest proportion was in Using Numbers (UN) (6.6%).

Quartile Analysis of Student Performance

To further analyze student performance, quartile distribution was applied to classify students based on their scores in each skill. The findings indicate the following patterns

Second Quartile (Q2): Most students scored in this range for ST, IN, ME, OD, and OB, indicating a moderate level of competency.

Third Quartile (Q3): The majority of students were in this quartile for CL, indicating a relatively high competency in classification skills.

First Quartile (Q1): Most students fell into this quartile for PR and UN, suggesting significant weaknesses in predictive and numerical skills.

Discussion

Performance Trends and Implications

The findings indicate that students demonstrated strong performance in classification skills (CL), suggesting that they can categorize concepts effectively based on shared characteristics. This result is consistent with prior studies that emphasize classification as one of the most fundamental science process skills, which serves as a foundation for higher-order thinking in science education (AlAli & Al-Barakat, 2024; Gizaw & Sota, 2023). This finding is also consistent with research by Darmaji (Darmaji et al., 2019), who found that physics education students generally perform better in classification tasks compared to more complex cognitive skills. This pattern can also be explained through the theoretical framework of science process skills (SPS), which are commonly categorized into basic and integrated skills. Basic skills such as observing, measuring, and classifying function as foundational competencies that support the development of higher - level reasoning skills including predicting, hypothesizing, and interpreting data. Several studies in science education indicate that classification plays a crucial role in helping students organize scientific information systematically, which later facilitates scientific reasoning and inquiry processes (Padilla M. J., 1990; Gizaw & Sota, 2023).

In contrast, the weakest skills were using numbers (UN) and predicting (PR), with mean scores of 0.64 (21.30%) and 0.97 (24.31%) respectively, and most students falling in the first quartile (Q1) for both dimensions. These results warrant a more specific analysis grounded in the nature of electrostatics as a content domain. For the Using Numbers skill, the representative item required students to apply Coulomb's Law quantitatively: given two charges of opposite sign and a fixed separation, students had to compute the magnitude of the electrostatic force and correctly identify it as attractive. This task demands not only arithmetic facility with scientific notation and unit manipulation, but also the ability to interpret the physical meaning of the sign of the charges independently from the magnitude calculation. The dual cognitive demand - numerical computation combined with conceptual reasoning about charge sign - likely contributed to the high error rate observed. This interpretation is consistent with Gizaw & Sota (Gizaw & Sota, 2023), who identified the integration of mathematical procedures with scientific concepts as a primary source of difficulty in science process skill assessments, and with Nurbaya (Nurbaya et al., 2022), who found that students exposed to limited problem-based learning environments develop insufficient numerical literacy for tasks requiring this type of integration. Previous research in science and physics education has also highlighted that students often struggle when mathematical reasoning must be integrated with conceptual understanding simultaneously. In science learning, the skill of using numbers involves not only performing calculations but also interpreting quantitative relationships and applying them to explain scientific phenomena. Studies on science process skills development emphasize that difficulties frequently arise when students must connect abstract formulas with conceptual meaning in physics contexts (Darmaji et al., 2019; Maison et al., 2019). For the Predicting skill, the representative item required students to determine the combined effect of halving the separation distance and doubling one charge on the resulting force, applying the inverse-square relationship and the linear charge dependence simultaneously. The abstract and invisible nature of electrostatic forces means that students cannot rely on intuitive or perceptual reasoning to cross-check their predictions, unlike mechanical phenomena where physical intuition serves as a reference point. Students must instead reason entirely through the mathematical structure of Coulomb's Law, applying two multiplicative scaling factors in sequence. Research indicates that students often struggle with this type of multi-step proportional reasoning in contexts where the underlying phenomenon is not directly observable (Darmaji et al., 2019; Maison et al., 2019). This finding aligns with broader research in science education showing that predictive reasoning requires higher-order cognitive processing, including proportional reasoning, inference, and the ability to mentally simulate outcomes based on variable relationships. Predicting scientific outcomes without direct observation is particularly challenging when students must coordinate multiple variables simultaneously, as commonly occurs in physics topics involving mathematical models (Padilla M. J., 1990; Darmaji et al., 2019). The low predictive performance observed in this study therefore reflects both a mathematical obstacle - chaining two proportional scaling operations - and a conceptual one, namely the inability to anchor abstract electrostatic predictions to any physical intuition about what the answer should approximately be.

Recent research by Troussas (C. Troussas et al., 2021) has demonstrated the effectiveness of adaptive learning strategies in enhancing students' cognitive skills, particularly in technical subjects like physics. These approaches use data-driven methods to personalize learning pathways according to individual student needs, which could be especially beneficial for developing the weaker science process skills identified in this study. Adaptive learning environments are particularly useful in addressing differences in students' prior knowledge and learning pace. Studies indicate that personalized instructional systems can help students gradually build both conceptual understanding and quantitative reasoning skills, which are essential for mastering physics concepts and science process skills (C. Troussas et al., 2021; Du Plooy et al., 2024) Empirical support for this approach is provided by Shi and Liu (2025), whose study of adaptive deep learning-oriented classroom strategies in higher education reported an 18% increase in average student performance scores, suggesting that similar personalized approaches could meaningfully enhance science process skill development in physics education contexts.

Strategies for Enhancing Science Process Skills

Based on these findings, several instructional approaches could be implemented to address these gaps.

a) Strengthening Numerical and Predictive Reasoning

Problem-Based Learning (PBL) Studies have shown that PBL can significantly improve students' ability to use numbers and make predictions in scientific contexts (Hamidi et al., 2024).

Predict-Observe-Explain (POE) strategies have been shown to enhance students' predictive skills by encouraging them to hypothesize, observe, and refine their understanding (Mirabueno & Basilio, 2023; Rahayu et al., 2015).

b) Integrating Digital Learning Tools

Digital Simulations (e.g., PhET) have been shown to enhance students' conceptual understanding of abstract scientific ideas (Parthiban J & Dr. Leo Stanly S, 2024; Gumilar & Trisnowati, 2018).

Augmented Reality (AR) Recent studies highlight that integrating AR into science education fosters engagement and improves students' ability to interpret data and construct logical predictions (Maisarah et al., 2024).

c) Implementing Adaptive Learning Approaches

Recent meta-analysis has shown that personalized adaptive learning implementations in higher education resulted in increased academic performance in 59% of cases and enhanced student engagement in 36% of studies examined (Du Plooy et al., 2024) These approaches use technology to customize learning pathways based on students' cognitive levels, interests, and learning pace.

The findings of this study align with broader educational trends highlighting the importance of both technical knowledge and soft skills development. As Vijaya et al (Vijaya C et al., 2025) note in their research on soft skills in engineering education, group projects and collaborative learning environments are instrumental in helping students develop essential skills such as persuasive communication, problem-solving, and leadership. Similar approaches could be beneficial in physics education to enhance students' science process skills.

CONCLUSION

This study highlights notable strengths in classification skills but significant weaknesses in predicting and numerical reasoning among students. The results suggest that traditional teaching methods may not be sufficiently reinforcing quantitative and inferential reasoning, necessitating a shift towards more interactive, inquiry-based, and problem-solving instructional strategies. Importantly, the low scores in these two dimensions are not merely a reflection of general mathematical weakness; they are compounded by properties specific to electrostatics as a content domain. Coulomb's Law, while mathematically straightforward in form, requires students to simultaneously manage scientific notation, interpret the physical significance of charge signs, and apply proportional reasoning across multiple variables - all within a phenomenon that is entirely invisible and cannot be verified through direct sensory experience. This combination of abstract content and multi-step quantitative demands creates a particularly challenging environment for developing both numerical and predictive science process skills. These findings suggest that instructional approaches in electrostatics should explicitly scaffold the transition from conceptual understanding to quantitative application, rather than treating numerical calculation and conceptual reasoning as separate learning objectives.

These findings collectively point to the value of integrating adaptive and technology-enhanced instructional approaches into physics education. As discussed in the preceding section, personalized adaptive learning strategies - including PBL, POE, PhET simulations, and augmented reality - offer promising pathways for addressing the specific gaps in numerical and predictive reasoning identified in this study. The quartile-level evidence is particularly instructive: the concentration of students in Q1 for both UN and PR, while the majority achieved Q2 or Q3 for the remaining six skills, indicates that targeted rather than broad-spectrum intervention is needed. Instructional design for electrostatics should therefore prioritize scaffolding the integration of quantitative procedures with conceptual understanding, ensuring that students can apply mathematical models within the abstract context of electrostatic phenomena.

Future research should investigate the effectiveness of specific interventions, such as project-based learning, real - world problem - solving tasks, and technology - assisted learning, in enhancing these critical science process skills. Furthermore, longitudinal studies could provide deeper insights into how students develop these skills over time and how pedagogical changes influence their competency.

To enhance students' science process skills, it is recommended that educators incorporate more inquiry-based learning strategies, such as Problem-Based Learning (PBL) and Predict-Observe-Explain (POE) models, to strengthen their ability to apply scientific reasoning. The integration of digital tools, including PhET simulations and augmented reality (AR), can provide engaging and interactive learning experiences that help students grasp complex scientific concepts.

Additionally, fostering active learning through hands-on experiments, collaborative projects, and real-world problem-solving activities can improve their analytical and critical thinking skills. Professional development programs for teachers should focus on evidence-based teaching methodologies to enhance instructional effectiveness.

Based on recent findings in adaptive learning research, educators should consider implementing personalized learning approaches that dynamically adjust to students' needs and learning paces. This aligns with the New Normal paradigm in education, emphasizing flexible learning environments and strategic technology integration.

Lastly, further research should explore the long-term impact of innovative teaching approaches on students' science process skills development and overall scientific literacy.

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REFERENCES

AlAli, R. M., & Al-Barakat, A. A. (2024). Assessing the Effectiveness of Environmental Approach-Based Learning in Developing Science Process Skills and Cognitive Achievement in Young Children. *Education Sciences*, 14(11), 1269. https://doi.org/10.3390/educsci14111269

American Association for the Advancement of Science. (n.d.). *Benchmarks for Science Literacy: A Tool for Curriculum Reform (Vol. 1995).* Oxford University Press. Retrieved https://www.project2061.org/publications/rsl/online/GUIDE/CH2/HBENCH0.PDF

C. Troussas, A. Krouska, & C. Sgouropoulou. (2021). A Novel Teaching Strategy Through Adaptive Learning Activities for Computer Programming. *IEEE Transactions on Education*, 2021(64), 103–109. https://doi.org/10.1109/TE.2020.3012744

Darmaji, D., Kurniawan, D. A., & Irdianti, I. (2019). Physics education students' science process skills. *International Journal of Evaluation and Research in Education (IJERE)*, 8(2), 293–298. https://doi.org/10.11591/ijere.v8i2.16401

Du Plooy, E., Casteleijn, D., & Franzsen, D. (2024). Personalized adaptive learning in higher education: A scoping review of key characteristics and impact on academic performance and engagement. *Heliyon*, 10(21), e39630. https://doi.org/10.1016/j.heliyon.2024.e39630

Gizaw, G., & Sota, S. (2023). Improving Science Process Skills of Students: A Review of Literature. *Science Education International*, 34(3), 216–224. https://doi.org/10.33828/sei.v34.i3.5

Gumilar, S., & Trisnowati, E. (2018). *Scientific approach-integrated virtual simulation: A Physics Learning design to Enhance Student's Science Process Skills (sps).* (7).

Hamidi, A., Akmala, R., Suyanta, & Wilujeng, I. (2024). Development of PBL Based E-Modules to Boost Students' Science Process Skills. *Jurnal Penelitian Pendidikan IPA,* 10(2), 820–827. https://doi.org/10.29303/jppipa.v10i2.5939

Kurniahtunnisa, Wola, B. R., Harahap, F., Tumewu, W. A., & Warouw, Z. W. M. (2024). Research trends of science process skills in Indonesian science education journals. *Journal of Turkish Science Education,* 21(4), 668–687. https://doi.org/10.36681/tused.2024.036

Lalthlamuanpuii, Walia, D. P., Lalthlamuanpuii, D. R., & Yashir Ahamed, D. M. (2025). *Twenty-*

Four Years of Science Process Skills Research: A Quantitative Scientometric Assessment. 2025.

Maisarah, M., Prasetya, C., Lailissa'adah, L., Nazwa, F., & Ain, I. N. (2024). The SIAR Book (Interactive Science with Augmented Reality) for Enhancing Science Process Skills of Students in Indonesia. *Mimbar Sekolah Dasar,* 11(4), 659–676. https://doi.org/10.53400/mimbar-sd.v11i4.78657

Maison, M., Darmaji, D., Kurniawan, D. A., Astalini, A., Dewi, U. P., & Kartina, L. (2019). Analysis of science process skills in physics education students. *Jurnal Penelitian Dan Evaluasi Pendidikan*, 23(2), 197–205. https://doi.org/10.21831/pep.v23i2.28123

Mirabueno, D., & Basilio, M. (2023). *A Mental Model of Predict-observe-explain (POE) Strategy as Thinking Skill to Promote Scientific Literacy*.

NARST. (2024, December 29). *The Science Process Skills.* Narst.Org. https://narst.org/research-matters/science-process-skills

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* National Academies Press. https://doi.org/10.17226/13165

Nurbaya, S. N. S., Sukmawati, S., & Rukli, R. (2022). The Effect of Numerical Literacy Activities in Problem Based Learning Environment toward Mathematical Reasoning Ability of Elementary School Students. *Jurnal Pendidikan MIPA*, 23(3), 984–994. https://doi.org/10.23960/jpmipa/v23i3.pp984-994

Padilla M. J. (1990). *The science process skills*. Research matters—To the science teacher. 1990. http://www.narst.org/publications/research/skill.cfm

Parthiban J & Dr. Leo Stanly S. (2024). Enhancing the Science Process Skills through Phet Simulation. *International Research Journal on Advanced Engineering and Management (IRJAEM)*, 2(03), 432–435. https://doi.org/10.47392/IRJAEM.2024.0060

Pathoni, H., Kurniawan, W., Muliawati, L., Kurniawan, D. A., Dari, R. W., Ningsi, A. P., & Romadona, D. D. (2020). The Effect of Science Process Skills on Study Critical Thinking Ability in Scientific Learning. *Universal Journal of Educational Research*, 8(11), 5648–5659. https://doi.org/10.13189/ujer.2020.081169

Rahayu, P., Widiyatmoko, A., & Hartono, H. (2015). Penerapan Strategi POE (Predict-Observe-Explain) dengan metode learning journals dalam pembelajaran IPA untuk meningkatkan pemahaman konsep dan keterampilan proses sains. *Unnes Science Education Journal*, 4(3), Article 3. https://doi.org/10.15294/usej.v4i3.8853

Rauf, R. A. A., Rasul, M. S., Mansor, A. N., Othman, Z., & Lyndon, N. (2013). Inculcation of Science Process Skills in a Science Classroom. *Asian Social Science*, 9(8), p47. https://doi.org/10.5539/ass.v9n8p47

Sarıoglu, S. (2023). Development of online science process skills test for 8th grade pupils: Research Article. *Journal of Turkish Science Education,* 20(3), 418–432. https://doi.org/10.36681/tused.2023.024

Vijaya C, Sujatha Priyadharshini P.R., Prabha Govindharaj, & Praveen Sam D. (2025). The role of group projects in enhancing soft skills. *Humanities and Social Sciences Communications,* 12(1), 506. https://doi.org/10.1057/s41599-025-04807-x

World Bank. (2024, February 20). *Fostering Foundational Skills in Thailand: From a Skills Crisis to a Learning Society* [Text/HTML]. World Bank. https://www.worldbank.org/en/country/thailand/publication/fostering-foundational-skills-in-thailand