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METACOGNITION AND INQUIRY-BASED LEARNING AS INFLUENCES OF SCIENCE PROCESS SKILLS IN STEM EDUCATION

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Abstract

The low science process skills among Science, Technology, Engineering, and Mathematics (STEM) students have become an urgent concern in education worldwide. This study assessed the influence of metacognition and inquiry-based learning on the science process skills of 114 STEM students, revealing that despite high levels of metacognitive awareness and inquiry-based learning, students exhibited only satisfactory science process skills, with notable deficits in hypothesizing and experimenting. Regression analysis showed that these two factors together accounted for only 10.2% of the variance in science process skills, pointing to a significant disconnect between students' cognitive awareness and their practical application of science competencies. This disparity suggests that current inquiry-based practices may lack the structured, explicit scaffolding required to translate theoretical knowledge into operational skill. Educators are encouraged to prioritize explicit, process-focused instruction and guided scaffolding within inquiry tasks to directly strengthen students' proficiency in experimental design and hypothesis formulation.

Keywords: *metacognitive awareness, inquiry-based learning, science process skills, constructivist theory, STEM education*

1. INTRODUCTION

1.1 Background of the Study

The low science process skills among STEM students have become an urgent concern in science education worldwide. Globally, studies show that many students' performance falls below expectations. Sufriyah et al. (2024) found that high school students' prediction-skill performance was very low, and Pozuelo-Muñoz et al. (2023) reported that students struggled with integrated science process skills. Apeadido, Opoku-Mensah, and Mensah (2024) similarly found that senior high school students exhibited low acquisition of science process skills in biology.

Comparable patterns appear across several countries. Studies conducted in Banjarmasin, Kanda Middle School, and Tarakan National-Plus Middle School in Indonesia show that most senior and junior high school students demonstrate low proficiency in science process skills (Kusuma & Rusmansyah, 2021; Listiani & Kusuma, 2024; Rophi et al., 2024), and university students also exhibit low competence in applying these skills (Rusmini et al., 2021). In Nigeria, senior secondary chemistry students showed poor acquisition of controlling variables, recording, and communication skills (Journal of Engineering and Applied Sciences, 2019), while in the Netherlands, students showed weak performance in interpreting data, drawing higher-level inferences, and specifying the limitations of their analyses or conclusions (Pols et al., 2021).

In the Philippines, national and local studies have consistently shown low levels of science process skills across grade levels. Jardinico III and Linaugo (2023) found that junior high school learners demonstrated low-to-moderate proficiency in both fundamental and integrated science process skills, and Tomas (2023) reported that

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even secondary science educators showed low proficiency in these skills. Studies conducted in selected Davao City schools likewise found low mastery of science process skills among senior high school students, particularly in experimental design and data analysis (Zabala & Dayaganon, 2023; Ventura, 2024), and in Tagum City, Canoy (2024) reported that college students' integrated science process skills were only "fairly manifested."

Despite this extensive documentation of deficits, a significant research gap remains regarding their underlying causes and potential remedies. Abate et al. (2020) found that existing studies had not explored the underlying causes of students' deficiencies, and that much research relies on general science achievement measures rather than the specific skills — observing, hypothesizing, experimenting, and analyzing — that are crucial for scientific literacy (Kampa et al., 2021). Moreover, empirical studies focusing specifically on senior high school STEM students and examining interventions or predictors to enhance science process skills remain limited (Kurniaty et al., 2025). This study addresses that gap by investigating the influence of metacognition and inquiry-based learning on the science process skills of senior high school STEM students.

1.2 Theoretical Framework

This study is anchored in Jerome Bruner's Discovery Learning Theory (Bruner, 1961), which holds that students learn best when they actively construct knowledge rather than passively receive information. Bruner proposed that learning should be inquiry-driven, with learners exploring, questioning, and experimenting to uncover principles and relationships on their own; through this process, students are theorized to develop deeper understanding, critical thinking, and problem-solving ability.

1.3 Conceptual Framework

The conceptual framework of this study illustrates the hypothesized relationships among the variables under investigation. It is anchored on established theories and models that explain how inquiry-based learning and metacognitive abilities contribute to the development of students' science process skills. Specifically, inquiry-based learning is operationalized through the 5E instructional model, while metacognition is represented by knowledge about cognition and regulation of cognition. These independent variables are proposed to influence the dependent variable, science process skills, which encompass observing, classifying, measuring, predicting, inferring, communicating, and experimenting. Figure 1 presents the conceptual framework that serves as the basis for examining the relationships among these variables in the context of STEM education.

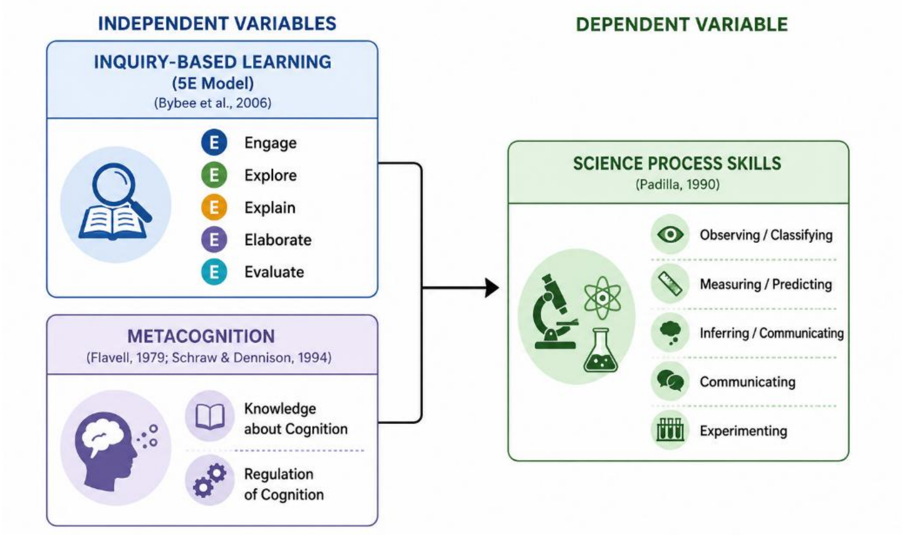

Figure 1. Conceptual Pradigm

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The independent variables are inquiry-based learning, operationalized through the 5E instructional model — engage, explore, explain, elaborate, and evaluate (Bybee et al., 2006) — and metacognition, operationalized through knowledge about cognition and regulation of cognition (Flavell, 1979; Schraw & Dennison, 1994). The dependent variable, science process skills, is indicated by observing, classifying, measuring, predicting, inferring, communicating, and experimenting (Padilla, 1990), reflecting the scientific competencies of STEM students as influenced by inquiry-based learning and metacognition.

1.4 Statement of the Problem

This study aimed to determine the influence of metacognition and inquiry-based learning on the science process skills of Senior High School STEM students. Specifically, it sought to answer:

1. What is the level of students' science process skills, metacognitive awareness (in terms of knowledge about cognition and regulation of cognition), and inquiry-based learning (in terms of engage, explore, explain, elaborate, and evaluate)?
2. Is there a significant relationship between metacognition and the science process skills of STEM students?
3. Is there a significant relationship between inquiry-based learning and the science process skills of STEM students?
4. Is there a significant influence of metacognition and inquiry-based learning on the science process skills of STEM students?

1.5 Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

H01: There is no significant correlation between metacognition and science process skills of STEM students.

H02: There is no significant correlation between inquiry-based learning and science process skills of STEM students.

H03: There is no significant influence of metacognition on science process skills of STEM students.

H04: There is no significant influence of inquiry-based learning on science process skills of STEM students.

H05: There is no significant combined influence of metacognition and inquiry-based learning on science process skills of STEM students.

1.6 Significance of the Study

This study aligns with Sustainable Development Goal (SDG) 4 — promoting inclusive, equitable, quality education and lifelong learning opportunities for all — and is significant to several stakeholders. For students, it identifies reflection (metacognitive) and inquiry-based strategies that could strengthen their science process skills and support independent, critical thinking. For teachers, the findings may guide the integration of metacognitive prompts and inquiry-based, student-centered classroom practices. Administrators and curriculum developers may use the results to design curricula that embed metacognition and inquiry practices, strengthening scientific literacy and supporting professional development. For future researchers, the study contributes to the growing literature on the intersection of metacognition, inquiry-based learning, and science process skills in the Philippine context, supporting the global agenda of SDG 4.

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1.7 Scope and Delimitation

This study was conducted among Senior High School STEM students in selected Cluster 5 schools of the Davao City Division. It examined the influence of metacognition and inquiry-based learning on science process skills, limited to six dimensions: observation, classification, hypothesizing, experimenting, analyzing, and communicating. The study was delimited to science classes during Academic Year 2025–2026; affective factors, prior academic performance, and teacher-related variables were not covered.

2. METHODS

2.1 Research Design

This study employed a quantitative, descriptive-predictive research design, combining validated, adapted questionnaires with statistical analysis to ensure reliable, meaningful interpretation. The descriptive component measured the current levels of the predictor variables (metacognition, inquiry-based learning) and the criterion variable (science process skills), while the predictive component examined the extent to which the predictors significantly predict science process skills. Creswell and Creswell (2018) note that descriptive-predictive designs are particularly useful for examining both the current status of variables and their predictive relationships.

2.2 Research Locale

The study was conducted in Cluster 5 public schools of the Davao City Division, Region XI, that offer the STEM strand at the Senior High School level. Cluster 5 was chosen for its diverse mix of public schools with a significant STEM population, making it suitable for examining variation in metacognition, inquiry-based learning, and science process skills; the primary inclusion criterion was the availability of the STEM strand, given its emphasis on scientific reasoning and higher-order thinking. Cluster 5 schools also reflect both the challenges and opportunities of implementing inquiry-driven, student-centered science education, providing a contextually relevant setting for the study.

2.3 Sample and Sampling Technique

The sample size was determined using Taro Yamane's formula (Yamane, 1967) with a 5% margin of error at a 95% confidence level, yielding 114 respondents from a population of 160 Senior High School STEM students (52 Grade 11 and 62 Grade 12). Inclusion criteria required that respondents be officially enrolled in science subjects during School Year 2025–2026, attend a Cluster 5 school, participate voluntarily, and be present during data collection.

Participants were selected through stratified random sampling (Neyman, 1934), with the population divided by grade level and samples proportionally allocated to ensure fair representation of both groups. Of the 114 respondents, 64 were Grade 12 and 50 were Grade 11, selected using a random number generator to minimize bias. An additional 10–15% of alternates were pre-selected to address potential non-response.

2.4 Research Instruments

A structured, adapted questionnaire was used, divided into three sections corresponding to the study's three variables: Metacognition, Inquiry-Based Learning, and Science Process Skills. The Science Process Skills section used multiple-choice items, while the Metacognition and Inquiry-Based Learning sections used a 4-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree).

Metacognition items were adapted from Schraw and Dennison's (1994) Metacognitive Awareness Inventory, with support from adaptations such as Ozturk (2021), and measured knowledge of cognition and its regulation. Inquiry-Based Learning items were adapted from Gejda and LaRocco's (2006) Inquiry-Based Instruction in Secondary Science Classrooms Survey, structured around the 5E Instructional Model (Engage, Explore, Explain, Elaborate,

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Evaluate). Science Process Skills items, in multiple-choice format, were adapted from Zeidan and Jayosi's (2015) Science Process Skills and Attitudes toward Science instrument and covered both basic skills (observing, classifying, measuring, predicting) and integrated skills (hypothesizing, experimenting, analyzing, communicating).

The instrument underwent content validation by three experts in science education. Prior to data collection, it was pilot-tested with 30 students who were not part of the study sample, and reliability was established using Cronbach's alpha, with a coefficient of 0.70 or higher considered acceptable.

Metacognition and Inquiry-Based Learning scores were interpreted using the following 4-point scale:

Range	Interpretation
3.26 – 4.00	Very High
2.51 – 3.25	High
1.76 – 2.50	Low
1.00 – 1.75	Very Low

Science Process Skills scores were interpreted using the following scale:

Range	Interpretation
3.20 – 4.00	Outstanding (O)
2.20 – 3.19	Very Satisfactory (VS)
1.60 – 2.19	Satisfactory (S)
0.80 – 1.59	Fairly Satisfactory (FS)
0.00 – 0.79	Did Not Meet Expectations (DNME)

2.5 Data Gathering Procedure

The adapted questionnaire was validated by three science education experts and pilot tested before administration. The researcher secured approval through a formal request to the Schools Division Superintendent of Davao City and the Public Schools District Supervisor of Cluster 5, with endorsements from the principals of participating schools. School coordinators were briefed on the study's objectives and the questionnaire-administration schedule. Respondents were oriented on the study's rationale, the voluntary nature of participation, and confidentiality, and informed consent (and, where applicable, parental consent and student assent) was obtained before distribution. Questionnaires were administered during regular science classes, either by the researcher or the teacher-in-charge, with clear instructions and sufficient time provided. All completed questionnaires were retrieved the same day and securely stored. Tabulated data were forwarded to a statistician for consolidation and analysis, after which results were presented and defended, then underwent technical reading and editing in preparation for publication.

2.6 Data Analysis

Mean and standard deviation were used to describe the levels of metacognition, inquiry-based learning, and science process skills. The Pearson product-moment correlation coefficient (Pearson r) was used to assess the relationship between the predictor variables (metacognition and inquiry-based learning) and science process skills. Multiple regression analysis was used to determine the predictive power of metacognition and inquiry-based learning on science process skills, addressing the predictive component of the research design. A significance level of $p < .05$ was set as the criterion for statistical significance.

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3. RESULTS

This section presents the descriptive, correlational, and regression analyses of data gathered from 114 STEM student respondents, followed by a summary of the findings.

3.1 Descriptive Analysis

Variable	SD	Mean	Interpretation
Metacognitive Awareness (MA)	**0.37**	**3.53**	**Very High**
Knowledge About Cognition	0.38	3.47	Very High
Regulation of Cognition	0.37	3.50	Very High
Inquiry-Based Learning (IBL)	**0.36**	**3.54**	**Very High**
Engage	0.50	3.50	Very High
Explore	0.43	3.49	Very High
Explain	0.41	3.55	Very High
Elaborate	0.40	3.55	Very High
Evaluate	0.37	3.62	Very High
Science Process Skills (SPS)	**0.79**	**2.47**	**Very Satisfactory**
Observing & Measuring	1.05	2.89	Very Satisfactory
Classifying & Inferring	1.49	3.12	Very Satisfactory
Communicating Results	1.50	2.44	Very Satisfactory
Hypothesizing & Predicting	1.48	2.06	Satisfactory
Experimenting & Analyzing	0.97	1.84	Satisfactory

Table 1. Descriptive analysis results (n = 114)

STEM students demonstrated a very high level of metacognitive awareness (M = 3.53, SD = 0.37), suggesting strong self-monitoring with moderate response variability; all MA indicators were likewise rated very high. Inquiry-based learning likewise obtained a very high overall mean (M = 3.54, SD = 0.36), indicating consistent immersion in an IBL environment with minimal variability, and all IBL indicators were rated very high. In contrast, science process skills yielded a markedly lower overall mean (M = 2.47, SD = 0.79), interpreted as Very Satisfactory but with substantially higher variability, indicating that students struggle with higher-order scientific abilities — particularly hypothesizing/predicting and experimenting/analyzing, both rated only Satisfactory. This pattern suggests that high metacognitive awareness and strong exposure to inquiry-based learning are, on their own, insufficient to produce advanced science process skills.

3.2 Correlation Analysis

Predictor	r	p	Decision on H0	Interpretation
Metacognitive Awareness	0.249	0.015	Reject H01	Positive, weak, significant
Inquiry-Based Learning	0.125	0.194	Fail to reject H02	Positive, very weak, not significant

Table 2. Correlation analysis results — relationship of predictors with science process skills

Metacognitive awareness showed a positive, weak, but statistically significant correlation with science process skills ($r = 0.249$, $p = 0.015 < .05$), leading to rejection of H01; as metacognitive awareness increased, science process skills increased slightly. Inquiry-based learning showed a positive but very weak, non-significant correlation with science process skills ($r = 0.125$, $p = 0.194 > .05$), and H02 was not rejected — indicating that despite students' high level of inquiry-based learning exposure, this was not meaningfully associated with their actual science process skills.

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3.3 Regression Analysis

Predictor	B	β	SE	t	p	Decision on H0	Interpretation
Intercept	2.75	—	0.66	4.18	0.000	—	—
Metacognitive Awareness	0.57	0.31	0.26	2.17	0.032	Reject H03	Significant
Inquiry-Based Learning	0.41	0.21	0.28	1.49	0.140	Fail to reject H04	Not significant

Table 3. Regression analysis results (DV: Science Process Skills). R = 0.320, R^2 = 0.102, Adjusted R^2 = 0.083, F = 4.38, p = 0.008.

Metacognitive awareness had a statistically significant but modest influence on science process skills (β = 0.31, p = 0.032), leading to rejection of H03; each one-point increase in metacognitive awareness was associated with a 0.57-point increase in science process skills, though the weak-to-moderate effect size indicates metacognitive awareness alone is not a dominant predictor. This is consistent with the descriptive results, where very high metacognitive awareness (M = 3.53) co-occurred with only Very Satisfactory science process skills (M = 2.47), suggesting that metacognitive strategies help but are insufficient on their own for developing skills such as hypothesizing and experimenting.

Inquiry-based learning did not have a statistically significant influence on science process skills (β = 0.21, p = 0.140), and H04 was not rejected — a striking result given that students reported very high IBL experiences (M = 3.54) across all subcomponents. This suggests that exposure to an inquiry-based environment does not, by itself, translate into the development of science process skills, and that the quality or fidelity of IBL implementation warrants closer examination.

Taken together, metacognitive awareness and inquiry-based learning accounted for only 10.2% of the variance in science process skills (R^2 = 0.102, Adjusted R^2 = 0.083), leaving nearly 90% unexplained; although the overall model was statistically significant (F = 4.38, p = 0.008), its low R^2 indicates weak practical predictive power. Notably, inquiry-based learning — despite being perceived as very high by students — contributed no significant unique variance beyond what metacognitive awareness already provided, a discrepancy that merits further pedagogical reflection.

3.4 Summary of Findings

1. Metacognitive awareness has a weak, significant correlation with science process skills.
2. Inquiry-based learning has no significant correlation with science process skills.
3. Metacognitive awareness has a weak, significant influence on science process skills.
4. Inquiry-based learning has no significant influence on science process skills.
5. Metacognitive awareness and inquiry-based learning combined have weak predictive power on science process skills (R^2 = 0.102).

4. DISCUSSION

4.1 Metacognitive Awareness, Inquiry-Based Learning, and Science Process Skills

A striking paradox emerged from the results: STEM students demonstrated very high levels of metacognitive awareness and inquiry-based learning, yet their actual science process skills — particularly hypothesizing/predicting and experimenting/analyzing — fell to only Satisfactory levels.

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These findings align with prior research. Mariano (2024) found that incorporating metacognitive design thinking into STEM students' science investigatory projects significantly enhanced their 21st-century skills, and Putri et al. (2025) showed that strengthening metacognitive-executive abilities further boosted students' critical thinking, cognitive flexibility, and self-regulation. On inquiry-based learning, Balanay and Fajardo (2025) documented the widespread adoption of the 5E Instructional Model in Philippine science classrooms, consistent with the very high IBL perceptions found here, while the low science-process-skill results mirror Aydoğan Ağmanalmaz and Polat (2025), who found students had significant difficulty identifying variables to control and manipulate in experimental setups. Kapici, Akcay, and Cakir (2022) similarly found that guided inquiry laboratories, while important for conceptual knowledge, had no significant impact on inquiry-skill acquisition.

In contrast to this study's very high IBL perceptions, Cairns (2019) reported curvilinear relations in which very high autonomy actually depressed achievement, challenging the assumption that more inquiry-based learning automatically improves outcomes and suggesting that too much autonomy without adequate structure may hinder skill development.

4.2 Correlation of Metacognitive Awareness and Inquiry-Based Learning with Science Process Skills

The weak positive correlation found between metacognitive awareness and science process skills aligns with Stanton, Sebesta, and Dunlosky (2021), who found that students' self-reported metacognitive awareness correlated only weakly with actual laboratory performance in introductory biology, pointing to a disconnect between perceived and applied cognition; Bellon, Fias, and De Smedt (2020) likewise suggest that metacognitive monitoring may be highly domain-specific. In contrast, research in Indonesia found that inquiry-based learning significantly improved both metacognitive and science process skills among high school students (Damopolii et al., 2020), a university study found a strong positive relationship between metacognitive awareness, metacognitive knowledge, and academic performance (Barta, Tamás, & Szamosközi, 2020), and De Backer, Van Keer, and Valcke (2020) found that certain types of socially shared metacognitive regulation were significantly related to student performance.

The absence of a significant correlation between IBL and SPS in this study is consistent with Jerrim, Oliver, and Sims (2022), who analyzed longitudinal PISA data and found near-zero correlations between reported IBL exposure and scientific procedural skills across 15 countries, and with Kruit et al. (2018), who found no significant relationship between the frequency of open-inquiry activities in Dutch classrooms and students' observation and measurement competencies. Fang, Wei, and Wang (2024), however, reported a modest but significant positive correlation between the implementation of structured inquiry and SPS in Chinese secondary science classes, suggesting that how IBL is operationalized — structured versus open-ended — matters for its effect on measurable skills.

4.3 Influence of Metacognitive Awareness and Inquiry-Based Learning on Science Process Skills

The correlation and regression analyses together showed that metacognitive awareness had a weak but statistically significant positive relationship with and predictive influence on science process skills, whereas inquiry-based learning showed a very weak, non-significant correlation and no significant predictive power. These results are consistent with Canoy (2024), who examined the influence of IBL on integrated science process skills among 249 Philippine college students and, despite a very high level of IBL perception, found no significant relationship with science process skills, and with Modesto (2025), who found a significant but weak positive relationship between shared metacognition and physics performance within a Community of Inquiry framework. Together, these studies support the conclusion that metacognitive awareness contributes modestly to student outcomes, while IBL perceptions alone do not reliably translate into measurable science process skills.

This contrasts with Irwanto, Rohaeti, and Prodjosantoso (2021), whose meta-analysis of forty-two studies found a significant positive effect of inquiry-based learning overall. This apparent contradiction may reflect differences in implementation quality and scaffolding: the meta-analysis predominantly included well-structured, guided-

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inquiry interventions that explicitly taught hypothesis formulation, experimental design, and data analysis prior to independent inquiry — a level of explicit scaffolding this study's IBL exposure may not have consistently provided.

5. CONCLUSION

While STEM students displayed high levels of metacognitive awareness and inquiry-based learning, their science process skills remained at only a Very Satisfactory level — a contradiction this study interprets through Bruner's Discovery Learning Theory (1961) as evidence that learning is not an automatic consequence of exposure to inquiry environments, but requires active, intentional engagement in the discovery process. The weak correlation between metacognitive awareness and science process skills ($r = 0.249$) and the non-significant relationship between inquiry-based learning and science process skills ($r = 0.125$) suggest that students may be experiencing what Bruner described as "passive discovery" — engaging in inquiry activities superficially without genuinely constructing knowledge through categorization, coding, and inductive reasoning. The finding that both variables combined account for only 10.2% of the variance in science process skills further underscores Bruner's position that deeper cognitive development requires authentic disequilibrium, active hypothesis formulation, and reflective abstraction, while the non-significant influence of inquiry-based learning ($p = 0.140$) corroborates his warning that, without explicit scaffolding and structured guidance, students may fail to develop higher-order thinking skills. Taken together, these findings validate the theory's central claim: inquiry-based learning and metacognitive awareness are essential components of effective science education, but their influence on science process skills is mediated by the quality and depth of students' cognitive engagement — consistent with Bruner's notion of a "spiral curriculum" that revisits and deepens skills over time rather than assuming they emerge from exposure alone.

6. RECOMMENDATIONS

1. Future researchers should examine other variables — such as intrinsic motivation and teacher-related factors — that may account for the remaining 89.8% of unexplained variance in science process skills.
2. The Department of Education should consider establishing hypothesis formulation and experimental design as formal, assessable competencies within the science curriculum.
3. School administrators should support this shift through sustained professional development in inquiry-based learning, extended laboratory time for reflection, and reduced class sizes to allow individualized scaffolding.
4. Teachers should intentionally design tasks that trigger cognitive disequilibrium and provide explicit, structured instruction before transitioning students to open inquiry.
5. Students should be encouraged to actively engage in self-regulation, treat cognitive conflict as a learning opportunity, and use metacognitive strategies to monitor their own investigative progress.

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