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The Metacognition–Social Complexity-Based Learning Model: A Culturally Grounded Framework to Improve HOTS and Collaboration in Science Learning

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Abstract. Improving Higher Order Thinking Skills (HOTS) and collaboration still poses various challenges in elementary science education, especially when learning materials are abstract and disconnected from students' cultural contexts. This study aims to develop, validate, and evaluate the MetaSC learning model designed to support culturally grounded and inquiry-oriented science learning in grade 4. The Research and Development (R&D) design was implemented using the Plomp model, including expert validation, user acceptance testing, and a quasi-experimental pre-test-post-test control group design. The instruments consisted of an expert validation sheet, teacher and student response questionnaires, a HOTS test, and a collaboration rubric. The results showed that the MetaSC model achieved an excellent level of expert validation, demonstrating theoretical coherence and instructional feasibility. User responses indicated a high level of practicality and acceptability. Furthermore, experimental findings revealed significant improvements in both HOTS (Higher Order Thinking Skills) and collaboration skills among students using the MetaSC model compared to those receiving conventional instruction. These findings suggest that

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the MetaSC framework offers a promising approach for integrating ethnoscience, metacognitive learning, and collaboration to support the development of 21st-century competencies in elementary science education.

Keywords: collaboration; science; HOTS; MetaSC model; metacognition; elementary

1. Introduction

The landscape of elementary education in the 21st century emphasizes competencies critical for the modern workforce, including higher-order thinking skills (HOTS), collaboration, and communication. The integration of 21st-century skills prepares students to navigate contemporary society. Studies indicate that critical thinking, problem-solving, and collaboration are prioritized in STEM disciplines as essential for success (Hamzah et al., 2022; Anugrah et al., 2025). Inquiry-based learning, emphasizing real-life problem-solving, advances these competencies among students (Shoimah & Fatoni, 2023).

Evidence shows that engagement in scientific research enhances creativity and higher-order thinking skills for addressing future challenges (Affandy et al., 2024). Elementary education faces challenges in science learning, primarily due to the abstract nature of scientific concepts leading to misconceptions among students. These misconceptions impede understanding of scientific material (Supiyati et al., 2023). Traditional methods often fail to address these issues, necessitating innovative teaching strategies for deeper conceptual understanding. Educators advocate for student-centered approaches like problem-based learning (PBL) and inquiry learning, which benefit students' comprehension of scientific concepts.

The need for contextual learning through ethnoscience has gained importance in educational discourse (Supiyati et al., 2023; Astuti et al., 2024). Ethnoscience connects scientific principles to cultural practices, promoting meaningful learning experiences (Supiyati et al., 2023). This approach develops critical thinking by relating concepts to local contexts and cultivates scientific inquiry rooted in cultural identities (Kristidhika et al., 2020). By grounding learning in familiar contexts, educators can enhance understanding of abstract scientific principles. Elementary education requires focus on 21st-century competencies while addressing science learning challenges (Dharma & Lestari, 2022). Through innovative, culturally responsive pedagogies like ethnoscience, educators can create effective learning environments for diverse student populations.

The implementation of metacognition-based learning models, such as Project-Based Learning (PjBL), is pivotal in fostering higher-order thinking skills (HOTS) among elementary students. Metacognitive frameworks encourage students to engage in self-regulation and reflection, thereby enhancing their ability to manage their cognitive processes during learning (Carvalho & Santos, 2022). The integration of PjBL within a STEM context has been effective in promoting both critical thinking and creativity (Safaruddin et al., 2020), while also encouraging collaboration and complex problem-solving (Dewi et al., 2023). However, these approaches are underexploited in elementary science education. Current literature highlights notable gaps in research surrounding metacognitive learning models catered specifically to elementary students, particularly regarding empirical validations of these models at the primary education level, this underscores the need for robust, evidence-based instructional strategies that blend metacognition with PjBL methodologies. Meanwhile, the ethnoscience approach is posited to effectively bridge conceptual gaps and address misconceptions that frequently arise due to the abstract nature of scientific material for elementary students, by connecting scientific concepts with local cultural practices, thereby rendering learning more meaningful (Wahyudi et al., 2022; Zaki et al., 2024). However, there currently exists no ethnoscience-based learning model that has been systematically developed, validated by experts, and empirically tested for its effectiveness within the context of elementary school science education.

Furthermore, although metacognition-based models and Project-Based Learning have been demonstrated to support the development of HOTS, creativity, and collaboration (Beier et al., 2019; Chen et al., 2018), their implementation in elementary education remains minimal and is not supported by structured, pedagogical, and contextual learning tools. This situation reveals a theoretical gap in the lack of a comprehensive synthesis between ethnoscience, HOTS, collaboration, and metacognition; a practical gap in the absence of learning models ready for teacher implementation in the field; and an empirical gap in the scarcity of experimental research testing the effectiveness of the developed models. Consequently, the development of the MetaSC model with an ethnoscience foundation, specifically utilizing Sukoharjo herbal medicine as an authentic local context, is both relevant and strategic for contributing to research and practice in elementary school science education.

The urgency of this research is underscored by the necessity to develop a science learning model that not only fosters higher-order thinking skills but also aligns with students' cultural contexts. This is crucial given that abstract learning devoid of meaningful experiences often leads to misconceptions and diminished learning engagement (Mora et al., 2020). While metacognition-based approaches and Project-Based Learning have demonstrated efficacy in enhancing students' higher-order thinking skills, creativity, and collaboration, their implementation in elementary education remains limited and lacks a structured pedagogical model supported by teaching tools and empirical validation.

Moreover, ethnoscience studies in science education have shown significant potential in enhancing the relevance of scientific content by linking scientific concepts with local cultural practices (Irdalisa et al., 2023). However, the integration of ethnoscience within Project-Based Learning designs and metacognition is infrequent and has not been fully developed into a replicable learning model. Consequently, the development of the ethnoscience-based MetaSC model in the context of Sukoharjo herbal medicine presents an innovative contribution. This model synthesizes metacognition, project-based learning, collaboration, and ethnoscience into a cohesive instructional framework that has been validated by experts and tested for classroom effectiveness (Mora et al., 2020; Chen et al., 2018). This innovation is anticipated to address existing theoretical, practical, and empirical gaps, while offering learning solutions that are more adaptive, contextual, and pertinent to the demands of 21st-century competencies in elementary education.

Responding to the urgency of the research and the identified theoretical and empirical gaps, this study aims to develop a MetaSC learning model that is feasible for implementation in elementary school learning based on evaluations from experts, teachers, and students, as well as to examine its association with students' higher-order thinking skills and collaboration skills. It is hoped that the successful achievement of these objectives will result in a learning model that is not only conceptually and practically validated but also proven to have an impact on pedagogical outcomes in elementary school science education.

2. Literature Review

2.1 MetaSC Learning Model in Elementary Science Education

The MetaSC Learning Model is positioned within a dynamic context of elementary science education, taking into account the cognitive development of elementary school students as framed by Piaget's stages of development, particularly from the concrete to transitional phase. At this stage, learners often grapple with the dual challenges of abstract reasoning and persistent misconceptions that can hinder their understanding of scientific concepts.

Research suggests that elementary students frequently exhibit low higher-order thinking skills (HOTS) and struggle to collaborate effectively, often due to inadequacies in their problem-solving capabilities (Nadia et al., 2023; Hussein, 2021). Furthermore, leveraging local phenomena in science education has been shown to enhance relevance and motivation, thereby facilitating better conceptual understanding and engagement (Zainil et al., 2022; Zaki et al., 2024). This contextual relevance aligns well with the need for instruction that supports students' developmental readiness, fostering both scientific inquiry and cognitive growth.

The theoretical foundations of the MetaSC Model converge on a synthesis of key educational theories, including Constructivism, Sociocultural Theory, and Metacognitive Learning, alongside methodologies such as Project-Based Learning (PBL) and perspectives on Social Complexity. These theories are particularly well-suited for the elementary education context as they promote learner-centered approaches where students are encouraged to construct knowledge collaboratively. For instance, the inclusion of metacognitive strategies and self-regulated learning practices supports students in reflecting upon their learning processes, thus enhancing their critical thinking skills (Cohen, 2018). The design of the MetaSC Model emphasizes pedagogical mechanisms such as scaffolding and role flexibility that empower both teachers and students, nurturing a collaborative learning environment characterized by inquiry and critical engagement.

Additionally, this model aims to specifically address the enhancement of HOTS and collaborative abilities, making it an innovative instructional framework that positions itself favorably against existing pedagogical models in elementary science education (Nazim et al., 2024). The integration of assessment practices within the MetaSC framework also ensures that learning outcomes are systematically aligned with educational goals, fostering a holistic approach to student assessment and performance. The reviewed literature highlights the potential of metacognitive, project-based, and collaborative learning approaches for promoting HOTS and student engagement. Building on these foundations, the present study introduces the MetaSC learning model, which integrates ethnoscience, metacognitive regulation, and structured collaboration within a coherent instructional framework for elementary science education.

2.2 Development and Effects of Learning Models Targeting HOTS and Collaboration

The evolution of learning models aimed at fostering Higher-Order Thinking Skills (HOTS) and collaboration reflects a shift from traditional, teacher-centered approaches to more student-centered, interactive, and technology-supported pedagogies. Research highlights those conventional methods, which focus primarily on information transfer, often fail to adequately develop students' analytical, creative, and problem-solving abilities—core components of HOTS.

Innovative models such as Blended Web Mobile Learning (BWML), Blended Inquiry Learning (BIL), and the INREACTIV approach integrate inquiry-based, problem-based, and blended learning strategies, frequently supported by digital platforms and applications (Riadi, 2024; Riwayatiningsih et al., 2025). These models emphasize phases like investigation, analysis, peer verification, and collaborative problem-solving, resulting in significant improvements in students' HOTS, engagement, and motivation across diverse educational contexts (Prahani et al., 2020). Notably, the integration of creative pedagogy within problem-based learning and the use of gamification and multimodal resources further enhance critical thinking, creativity, and collaborative skills, making learning more relevant and effective for 21st-century demands (Anugrah et al., 2025; Supena et al., 2021).

Collaboration-focused models, including co-teaching, peer assessment, and community-based social collaborative e-learning, have demonstrated moderate to strong positive effects on both academic achievement and the development of collaborative competencies. Studies show that collaborative learning not only improves content mastery and motivation but also narrows achievement gaps among students of varying academic abilities (Rodriguez-Salvador & Castillo-Valdez, 2023; Syamsudin et al., 2025). However, challenges such as digital infrastructure disparities, the need for teacher professional development, and the sustainability of collaborative gains remain. Overall, the literature underscores the necessity of continuous innovation and adaptation in learning model design to effectively cultivate HOTS and collaboration, ensuring students are equipped for lifelong learning and professional success in dynamic environments (Mora et al., 2020; Vembye et al., 2023).

To address the limitations of existing instructional approaches, this study proposes the MetaSC learning model as an integrated framework that combines ethnoscience, metacognitive regulation, Project-Based Learning (PjBL), and structured collaboration within elementary science education. Unlike many previous models that focus primarily on either HOTS or collaboration, MetaSC is designed to simultaneously foster both competencies through culturally relevant and inquiry-oriented learning experiences.

The model employs local ethnoscience contexts as meaningful learning anchors, while metacognitive scaffolding supports students in planning, monitoring, and evaluating their learning processes. In addition, structured collaborative roles are embedded throughout the learning process to promote equitable participation, shared responsibility, and collective knowledge construction. The operational structure of the MetaSC model is organized into six interconnected phases, as presented in Table 1.

Table 1: Syntax of the MetaSC Learning Model

Phase	Teacher Role	Student Activity
1. Contextual Exploration	Introduces local ethnoscience phenomena (e.g., *jamu* Sukoharjo) and presents authentic problems.	Observe, discuss prior knowledge, and identify issues related to the phenomenon.
2. Project Planning	Guides students in defining project goals, organizing groups, and assigning collaborative roles.	Formulate questions, develop investigation plans, and distribute responsibilities.
3. Investigation and Knowledge Construction	Facilitates inquiry activities, provides scaffolding, and supports evidence gathering.	Collect data, conduct observations, analyze information, and construct explanations.
4. Collaborative Reflection and Revision	Encourages peer discussion, feedback exchange, and reflection on learning progress.	Compare findings, evaluate ideas, revise project outputs, and solve emerging problems collaboratively.
5. Presentation and Evaluation	Facilitates project presentation and assesses learning outcomes.	Present project results, communicate conclusions, and respond to peer questions.
6. Metacognitive Consolidation	Guides students in reflecting on both learning outcomes and learning processes.	Evaluate personal and group learning experiences and identify future improvements.

The MetaSC learning model integrates ethnoscience as a contextual learning foundation, Project-Based Learning as the instructional structure, metacognitive regulation as a mechanism for self-monitoring and reflection, and structured collaboration as a means of promoting equitable participation and collective knowledge construction. Through these six interconnected phases, students are guided from contextual exploration to metacognitive consolidation, enabling the simultaneous development of HOTS and collaboration skills in elementary science learning.

3. Methodology

3.1 Research Design

This study employs a Research and Development (R&D) methodology to develop and evaluate the feasibility of the MetaSC learning model within the context of Elementary School Science education (Gustiani, 2019). The development process consist of three phases based on Plomp Model: (1) Preliminary Research, encompassing needs analysis, student characteristics, curriculum documents, and pertinent theories; (2) Design and Development of Prototype, involving the design of the initial model alongside learning tools and instruments, followed by expert validation and revisions based on feedback; and (3) Assessment Phase, which emphasizes the trial implementation and evaluation of the model's effectiveness (Hastuti et al., 2020).

During the assessment phase, a quasi-experimental Pretest–Posttest Control Group Design was employed, with one experimental group receiving instruction via the MetaSC model and a control group receiving conventional instruction. Before implementation, participating teachers attended a training workshop on the MetaSC model, covering its theoretical foundations, instructional syntax, learning materials, and assessment procedures. Lesson simulations and guided discussions were conducted to ensure consistent implementation. Although all teachers had experience teaching elementary science, they had limited prior experience with structured metacognitive instruction, making the training an important step in maintaining implementation fidelity.

3.2 Participants and Research Site

The research was conducted at a public elementary school in Sukoharjo Regency, Indonesia, during the even semester of the 2024/2025 academic year. The participants comprised three groups: (1) validator experts, including two specialists in learning models and one expert in science education, who evaluated the validity of the model and its supporting tools; (2) four Grade 4 teachers, who served as implementers and users of the model during the practicality testing phase; and (3) 194 Grade 4 students, who participated in the effectiveness testing. During the assessment phase, a quasi-experimental pretest–posttest control group design was employed. Four parallel Grade 4 classes were available at the research site, from which two classes were randomly selected using cluster random sampling (Asenahabi & Peters, 2023).

Due to the use of intact classroom groups in a natural school setting, one selected class was assigned as the experimental group (n = 97) and received instruction using the MetaSC model, while the other class was assigned as the control group (n = 97) and received regular science instruction consisting of teacher explanation, textbook-guided learning activities, and classroom discussions without the integration of ethnoscience, project-based learning, or metacognitive scaffolding. This approach was adopted to maintain the existing classroom structure and minimize disruption to regular instructional activities (Asenahabi & Peters, 2023).

3.3 Research Instruments

A research instrument was developed to collect data related to model validity, user acceptance, and learning effects on target competencies. Details of the instrument are shown in the following table.

Table 2: Use of Research Instruments

Instruments	Objectives	Format
Expert Validation Sheet	To assess the feasibility of the model and teaching tools	Likert scale + comments
Teacher & Student Response Questionnaire	To measure perceptions, experiences, and acceptance	Likert scale + open-ended
HOTS Test	Measuring improvements in higher-order thinking skills	Pretest–Posttest
Collaboration Rubric	To measure students' collaborative skills	Structured observation

The instruments were developed in accordance with curriculum competency indicators, the principles of Higher Order Thinking Skills (HOTS) at levels C4–C6, and observable indicators of collaborative behavior in group learning (Nadia et al., 2023; Binti Misrom et al., 2020; Megawati et al., 2020). Prior to their application in the implementation phase, all research instruments were subjected to validity and reliability testing. Content validity was established through evaluations conducted by two experts in learning models and one expert in science subject matter, utilizing a four-level Likert-scale validation sheet (Perdana et al., 2021).

The validation outcomes were subsequently analysed using mean scores and categorized based on the assessment range. Instrument reliability was assessed using Cronbach's Alpha coefficient for scale-based instruments and inter-rater reliability for performance assessment instruments. A summary of the validity and reliability analysis results is presented in the following table 3.

Table 3: Results of Instrument Validity and Reliability Tests

HOTS Test Instrument	Average Validity (0–4)	Validity Category	Reliability	Types of Reliability	Interpretation
Collaboration Rubric	3.60	Excellent	0.82	Cronbach's Alpha	Reliable
HOTS Test Instrument	3.55	Good	0.91	Inter-rater Reliability	Consistent across raters

According to the analysis results presented in Table 3, all instruments exhibited validity within the good to very good range (score range 3.45–3.72), thereby meeting the eligibility criteria for research instruments. The expert validation sheet received the highest score, reflecting the alignment of its constructs, indicators, and structure with the development objectives. Conversely, the teacher and student response questionnaires, while receiving the lowest scores, were still deemed feasible, albeit requiring minor revisions to the wording of certain items (Okello, 2022). The collaboration rubric was evaluated using two complementary reliability indicators. Cronbach's Alpha ($\alpha = 0.82$) was used to assess the internal consistency of the rubric dimensions, while inter-rater reliability (IRR = 0.91) was calculated to determine the level of agreement between observers during classroom observations. The results indicate that the rubric demonstrated both strong internal consistency and high scoring consistency across raters.

3.4 Data Analysis
Data were analyzed employing a mixed-methods approach. Expert validation data were assessed by calculating mean scores and categorizing eligibility. Teacher and student response data were examined using descriptive statistics, including means, standard deviations, and category intervals. Paired sample t-tests were conducted to evaluate learning effectiveness for each group, while ANCOVA was utilized to compare the final outcomes between the experimental and control groups (Okello, 2022). Qualitative data, such as expert comments and open-ended responses, were analyzed through a thematic coding approach to identify patterns of perception and input for model development (Vaismoradi & Snelgrove, 2019).

3.5 Ethical Consideration
This study received institutional approval from Universitas Negeri Yogyakarta prior to data collection. Written informed consent was obtained from school administrators and parents or guardians of all participating students, while verbal assent was obtained from the students themselves. Participation was voluntary, and all data were collected anonymously to ensure confidentiality and protect participants' privacy throughout the research process.

4. Results and Findings
3.6 Results of Expert Validation of the MetaSC Model and Instructional Materials
The validation process was conducted by three experts: two learning model specialists and one elementary science content expert. Validation employed structured instruments with a four-point Likert scale (1 = poor, 2 = fair, 3 = good, 4 = excellent) covering multiple dimensions of the MetaSC model and its supporting materials. Experts evaluated each component independently over a two-week period, providing both quantitative ratings and qualitative feedback for improvement.

Table 4: Expert Validation Results of MetaSC Model Components

No	Validation Aspect	Mean Score	Category	Key Feedback
1	Model Components (Rationalization & Theory)	3.71	Excellent	Strengthen explicit linkage between theories
2	Context, Relevance, and Integration	3.75	Excellent	Jamu integration already clear and appropriate
3	Theoretical System (Accuracy & Currency)	3.67	Excellent	Ensure consistency in theoretical framework
4	Syntax of MetaSC Model	3.80	Excellent	Logic and sequence well-structured
5	Social System	3.73	Excellent	Clarify structured interaction patterns

6	Reaction Principles	3.78	Excellent	Explicit scaffolding guidelines needed
7	Supporting System (Instructional Materials)	3.69	Excellent	Enhance alignment between materials and syntax
8	Instructional and Nurturant Effects	3.72	Excellent	Theoretical potential for HOTS clearly articulated
9	Content/Substance Quality	3.74	Excellent	Ethnoscience integration scientifically accurate
10	Language Quality	3.65	Excellent	Minor revisions for clarity and consistency
11	Presentation Format	3.82	Excellent	Systematic and coherent
12	Cover Design	3.70	Excellent	Ethnoscience elements well-represented
13	Content Design	3.76	Excellent	Typography and proportionality appropriate
14	Implementation and Innovation	3.77	Excellent	Unique contribution clear; ease of use confirmed
	Overall Average	3.73	Excellent	Minor revisions required across components

The overall validation score of 3.73 indicates that the MetaSC model achieved an "excellent" validity level across all assessed dimensions. The syntax structure received the highest rating (M = 3.80), reflecting strong logical coherence in phase sequencing and instructional flow. Presentation format was also highly rated (M = 3.82), demonstrating systematic organization and visual clarity. The lowest score appeared in language quality (M = 3.65), pointing to the need for minor refinements in terminology consistency and sentence clarity.

Table 5: Expert Validation Results of Instructional Materials

Component	**Mean Score**	**Category**	**Specific Notes**
Lesson Plans (Modul Ajar)	3.68	Excellent	Add time allocation details per phase
Student Worksheets (LKPD)	3.72	Excellent	LKPD facilitates HOTS and collaboration well
Teacher's Guidebook	3.70	Excellent	Include step-by-step implementation examples
Student Book	3.75	Excellent	Content clear and age-appropriate
Assessment Instruments	3.66	Excellent	Align assessment more explicitly with HOTS levels (C4-C6)
Collaboration Rubric	3.69	Excellent	Operationalize behavioral indicators more explicitly
Overall Materials	3.70	Excellent	Materials ready with minor refinements

All instructional materials scored above 3.65, confirming strong alignment with the MetaSC model framework. The Student Book received the highest rating (M = 3.75), with experts commending its age-appropriate language and clear presentation of ethnoscience contexts. Assessment instruments, while still in the excellent category (M = 3.66), required the most attention, particularly in ensuring that test items directly measure higher-order cognitive processes (analyzing, evaluating, creating) rather than recall or comprehension.

Overall, the expert feedback supported the feasibility of the MetaSC framework while highlighting areas requiring refinement to strengthen the integration of metacognitive scaffolding, ethnoscience authenticity, collaborative role structures, and assessment alignment. These findings suggest that the contribution of the study lies not merely in proposing a new instructional model, but in providing a coherent metacognitive ethnoscience-based collaborative science framework that systematically integrates these complementary components within elementary science learning.

Table 6: Major Revisions Implemented Based on Expert Feedback

Aspect	Before Revision	After Revision
Metacognitive prompts	Generic reflection questions	Phase-specific sentence starters and guided questions
Ethnoscience mapping	Jamu mentioned as cultural context	Explicit table linking jamu properties to science concepts
Collaborative roles	General group work instructions	Defined roles with task cards and responsibility charts
Assessment items	Mixed cognitive levels (C2-C5)	Targeted HOTS items (C4-C6) with ethnoscience contexts
Teacher scaffolding	Brief general guidance	Detailed dialogue examples and scaffolding strategies per phase

All recommended revisions were incorporated into the final prototype prior to user response testing and field implementation. Expert consensus was documented through signed validation sheets, with both model experts and the content expert concluding that the MetaSC model and its instructional materials were "suitable for field use with minor revisions." Based on these results, the model advanced to the next phase of evaluation, meeting the validity threshold required for empirical testing in elementary science classrooms.

3.7 User Response to the Implementation of the MetaSC Model

User response data were collected from four fourth-grade teachers and 194 students across four classes who participated in the field implementation of the MetaSC model. Teachers completed a 25-item questionnaire assessing clarity, practicality, engagement potential, and overall acceptability of the model. Students responded to a 20-item age-appropriate questionnaire focusing on learning experience, ease of understanding instructions, interest in activities, and perceived value of collaboration. Both instruments used a four-point Likert scale (1 = poor, 2 = fair, 3 = good, 4 = excellent) and included open-ended questions for qualitative feedback.

Table 7: Summary of User Response Results

Respondent Group	N	Mean Score	SD	Category	Response Rate
Teachers	4	3.68	0.21	Excellent	100%
Students	194	3.54	0.38	Excellent	100%
Overall	198	3.56	0.35	Excellent	100%

Both teachers and students demonstrated highly positive responses to the MetaSC model implementation. Teachers' mean score (M = 3.68, SD = 0.21) indicates strong acceptance with minimal variation across respondents, suggesting consistent perceptions of the model's quality and feasibility. Students' responses (M = 3.54, SD = 0.38) also fall within the excellent category, though with slightly greater variability typical in elementary-age populations with diverse learning preferences and prior experiences.

Table 8: Teacher Response by Dimension

Dimension	Mean	SD	Category	Key Indicators
Clarity of Instructional Steps	3.75	0.18	Excellent	Syntax phases easy to follow
Practicality of Implementation	3.58	0.25	Excellent	Time management requires practice
Student Engagement Potential	3.81	0.15	Excellent	Ethnoscience context highly motivating
Material Completeness	3.62	0.22	Excellent	LKPD and teacher guide helpful
Assessment Usability	3.65	0.20	Excellent	Rubrics clear but require familiarization
Overall, Teacher Acceptance	3.68	0.21	Excellent	Willing to continue using model

Teachers rated student engagement potential highest (M = 3.81), particularly noting that the integration of local jamu knowledge captured students' curiosity and cultural pride. Practicality of implementation received the lowest score among dimensions (M = 3.58), primarily due to initial challenges in managing time during the metacognitive reflection phases. However, teachers reported that pacing improved significantly by the second lesson as they became more familiar with facilitation techniques.

Table 9: Student Response by Dimension

Dimension	Mean	SD	Category	Key Indicators
Ease of Understanding Instructions	3.48	0.42	Good	Some students needed repeated explanations
Interest in Learning Activities	3.67	0.35	Excellent	Hands-on jamu exploration highly enjoyable
Collaboration Experience	3.59	0.38	Excellent	Working in groups was fun and helpful
Cultural Relevance	3.62	0.36	Excellent	Learning about jamu felt meaningful
Perceived Learning Gain	3.51	0.40	Excellent	Students felt they learned new thinking skills
Overall Student Satisfaction	3.54	0.38	Excellent	Would like more lessons using this approach

Students expressed strongest positive responses toward interest in learning activities (M = 3.67) and cultural relevance (M = 3.62), indicating that the ethnoscience-based approach successfully connected abstract science concepts to tangible, familiar contexts. The dimension receiving the lowest rating was ease of understanding instructions (M = 3.48), suggesting that some students, particularly those with lower prior achievement, required additional scaffolding during initial implementation. Qualitative analysis of open-ended responses using thematic coding revealed four dominant themes:

Table 10: Thematic Analysis of Qualitative Responses

Theme	Frequency (Teachers/Students)	Representative Quotes	Key Findings
Clarity of Instruction	T: 3/4 S: 28/112	Teachers: "The step-by-step format made it easy to know what to do next" "The metacognitive prompts were helpful for guiding student reflection" Students: "At first the reflection questions were confusing, but then we got used to it" "The instructions in LKPD were clear"	Structured syntax and explicit guidance appreciated; initial familiarization period needed for metacognitive components
Engagement and Motivation	T: 4/4 S: 87/112	Teachers: "Students were far more engaged than in regular lessons" "The use of jamu immediately grabbed their attention because it's part of their daily lives" Students: "I liked learning about jamu my grandmother makes" "Working on the project was fun because we could try real things" "I didn't know science could be about things we see at home"	Most frequently mentioned theme; ethnoscience context significantly enhanced motivation and relevance
Collaboration Experience	T: 3/4 S: 71/112	Teachers: "Defined roles	Generally positive; role structuring

		helped students participate more equally" "Even quieter students contributed because they had specific responsibilities" Students: "My friends helped me when I didn't understand" "It was good to share ideas" "Sometimes one person wanted to do everything" (challenge) "We had to learn to listen to each other" (challenge)	improved equitable participation, though some groups needed support managing dominance issues

Thematic analysis revealed strong positive sentiment across all four major themes. Engagement and motivation emerged as the most prominent theme, with universal teacher endorsement and mention by 78% of students who provided qualitative feedback. The ethnoscience approach successfully bridged abstract scientific concepts with students' everyday experiences, creating authentic learning contexts that resonated with their cultural backgrounds.

Minor concerns raised by teachers included the need for additional time during initial implementation to familiarize students with metacognitive reflection and the importance of advance preparation for ethnoscience materials (jamu samples, visual aids). One teacher suggested providing video tutorials for complex procedures. Student feedback occasionally mentioned dominance issues in group work, indicating the need for ongoing teacher monitoring to ensure equitable participation. Teachers and students demonstrated high levels of acceptance toward the MetaSC model, with particularly positive perceptions regarding cultural relevance, engagement potential, and collaborative learning experiences.

The integration of local jamu knowledge successfully enhanced motivation and created meaningful connections between scientific concepts and students' lived contexts. While minor adjustments in instructional pacing and scaffolding intensity were recommended, overall user response confirms that the MetaSC model is both practical and well-received, meeting the criteria for sustained implementation in elementary science education.

3.8 Pre-Implementation Equivalency Test

Prior to intervention, equivalency testing was conducted to ensure comparable baseline abilities between experimental (n = 97) and control (n = 97) groups.

Normality was confirmed using Shapiro-Wilk test ($p > 0.05$ for both groups on both variables), and homogeneity of variance was verified through Levene's test ($p > 0.05$). Independent samples t-test results indicated no significant differences in pretest scores for either HOTS ($t = 0.784$, $p = 0.435$) or collaboration skills ($t = 0.621$, $p = 0.536$), confirming initial equivalence between groups.

Table 11: Pre-Implementation Equivalency Test Results

Variable	Group	N	Pretest Mean (SD)	t	df	p	Conclusion
HOTS	Experimental	97	54.32 (8.45)	0.784	192	0.435	Equivalent
	Control	97	53.18 (8.92)				
Collaboration Skills	Experimental	97	58.75 (7.63)	0.621	192	0.536	Equivalent
	Control	97	57.89 (8.12)				

3.9 Impact on Higher Order Thinking Skills (HOTS)
Both groups showed significant improvement from pretest to posttest, but the experimental group demonstrated substantially greater gains (24.32 points) compared to the control group (11.39 points). ANCOVA results, controlling for pretest scores, confirmed that the experimental group's posttest performance was significantly superior ($p < .001$) with a large effect size ($\eta^2 = 0.566$), indicating that 56.6% of variance in posttest HOTS scores was attributable to the MetaSC model intervention, as can be seen in table 12.

Table 12: HOTS Score Comparison and Analysis Results

Group	Pretest M (SD)	Posttest M (SD)	Gain	Paired t-test	Cohen's d
Experimental	54.32 (8.45)	78.64 (7.21)	24.32	$t = 18.45$, $p < .001$	3.12 (large)
Control	53.18 (8.92)	64.57 (8.34)	11.39	$t = 9.87$, $p < .001$	1.34 (large)

Also, both groups demonstrated improvement in HOTS following instruction; however, students who learned through the MetaSC model showed substantially greater progress than those receiving conventional instruction. After controlling for initial differences in HOTS, the experimental group consistently achieved higher posttest performance, indicating that the observed gains were associated with the implementation of the MetaSC model rather than pre-existing ability differences. The magnitude of the effect suggests that MetaSC provided a meaningful educational advantage by supporting students' analytical, evaluative, and problem-solving skills through culturally grounded, project-based, and metacognitive learning experiences.

Table 13: Between-Group Comparison (ANCOVA)

Source	SS	df	MS	F	p	Partial η^2	Power	Adjusted M (SE)	Mean Diff	95% CI
Pretest (covariate)	1247.36	1	1247.36	28.45	< 0.001	0.207	0.999	—	—	—
Group	6238.92	1	6238.92	142.36	< .001	0.566	1.000	Exp: 78.52 (0.89) Con: 64.69 (0.89)	13.83***	[11.63, 16.03]
Error	4778.14	109	43.84							

*Note: *p < .001; Exp = Experimental; Con = Control; Adjusted M = posttest means controlling for pretest*

Effect size analysis was conducted to evaluate the practical significance of the MetaSC model's impact on student outcomes. Effect sizes provide a standardized measure of the magnitude of differences or changes, independent of sample size, allowing for meaningful interpretation of intervention effectiveness. Cohen's d was calculated for within-group changes (pretest to posttest), while partial eta-squared (η^2) was derived from ANCOVA results to assess between-group differences controlling for pretest scores.

Table 14: Effect Size Analysis Across Variables

Variable	Effect Size Measure	Value	Interpretation	Practical Significance
HOTS (within experimental)	Cohen's d	3.12	Very large	Highly meaningful improvement
HOTS (between groups)	Partial η^2	0.566	Large	Strong model effect (56.6% variance explained)
Collaboration (within experimental)	Cohen's d	3.21	Very large	Highly meaningful improvement
Collaboration (between groups)	Partial η^2	0.590	Large	Strong model effect (59.0% variance explained)

Results revealed consistently large to very large effect sizes across both dependent variables. For HOTS, the experimental group demonstrated a very large within-group effect size (d = 3.12), while the between-group analysis produced a large effect (partial η^2 = 0.566). Similarly, collaboration skills showed a very large within-group effect size (d = 3.21) and a large between-group effect (partial η^2 = 0.590). These findings indicate a strong association between participation in the MetaSC learning model and higher levels of HOTS and collaboration skills. The magnitude of the observed effects suggests that the model was associated with meaningful educational benefits beyond statistical significance.

4. Discussion

The expert validation results, classified as "excellent," not only signify numerical success but also demonstrate the conceptual appropriateness and pedagogical readiness of the MetaSC model for the elementary school science learning environment. Pedagogically, this high score indicates that the components of syntax, social system, and learning response principles align with the characteristics of an effective learning model, as per the criteria for structured and implementable model development (Nadia et al., 2023; Kurniahtunnisa & Wowor, 2023).

Consistent with the perspective that expert validation is essential for a model to be deemed instructionally sound, this process ensures that the model design, teaching tools, and assessment indicators have been rigorously evaluated based on content appropriateness, structural coherence, and relevance to the learning context (Nurmawati et al., 2022; Kurniahtunnisa & Wowor, 2023; Nuraini et al., 2023). Consequently, the validation obtained is not merely a form of technical verification but rather an affirmation that MetaSC has satisfied the standards for core components of a logical, directed, and applicable learning design tailored to the characteristics of elementary school students.

These findings are also in agreement with previous studies indicating that metacognition-based learning models, Project-Based Learning (PjBL), and ethnoscience necessitate theoretical and instructional validation as a critical step prior to classroom implementation. Research by Sukmana & Sudarma (2021) demonstrated that PjBL enhances collaboration and creativity while improving students' problem-solving abilities, whereas the integration of ethnoscience within the PjBL context has been shown to enhance critical thinking skills and conceptual understanding through culturally-based learning experiences (Anattri et al., 2024; Sudarmin et al., 2023).

Empirical literature further indicates that the application of metacognitive strategies strengthens students' capacity to address complex problems through reflection and self-regulation in learning (Supiyati et al., 2023; Sumo et al., 2024). Supported by expert validation and alignment with these empirical foundations, these results provide a logical basis for asserting that the MetaSC model is not only structurally and theoretically robust but also ready for empirical testing as a potential learning approach to enhance higher-order thinking skills (HOTS) and collaborative skills in elementary school science learning.

Teacher and student feedback demonstrated a high level of acceptance of the MetaSC model, highlighting its user-friendliness from the instructor's perspective and its engaging and clear instructional approach for students. Educators perceived the systematic learning structure, which includes step-by-step syntax and supportive evaluative tools, as conducive to facilitating classroom learning activities (Nurmawati et al., 2022). Students reported that the learning experience was more meaningful, engaging, and comprehensible due to its connection to experiences and cultural contexts relevant to their own lives. This interpretation is consistent with the relevance and authenticity-based learning motivation theory, which posits that when learning is linked to students' personal and cultural contexts, curiosity, attention, and engagement in learning are significantly enhanced (Ilhan, 2021). The incorporation of ethnoscience into the learning process not only strengthens experiential understanding of science but also enhances a sense of ownership and cultural pride, thereby fostering increased learning motivation while enriching students' emotional connection to the material (Martawijaya et al., 2023; Shoimah & Fatoni, 2023).

In addition to its cultural relevance, the structure of the MetaSC model, which incorporates metacognitive scaffolding and collaborative work, significantly contributes to its favorable user acceptance. Metacognition enables students to independently reflect on their understanding and monitor their learning strategies, while collaborative activities facilitate the exchange of ideas, peer feedback, and the social construction of understanding (Hamzah et al., 2022). These findings corroborate previous research indicating that context-based learning and metacognition can enhance student engagement, critical analysis, and learning experiences (Purnomo et al., 2020; Liline et al., 2024). However, the MetaSC model offers an additional contribution by not only integrating cultural context and metacognitive reflection but also explicitly establishing the syntax of collaborative learning, thereby making learning structured and easily implementable by teachers in the classroom.

Consequently, the MetaSC model is not only conceptually valid based on expert validation but also demonstrates a high level of usability, rendering it practical and feasible for application in real-life elementary school science instruction. The study's results indicate that the implementation of the MetaSC model significantly improved HOTS, as evidenced by the difference in scores between the experimental and control groups. Pedagogically, these results affirm that MetaSC not only strengthens conceptual understanding but also enhances analytical, evaluative, and problem-solving skills through Project-Based Learning (PjBL) syntax (Subiyantoro, 2024; Zaki et al., 2024).

The integration of ethnoscience into the model serves as a contextual cognitive anchor that connects learning to students' cultural experiences, while simultaneously increasing motivation and deepening conceptual understanding (Zaki et al., 2024). Furthermore, the improvement in collaboration skills indicates that MetaSC is not solely oriented toward individual achievement but also fosters group dynamics through role allocation, evidence-based discussions, and collective decision-making. The incorporation of cultural dimensions into collaborative work renders learning more authentic and inclusive, supporting the finding that local context and reflective learning can enhance the quality of interaction and collaboration (Zaki et al., 2024). Thus, MetaSC has proven effective not only in enhancing HOTS but also in creating a collaborative learning ecosystem that is pertinent to the needs of 21st-century science learning.

The findings of this study demonstrate that the MetaSC model enhances collaborative skills by implementing a structured collaborative role framework, thereby promoting a more equitable distribution of responsibilities. This approach is consistent with the principles of social constructivism and contrasts with traditional group work, which often results in the dominance of certain students. It facilitates more inclusive interactions, enabling each student to contribute equally. Despite these positive outcomes, the implementation of the MetaSC framework was not without challenges.

Initial observations indicated that some students experienced difficulty engaging in metacognitive reflection, particularly during planning and evaluation activities, suggesting that self-regulated learning skills may require sustained scaffolding at the elementary level. Variations in participation during collaborative tasks were also observed, with several groups requiring additional teacher facilitation to ensure equitable involvement among members. Furthermore, the strong student engagement observed during implementation may have been influenced not only by the instructional features of MetaSC but also by the novelty of the learning experience and the cultural familiarity of the ethnoscience context. These considerations suggest that the effectiveness of the framework should be interpreted within the broader instructional and contextual conditions in which it was implemented.

5. Limitation

Despite the promising findings, several limitations should be acknowledged. The study was conducted within a single elementary school context, which may limit the transferability of the findings to schools with different demographic, cultural, or instructional characteristics. In addition, the intervention was evaluated over a relatively short implementation period, preventing an examination of the long-term sustainability of gains in HOTS and collaboration skills. The classroom-based nature of the study also means that contextual factors, including teacher facilitation and student awareness of participation in an innovative learning program, may have influenced learning outcomes. Furthermore, the study focused primarily on HOTS and collaboration skills, leaving other important outcomes such as scientific literacy, creativity, and long-term knowledge retention unexplored. These limitations provide opportunities for future studies to replicate and extend the implementation of the MetaSC model across broader educational settings, longer timeframes, and a wider range of learning outcomes.

6. Conclusion

This study aimed to develop and test the ethnoscience-based MetaSC learning model for elementary school science learning. Expert validation showed the model and supporting learning tools were very good, indicating conceptual and instructional feasibility, and suitability for elementary school students. Teacher and student responses during implementation demonstrated high acceptance, indicating the model is practical, adaptable, and relevant to students' cultural contexts. Effectiveness testing showed MetaSC significantly improved students' Higher Order Thinking Skills (HOTS) and collaboration skills, with project-based learning, ethnoscience, and metacognitive structures supporting students' cognitive and socio-emotional development. These findings confirm MetaSC can enhance 21st-century science learning by creating contextual, reflective, and learner-centered experiences. Based on the findings, several recommendations can be put forward. First, MetaSC implementation needs expansion to different school contexts and curricula to test its effectiveness across various student characteristics. Future research should implement a longitudinal design to see the model's sustained impact on HOTS, collaboration, and other scientific competencies over time.

Conflict of Interest

The authors have no conflict of interest.

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