iejee

International Electronic Journal of Elementary Education
December 2025, Volume 18, Issue 1

Designing a Metacognition–Social Complexity-Based Model for Science Subject in Elementary Education: A Comprehensive Needs Analysis Study

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Received : 20 August 2025
Revised : 19 November 2025
Accepted : 26 December 2025
DOI : 10.26822/iejee.2025.424

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KURA group
www.iejee.com
ISSN: 1307-9298

Abstract

Enhancing Higher Order Thinking Skills (HOTS) and collaborative abilities is a strategic necessity in elementary science education, aligning with the requirements of 21st-century competences. Previous research have demonstrated the shortcomings of traditional methods that fail to incorporate metacognitive and social complexity elements, along with the absence of a mixed-method requirements analysis. This study seeks to ascertain the foundational conditions of Higher Order Thinking Skills (HOTS) and collaborative abilities, investigate the perceptions of educators and learners concerning developmental obstacles and possibilities, delineate the requirements of a MetaSC-based learning model, and identify critical components pertinent to the elementary school environment. The exploratory sequential mixed-method approach involved conducting in-depth interviews during the qualitative phase and utilizing a questionnaire in the quantitative phase. The findings indicated that students' higher-order thinking skills (HOTS) were rated as low (mean = 2.49), particularly in creative talents, although collaborative skills fell into the intermediate range (mean = 3.11), exhibiting deficiencies in communication. The primary impediments consist of inadequate infrastructure, restricted learning time, and the prevalence of lecture-based methodologies. The findings necessitate the development of a Metacognition–Social Complexity (MetaSC) model that integrates project-based techniques, technological incorporation, and educator training to enhance creativity and communication. This study theoretically enhances the literature on the integration of metacognition and social complexity, while realistically offering ideas for developing learning models that address the actual needs of educators and learners.

Keywords:

Higher Order Thinking Skills (HOTS), Collaboration Skills, Technology Integration, Social Complexity, Learning Model

Introduction

In the context of natural sciences at the elementary school level, the development of Higher Order Thinking Skills (HOTS) and collaboration skills is of the utmost importance in 21st-century education. These skills not only improve students' analytical, evaluative, and creative abilities, but also cultivate effective communication and collaboration, which are indispensable elements of contemporary educational environments (Aini et al., 2020). The significance of HOTS and collaboration is becoming more apparent as the global educational landscape transitions to interdisciplinary approaches, including STEM and project-based learning (Nugroho et al., 2021). These frameworks are consistent with curriculum standards and satisfy the need for competencies that equip students with the skills necessary to navigate a world that is both intricate and swiftly evolving (Suryandari et al., 2018)(Melliofatria et al., 2024). The incorporation of HOTS into science education fosters a more profound comprehension and empowers students to collaboratively address real-world issues, thereby providing them with the skills required for their future educational and professional endeavors (Nurudin et al., 2023).

The teaching and learning of science at the elementary level are plagued by a variety of challenges, despite the critical role of HOTS and collaboration skills. The effective development of these skills is frequently impeded by limitations in instructional strategies, access to appropriate learning media, and inadequate assessment methods (Perdana et al., 2021; Hashim & Damio, 2023). Traditional teaching methods that prioritize rote memorization over inquiry-based learning, which is essential for the development of critical thinking and collaborative capabilities, are frequently a source of difficulty for educators (Hardiansyah et al., 2024). Furthermore, the successful implementation of innovative learning models is contingent upon the abilities of instructors to create such environments, which may not always be the case due to insufficient training or resources (Ishartono et al., 2021; Nahar et al., 2022;). In order to confront these obstacles, it is necessary to implement effective teaching strategies that encourage critical thinking and collaboration in science education, as well as to improve teacher preparation and develop appropriate assessment tools (Suryandari et al., 2018).

Numerous studies have investigated the development of Higher-Order Thinking Skills (HOTS) and collaboration skills in elementary school science education by employing a variety of pedagogical methods. For instance, Multiple Skill Laboratory Activities have been demonstrated to be more effective in enhancing students' collaboration skills than communication skills (Malik & Ubaidillah, 2021; Taningrum et al., 2024). Additionally, Problem-Based Learning with Collaboration (PBL-C) has been suggested as a potential model for elementary school science education (Sajidan et al., 2022). Wahyudi et al. (2022) have also demonstrated that HOTS-oriented e-Project-Based Learning (HOTS-oriented e-Project-Based Learning) is highly effective in enhancing 4C skills and science learning outcomes. Additionally, a mobile learning approach that is based on collaborative and inquiry-based strategies is effective in enhancing communication skills and HOTS (Afikah et al., 2022). Digital Mind Maps are significantly associated with cognitive learning outcomes, collaboration, and communication skills when integrated with PBL (Hidayati et al., 2020). The critical thinking abilities of elementary school pupils have been demonstrated to be enhanced by the practice of addressing HOTS-based science problems (Muthmainnah et al., 2022; Sidiq et al., 2021).

In elementary institutions, students' Higher-Order Thinking Skills (HOTS) abilities remain in the low category, particularly in the areas of creating and evaluating. Collaboration skills are in the medium category, with a notable weakness in communication skills, according to empirical findings. This condition is consistent with the findings of (Sidiq et al., 2021), who asserted that elementary school students' critical thinking skills in science learning still require systematic strengthening. Additionally, the results of research conducted by Hidayati et al. (2020) indicate that communication skills are generally weaker than collaboration skills. Afikah et al. (2022) have also emphasized that conventional learning approaches are insufficient to cultivate HOTS and communication skills, as the dominance of simple lecture and demonstration methods that do not encourage active student participation, limited learning infrastructure, and a science time allocation of only four hours per week are also barriers faced by teachers. Students' potential for critical thinking, creativity, and effective collaboration is not being optimally developed due to the mismatch between the current approach and the learning needs that necessitate interactive, collaborative, and HOTS-oriented strategies (Kruger & Buley, 2022; Sarnoko et al., 2024). Consequently, interventions that involve more contextual and innovative learning models are required.

Modern educational philosophy states that developing Higher Order Thinking Skills (HOTS) and teamwork involves more than Project-Based Learning (PBL) or STEM; it requires metacognitive attention. PBL-C and e-PBL improve 4C skills (Sajidan et al., 2022), but they often omit self-regulatory procedures that help students plan, monitor, and assess their thinking. According to (Hamzah et al., 2023), metacognition is essential for real higher-order reasoning, allowing learners to carefully coordinate cognitive methods during problem-solving. The lack of systematic metacognitive scaffolding in current models limits their ability to encourage students' autonomous analytical and creative science thinking.

Social complexity requires negotiation, adaptability, and emergent coordination to solve real challenges. Collaboration is generally portrayed as a static arrangement rather as a sophisticated adaptive process that deepens communication and shared responsibility in primary science (Virranmäki et al., 2021). This highlights the necessity for an educational strategy that actively integrates metacognitive self-regulation and social interaction dynamics. Prior research on HOTS and collaboration development relied heavily on quantitative surveys or isolated experiments that ignored contextual barriers perceived by teachers and students (Megawati et al., 2020). Few research use mixed-method exploratory sequential designs to create context-sensitive instructional models, combining qualitative and quantitative insights (Chang et al., 2024). In Indonesia, these issues are compounded by systemic constraints, including limited science instructional time and the persistence of teacher-centered pedagogy (Afikah et al., 2022). Despite the national Merdeka Curriculum's emphasis on project-based and collaborative learning (Rizki et al., 2022), metacognitive reflection and socially complex collaboration remain systematically overlooked at the elementary level. Consequently, an urgent need exists for a learning model that not only embodies 21st-century competence frameworks but also aligns with the empirical realities of Indonesian classrooms. Addressing this imperative motivates the present development of the Metacognition–Social Complexity (MetaSC) model.

This study operationalizes Higher Order Thinking Skills (HOTS) through the three highest cognitive domains in Bloom's Revised Taxonomy: analyzing (C4), evaluating (C5), and creating (C6) (Melati & Rasyid, 2023). These indicators manifest as students' abilities to deconstruct scientific problems, synthesize evidentiary support, and formulate inventive solutions within inquiry-based learning environments (Bahri et al., 2021). This operational definition corroborates existing research asserting that HOTS in science education requires not merely cognitive effort but also deliberate metacognitive regulation of one's thinking procedures.

Previous research has illustrated a variety of strategies for enhancing HOTS and collaboration skills, including Multiple Skill Laboratory Activities, which are effective in enhancing collaboration but less optimal in communication (Malik & Ubaidillah, 2021), Problem-Based Learning with Collaboration (Sajidan et al., 2022), and HOTS-oriented e-Project-Based Learning, which is capable of developing 4C skills and science learning outcomes (Handayani et al., 2023). Additionally, the integration of Digital Mind Maps with PBL has demonstrated a substantial correlation between cognitive learning outcomes, collaboration, and communication skills (Hidayati et al., 2020). Additionally, HOTS and communication have been demonstrated to be enhanced by collaboration and inquiry-based mobile learning approaches (Afikah et al., 2022). Within elementary education, this three-part construct facilitates learners' progression from concrete to abstract reasoning, enabled by instructional scaffolding and collaborative engagement (Suryandari et al., 2018; Zainil et al., 2022). The Metacognition–Social Complexity (MetaSC) model is based on the analytical, evaluative, and creative dimensions. Metacognitive awareness allows learners to supervise and adjust their cognitive approaches, while social complexity promotes negotiation, adaptive behavior, and collective problem-solving. This integrated relationship ensures that HOTS development is introspective, socially located, and culturally relevant, not just intellectual.

However, past research had significant limitations. Most scholars have not explicitly integrated metacognitive methods with social complexity, failing to adequately account for collaborative problem-solving and individual cognitive regulation. In order to determine the beginning circumstances of HOTS and collaborative skills in elementary school children, this research aims to answer the following questions:

1. What are the initial conditions of Higher Order Thinking Skills (HOTS) and collaboration skills among elementary school students in science learning?
2. How do teachers and students perceive the barriers, challenges, and opportunities in developing HOTS and collaboration skills?
3. What are the contextual requirements and key components needed to develop a Metacognition–Social Complexity (MetaSC)-based learning model for elementary science education?

Literature Review

Concept and Theoretical Basis of HOTS and Collaboration Skills in Science Learning

The concept of Higher Order Thinking Skills (HOTS) encompasses critical cognitive processes, including analyzing, evaluating, and creating, that are essential for the development of effective scientific reasoning at the elementary level. Indicators of HOTS in education encompass not only the capacity to comprehend and retain information, but also the ability to implement, analyze, and synthesize knowledge in a variety of contexts (Muhayimana et al., 2022; Singh et al., 2023). These abilities facilitate the development of students' ability to advance from rote memorization to more profound learning, thereby encouraging innovation and creative problem-solving (Setiawan et al., 2020). Furthermore, collaboration skills which are defined by responsibility, communication, and participation are essential for the acquisition of scientific knowledge, particularly in the context of fostering cooperation among students. This is in close alignment with the merdeka Curriculum, which prioritizes project-based and collaborative learning (Khaeruddin et al., 2023;Rizki et al., 2022).

The demands of the merdeka Curriculum, which is intended to cultivate the competencies required for the 21st century, serve to emphasize the significance of HOTS and collaboration skills. This curriculum fosters the development of the "4Cs" in addition to academic achievement (Adnyani & Suniasih, 2023; Zulkardi & Putri, 2020). In addition, it fosters the development of interpersonal skills, critical thinking, and problem-solving. Educators endeavor to improve students' cognitive and collaborative capabilities by incorporating HOTS into learning objectives, thereby equipping them for future challenges in a world that is becoming more intricate and interconnected (Amrina et al., 2024; Marshel & Ratnawulan, 2020). HOTS and cooperation skills are crucial for primary pupils, but many obstacles prevent their growth. Teacher unpreparedness and understanding of HOTS techniques hinders the formulation and implementation of effective instructional strategies and learning assessments (Retnawati et al., 2018). The integration of both HOTS and collaboration skills into elementary science education necessitates the collaborative efforts of educational authorities, curriculum designers, and instructors to address these challenges.

Metacognition-Social Complexity Based Learning Model

The Metacognition-Social Complexity (MetaSC) learning model incorporates metacognitive strategies to improve Higher Order Thinking Skills (HOTS) and social complexity to enhance collaboration among students in an elementary education context. In particular, the model underscores the importance of self-regulation and reflective thinking, which allows learners to evaluate and monitor their problem-solving and comprehension processes, thereby improving their analytical, evaluative, and creative capabilities (Hendarwati et al., 2021). Parallel to this, the social complexity aspect promotes collaboration by facilitating participatory learning environments, in which students interact with one another to develop collective problem-solving capabilities and a shared understanding (Dwikurnaningsih & Paais, 2022; Trullàs et al., 2022). This dual focus is consistent with the current educational objectives and meets the requirements of the revised curriculum, which promotes real-world applications and collaboration by advocating for interdisciplinary approaches like Project-Based Learning (PBL) and STEM methodologies (Siska & Maarif, 2023).

Compared to established learning frameworks such as Problem-Based Learning (PBL), STEM education, and inquiry-based learning, the MetaSC paradigm occupies a distinctive position at the intersection of cognitive and social processes. Although PBL and inquiry-based models primarily facilitate experiential learning through real-world problems and inquiry, respectively, the MetaSC introduces an explicit metacognitive component that motivates students to reflect on their learning strategies and collaborate effectively (Bonilla et al., 2021). The MetaSC model and similar approaches are effective in elementary settings, as evidenced by empirical evidence. Studies have shown that students' critical thinking skills, self-efficacy, and collaborative competencies have improved (Muvid et al., 2022; Shojaee et al., 2019). The MetaSC model has the potential to be a powerful pedagogical tool in the development of essential 21st-century skills among elementary learners, as research has demonstrated that the integration of metacognitive strategies within collaborative learning frameworks significantly improves student engagement and academic achievement (Tucker et al., 2024).

Needs Analysis In Learning Model Development

In educational research, needs analysis is essential to creating effective learning models. Needs analysis aims to discover gaps between the current educational environment and desired learning outcomes. This allows teachers to tailor their lessons to specific students (Gangadharan et al., 2025). This involves gathering extensive data about learners' histories, preferences, and skills. Through rigorous study of these demands, educational practices are relevant, focused, and effective in engaging and succeeding students. Prior research has shown that needs analysis is an effective first step in learning model design. A study showed how needs analysis influenced project-based science teaching materials to promote primary pupils collaborative thinking (Sudarmono et al., 2023). Another study used a requirements assessment to build mobile learning media that fits students' learning patterns and preferences, improving learning outcomes and engagement (Wulansari et al., 2023). This shows that comprehensive needs analysis provides basic insights for educational growth and enables educators to create new, learner-centered instructional strategies that meet their educational environments' unique demands.

Method

Research Design

Starting with data collection through teacher interviews and student group discussions, this study employed a mixed method exploratory sequential design with a qualitative dominance to investigate the obstacles, challenges, and opportunities for the development of Higher Order Thinking Skills (HOTS) and collaboration skills in science learning (Shield, 2013). The quantitative stage was conducted to provide support by means of a straightforward questionnaire that numerically mapped the initial conditions (McKim, 2017). The integration of both data sets resulted in a comprehensive understanding of the requirements that served as the foundation for the development of the MetaSC learning model.

Research Sample

This study was carried out at eight elementary school in Sukoharjo Regency, Central Java, involving five upper-grade science teachers as key participants in the qualitative phase, along with seven fourth-grade students who participated in in-depth interviews. Participants were selected through purposive sampling, considering teachers' engagement in science instruction and the accessibility of suitable fourth-grade students (Hennink & Kaiser, 2022). For the quantitative component, 112 fourth-grade students from eight elementary school completed a questionnaire to establish baseline numerical data.

Data Collection Techniques and Research Instruments

In both phases of this investigation, non-test methodologies were implemented for data collection. During the qualitative phase, data were collected through in-depth interviews with science teachers and elementary school students to investigate the obstacles, challenges, and opportunities for the development of Higher Order Thinking Skills (HOTS) and collaboration skills in science education. Data were collected during the quantitative phase using a straightforward questionnaire that was crafted to numerically represent the initial conditions of students' HOTS and collaboration abilities (McKim, 2017).

The research instrument was developed to assess variables that were pertinent to the objectives of the requirements analysis. During the qualitative phase, a teacher interview guide was employed, which included open-ended questions regarding learning barriers, strategies employed, and the requirements of the learning model (Aspers & Corte, 2021). Meanwhile, a student interview guide was utilized, which concentrated on the science learning experiences, challenges encountered, and expectations for learning. The questionnaire instrument was designed as statements with a Likert scale of 1–5 during the quantitative phase. The HOTS questionnaire assessed students' capacity to analyze, evaluate, and generate, whereas the collaboration skills questionnaire assessed their communication, responsibility, and participation (Hamzah et al., 2022; Sidiq et al., 2021 ; Virranmäki et al., 2021). Table 1 below presents the instrument grid used for data collection.

Table 1.
Research Instrument Grid

Instruments	Measured Indicators	Instrument Format	Data Source
Teacher Interview Guide	Learning barriers, strategies, model needs	Open-ended Questionnaire	Elementary School Science Teacher
Student Interview Guide	Science learning experiences, challeng-es, expectations	Open-ended Questionnaire	Elementary School Students
HOTS Questionnaire	Ability to analyze, evaluate, and create	Likert-scale Statements	Elementary School Students
Collaboration Skills Question-naire	Participation, communication, and responsibility	Likert-scale Statements	Elementary School Students

Validity and Reliability of Instruments

Systematic procedures were implemented to guarantee the validity and reliability of the data in this investigation. Source triangulation, which involved the comparison of information from instructors and students, and technical triangulation, which involved the use of interviews to ensure the consistency of information, were employed to maintain validity for qualitative data (Aqodiah et al., 2023). Additionally, member verification was implemented by verifying the interpretation results with participants to guarantee that they were consistent with their intentions and experiences. In the interim, two subject matter experts conducted content validity testing for quantitative data. They evaluated the indicators and questionnaire items' alignment with the concepts of Higher Order Thinking Skills (HOTS) and collaboration skills. The findings indicated that all items were designated valid due to a content validity coefficient (CVI) of 0.80 or higher. The Cronbach's Alpha technique was employed to conduct reliability testing on the instrument trial data. The HOTS questionnaire and the collaboration skills questionnaire yielded values of 0.86 and 0.88, respectively, which exceeded the criterion limit of ≥ 0.70. Consequently, the instrument was deemed reliable and appropriate for research use.

Data Analysis Techniques

Thematic analysis was employed to conduct qualitative data analysis, which involved the transcription of interview results, the classification of codes into themes or subthemes, the interpretation of findings based on pertinent theories and literature, and the provision of open coding (Lochmiller, 2021). In the interim, quantitative data analysis employed descriptive statistics to determine the mean value, standard deviation, and percentage for each Higher Order Thinking Skills (HOTS) and collaboration skills indicator (Okello, 2022). These values were subsequently displayed in tables to facilitate interpretation. The mean value interpretation criterion was employed in quantitative data analysis to facilitate the interpretation of the results, thereby enabling the distinct categorization of the levels of HOTS and collaboration skills among students.

Table 2.
Quantitative Data Analysis

Mean Range	Category	Interpretation
4.21 – 5.00	Very high	Highly developed competency
3.41 – 4.20	High	Well-developed competency
2.61 – 3.40	Medium	Moderately developed competency
1.81 – 2.60	Low	Underdeveloped competency
1.00 – 1.80	Very Low	Undeveloped competency

Results

Research Context and Participant Profile

The research was done at eight public elementary school in Sukoharjo Regency, Central Java. Science study facilities include basic teaching aids, a library, and a lab. The merdeka Curriculum teaches science for four hours per week in grades IV (four) using lectures and simple demonstrations. Teachers recognize the need of developing Higher Order Thinking abilities (HOTS) and cooperation abilities, but often struggle to create effective learning and assessment systems. Four teachers have primary school backgrounds, one specialized in science, and 80% are certified. Average teaching experience is 10.2 years. Seven students were selected to become sample of interviewed in-depth, while 112 students completed questionnaires. Most students had good to excellent academic performance and came from diverse academic backgrounds. They also assist Science Clubs and Olympiads.

Quantitative Findings: Baseline Profiles of HOTS and Collaboration Skills

Based on the questionnaire results, pupils' Higher Order Thinking Skills (HOTS) were categorized as low, with an overall mean score of 2.49 (49.8% achievement). Among the assessed indicators, analyzing achieved the highest score (mean = 2.74; medium category), followed by evaluating (mean = 2.45; low category) and generating (mean = 2.28). These findings indicate that pupils demonstrate greater ability in processing and interpreting information than in producing or critically assessing new ideas. Meanwhile, pupils' collaboration skills fell within the medium category, with average indicator scores ranging from 2.89 to 3.28. Participation (mean = 3.15; 63.0%) and responsibility (mean = 3.28; 65.6%) were the strongest indicators, suggesting that pupils are reasonably engaged and capable of fulfilling group tasks. In contrast, communication received the lowest score (mean = 2.89; 57.8%), indicating a need for improvement in how pupils convey ideas and interact within group activities. Table 3 shows the analysis results.

Table 3.
Results of HOTS Questionnaire Analysis and Students' Collaboration Skills

HOTS Indicators	Mean	Std. Deviation	Category	Percentage of Achievement
Analyze	2,74	0.68	Medium	54.8%
Evaluate	2,45	0.72	Low	49.0%
Create	2,28	0.81	Low	45.6%
Average HOTS	2,49	0.74	Low	49.8%
Collaboration Skills Indicators	**Mean**	**Std. Deviation**	**Category**	**Percentage of Achievement**
Participation	3,15	0.59	Medium	63.0%
Communication	2,89	0.64	Medium	57.8%
Responsibility	3,28	0,71	Medium	65.6%
Average Collaboration Skills	3,11	0,65	Category	62.2%

Quantitative findings indicate students' Higher Order Thinking Skills (HOTS) fall within a low range, with analytical skills showing relative strength while creative capabilities remain particularly underdeveloped. Half of the students demonstrated low to very low performance, signaling an urgent need for pedagogical reinforcement. Conversely, collaborative skills were moderately developed, with responsibility being a strength and communication the weakest dimension. While these quantitative results establish a foundational profile, qualitative insights from teacher interviews were crucial for interpreting the underlying causes and contextual factors shaping these outcomes.

Qualitative Findings: Teachers' Perspectives on Barriers and Opportunities in Developing HOTS and Collaboration Skills

Thematic analysis of in-depth interviews with five science teachers from eight public elementary schools in Sukoharjo Regency revealed the teachers' perceptions of the barriers, challenges, and opportunities of developing HOTS and collaboration skills in science education. Analysis involved interview transcription, open-coding keywords, categorizing data, and developing themes. Resource and time limits, HOTS teaching and assessment issues, and instructor-technology collaboration were significant concerns. The quantitative results confirm these findings, as students' HOTS were low (mean = 2.49), with creation being the lowest indicator (mean = 2.28), collaborative skills medium (mean = 3.11), and communication weakest (2.89). According to the MetaSC learning approach, educators stressed student connection and innovation. Table 4 shows teacher interview thematic analysis results.

Infrastructure and time were the primary obstacles that impeded the development of HOTS (mean = 2.49, low) and collaboration skills (mean = 3.11, medium) for teachers. The low scores in creating (mean = 2.28) and communicating (mean = 2.89) in the quantitative data were indicative of the challenges in instruction and assessment strategies. The insights obtained from teachers highlight both systemic and pedagogical challenges in fostering higher-order thinking and collaboration. To complement these perspectives, students' experiences and expectations were explored to reveal how learning processes and classroom dynamics are perceived from the learners' standpoint.

Qualitative Findings: Students' Experiences and Expectations for Interactive Science Learning Activities

Thematic analysis of student interviews revealed a strong desire for interactive learning, alongside challenges in critical thinking and collaboration. Students frequently cited monotonous, rote-based instruction, which aligns with their low HOTS scores, particularly in creative tasks. Despite moderate overall collaboration skills, communication was a specific weakness. Notably, student enthusiasm for group work and technology presents a strategic opportunity for refining the MetaSC model. The results of the thematic analysis of student interviews are presented in Table 5.

Students' challenges, particularly in the areas of communication (mean = 2.89) and creation (mean = 2.28) are reflected in their monotonous learning experiences and challenges in HOTS (mean = 2.49) and collaboration skills (mean = 3.11). The MetaSC model, which is capable of satisfying these requirements, is facilitated by students' expectations for interactive and collaborative learning. The voices of students corroborate the teachers' reflections, showing congruent barriers such as monotonous instruction, low communication efficacy, and limited inquiry opportunities. Integrating these perspectives with quantitative results leads to a clearer identification of the essential components required for the MetaSC learning model.

Synthesizing Quantitative and Qualitative Results Towards MetaSC Model Design

The synthesis of qualitative and quantitative findings underscores the critical need for a MetaSC learning model in Sukoharjo's elementary school. Quantitative results reveal deficient HOTS performance (mean=2.49), with creation (mean=2.28) and evaluation (mean=2.45) as particular weaknesses, though analytical skills (mean=2.74) show moderate development. Collaborative abilities (mean=3.11) remain constrained by inadequate communication (mean=2.89) despite stronger performance in responsibility and participation. Qualitative data from teachers cite infrastructural limitations, time constraints, and pedagogical challenges, while students describe monotonous instruction and collaborative difficulties. Together, these findings substantiate the requirement for an interactive, technology-enhanced collaborative learning framework, with detailed specifications analyzed in Table 6.

Mixed-methods research shows that pupils have low Higher Order Thinking Skills (HOTS), with overall performance in the low range (M = 2.49) and significant impairments in creating (M = 2.28) and assessing (M = 2.45). While moderately demonstrated (M = 3.11), poor communication abilities (M = 2.89) hinder collaborative competencies. These quantitative patterns are supported by qualitative educator descriptions of infrastructural constraints, instructional time limits, and a lack of effective HOTS cultivation and measurement methodologies. Student evaluation confirms this, calling conventional learning situations dull and specifically challenging conceptual articulation and productive group involvement. However, teachers and students agree that technology-enhanced, interactive, and activity-driven pedagogy is promising for educational innovation.

Half of the pupils had low to very low HOTS, whereas over 70% have moderate to high cooperation abilities, indicating increased readiness for collaborative enhancement. The converging results suggest that the MetaSC model should promote HOTS through project-based and inquiry-oriented learning activities that foster critical and creative thinking. Structured group techniques and digital collaborative tools facilitate communication, a key component of collaboration. The findings also emphasize the relevance of teacher capacity building in collaborative learning design and management and formative assessments that capture students' higher-order reasoning. These findings form the scientific basis for the MetaSC learning paradigm, which addresses contextual barriers and promotes interactive and meaningful elementary science learning.

Table 4.

Thematic Analysis of Interviews with Teachers

Open Coding (Key Words/Sentences)	Category	Themes	Interview Excerpts
"Lack of teaching aids", "Simple labs", "Slow internet"	Lack of supporting facilities	Infrastructure Barriers	"We have a simple lab, but limited teaching aids, so it's difficult to encourage students to create new experiments." (Teacher A)
"Only 4 hours of class time per week", "Lots of administration", "Students are tired after other subjects"	Time and workload constraints	Time Barriers	"With only four hours a week, it's difficult to develop HOTS because students need time for group discussions." (Teacher B)
"Students find it difficult to collaborate", "Lack of confidence in speaking", "Teachers lack training"	Student difficulties and teacher skills	Teaching Strategy Challenges	"Students are often shy about communicating in groups, and I personally need more training to integrate collaboration skills." (Teacher C)
"HOTS evaluations are difficult to assess", "Curriculum is too dense", "Lecture method is dominant"	Ineffective methods and assessments	Assessment and Curriculum Challenges	"Assessing creative skills is a big challenge because the curriculum focuses more on memorization than evaluating creative ideas." (Teacher D)
"Technology can help with visualization", "Online applications for collaboration", "Opportunities for students to explore independently"	Digital integration in learning	Technology Opportunities	"With apps like Zoom or Google Classroom, we can improve collaboration skills even outside of class." (Teacher E)
"Collaboration between teachers", "Joint workshops", "Sharing best practices"	Support from the teaching community	Professional Collaboration Opportunities	"If teachers share strategies, there's a huge opportunity to develop HOTS through new models like MetaSC." (Teacher A)

Table 5.

Results of Interview Analysis with Students

Open Coding (Key Words/Sentences)	Category	Theme	Interview Excerpts
"Learning science by memorizing facts", "Teachers give long lectures", "Rarely do experiments"	Conventional teaching methods	Monotonous Learning Experience	"In science lessons, the teacher often just tells stories. We memorize formulas but don't understand why." (Student 1)
"Enjoy demonstrations", "But rarely work in groups", "Prefer to study alone"	Limited activity variety	Lack of Interactive Experience	"Sometimes there are demonstrations of demonstration equipment, but we want more group discussions to help each other." (Student 2)
"Difficult to analyze data", "Can't generate new ideas", "Embarrassed if I answer incorrectly"	Difficulty with higher-order thinking	HOTS Challenges	"When asked to analyze experimental results, I'm confused because I'm not used to thinking about my own evaluation." (Student 3)
"Friends don't listen to ideas", "Difficult to communicate within a team", "Uneven responsibility"	Group interaction problems	Collaboration Skills Challenges	"In the group, some people just stay quiet, communication is difficult, so I'm the only one responsible for the work." (Student 4)
"Want more experiments", "Use gadgets to study", "Learn while playing"	Activity-based learning	Interactive and Creative Expectations	"I wish science would use videos or apps so we could create our own projects and have fun." (Student 5)
"Teachers provide more help", "Groups are fair", "Rewards for good collaboration"	Support from teachers and peers	Collaborative Support Expectations	"I hope the teacher teaches us how to communicate in groups and gives us rewards for taking responsibility together." (Student 6)

Table 6.

Mapping of Requirements and Components of the MetaSC Model

Needs	Proposed MetaSC Model Components	Link to HOTS/Collaboration Skills
Infrastructure barriers (minimal teaching aids, simple labs) and the need for interactive learning (students: mean HOTS score = 2.49 low)	Technology integration (learning videos, collaboration apps)	Improving creation (mean = 2.28) through digital visualization and exploration
Time constraints (4 hours/week) and monotonous methods (students: rote learning experience)	Project-based approach with simple experiments	Supporting analysis (mean = 2.74) and evaluation (mean = 2.45) through hands-on activities
Group communication challenges (mean = 2.89) and difficulties with student interaction	Structured collaboration strategies with role allocation	Improving communication (mean = 2.89) and participation (mean = 3.15)
HOTS assessment difficulties (teachers: assessment is complicated, mean = 2.28 creative)	Process-based HOTS formative assessment	Measuring creation and evaluation more effectively
Lack of teacher training in HOTS and collaboration (teachers: training needed)	HOTS-based teacher training and collaboration	Supporting all HOTS and collaboration skills indicators through enhanced teaching strategies

Discussion

The primary discovery of this investigation was that students' Higher Order Thinking Skills (HOTS) abilities were classified as low, with a mean score of 2.49. The indicator of creating was the weakest, with a mean of 2.28, suggesting that students were experiencing difficulty in generating creative ideas. Conversely, the mean score of analyzing was relatively higher, at 2.74. In contrast, students' collaboration skills were classified as medium (mean = 3.11), with communication being the primary deficit (mean = 2.89), despite the fact that responsibility was stronger (mean = 3.28). This data was corroborated by qualitative findings from teacher and student perceptions, which identified infrastructure barriers, monotonous methods, and collaboration challenges as the primary issues. Technological opportunities were identified as potential solutions (Hendarwati et al., 2021). This aligns with prior findings emphasizing digital tools as enablers of student-centered learning (Chang et al., 2024; Saad & Zainudin, 2024). Consequently, these discoveries are exceedingly pertinent to the research objective, which is to identify the necessity of creating an integrative MetaSC learning model to enhance HOTS and collaboration abilities in the field of science education.

The results of this study indicate that the Higher Order Thinking Skills (HOTS) abilities of elementary school students in Sukoharjo Regency, particularly grade 4, were low (mean = 2.49), especially in the indicators of creating (mean = 2.28) and evaluating (mean = 2.45). This finding aligns with numerous previous studies that reported similar deficiencies in students' cognitive performance within elementary science learning (Bahri et al., 2021;Zainil et al., 2022). Consistent with Afikah et al. (2022) and Purnami et al. (2021), inadequate critical and creative thinking abilities are often associated with both learner-related and teacher-related factors, including limited exposure to inquiry-based activities and the dominance of rote learning. The weaknesses in creation and evaluation indicators reinforce the argument that HOTS development in science learning requires more authentic, technology-based, and project-based pedagogical approaches (Sidiq et al., 2021; Suwarto et al., 2022). These approaches encourage learners to generate, test, and refine ideas through meaningful engagement with scientific problems. Similar to findings by Kosasih et al. (2022) and Susilowati and Suyatno (2021), this study underscores that teacher competence and pedagogical design are pivotal in the successful implementation of HOTS-oriented instruction. Supporting this, recent innovations such as HOTSEP, Android-based modules, and digital mind mapping have demonstrated significant potential to enhance HOTS by facilitating metacognitive monitoring, creativity, and independent inquiry (Ichsan & Rahmayanti, 2020). These findings collectively provide an empirical foundation for developing the MetaSC model that integrates metacognitive regulation and social complexity to strengthen students' analytical, evaluative, and creative thinking capacities.

This situation is closely related to the pedagogical challenges that educators consistently face, which often hinder the effective implementation of constructivism-based learning in elementary science education. Prior studies have emphasized that teachers' limited ability to facilitate inquiry and collaborative learning environments reduces students' opportunities to develop metacognitive awareness and higher-order reasoning (Bahri et al., 2021;Hamzah et al., 2023). The constructivist learning paradigm asserts that learners construct understanding through active engagement, social negotiation, and reflective interaction—processes that are fundamental for developing higher-order cognitive abilities such as analysis, evaluation, and creation (Minarni & Napitupulu, 2020). Consistent with this view, several researchers have found that learning environments dominated by rote memorization and teacher-centered instruction restrict the growth of HOTS and 21st-century competencies (Orak & Al-khresheh, 2021; Shalikhah & Nugroho, 2023). Consequently, the MetaSC model should be grounded in constructivist principles that integrate project-based, inquiry-oriented, and technology-enhanced learning to foster students' intrinsic motivation, engagement, and creativity (Chang et al., 2024; Saad & Zainudin, 2024). This alignment with constructivist theory is also supported by empirical evidence showing that active and technology-integrated learning environments significantly enhance students' motivation, collaboration, and academic achievement (Hussein, 2021; Ichsan & Rahmayanti, 2020).

In accordance with research that underscores the significance of structured approaches, such as robotics programs (Nemiro, 2020; Stewart et al., 2021) and problem-based learning with collaboration (Stewart et al., 2021), the collaboration skills achievement of fourth-grade elementary school students from eight elementary schools in Sukoharjo Regency was in the moderate category (mean = 3.11). The highest responsibility indicator (mean = 3.28) was observed, while the weakest communication (mean = 2.89) was observed. The students' inclination to concentrate on completing individual tasks in groups, as evidenced by student interviews that indicated burden imbalance and challenges with group interaction, may account for the high responsibility score in comparison to communication. The monotony of conventional teaching methods (lecture dominance) and the absence of structured collaboration strategies, as conveyed by teachers who felt untrained in facilitating group dynamics, impeded the support of supporting factors, such as student enthusiasm for group activities. The minimal implementation of collaboration elements, such as negotiation and cooperation, is evident in the low communication (Kruger & Buley, 2022; Suwarto et al., 2022). The implication for the MetaSC model's development is the necessity of prioritizing communication through structured collaboration strategies, such as clear role allocation and teacher training to facilitate interactions, in order to foster more interactive science learning and support the conceptual framework of collaboration in schools (Griffiths et al., 2020; Hendarwati et al., 2021).

The findings from the integration of quantitative and qualitative data across eight elementary schools in Sukoharjo Regency indicate that fourth-grade students' Higher Order Thinking Skills (HOTS) remain in the low category (M = 2.49), with the weakest performance found in the creation indicator (M = 2.28). Collaboration skills are in the medium category (M = 3.11), with communication emerging as the weakest dimension (M = 2.89). These results are consistent with prior studies that reported limited development of higher-order reasoning and creative capacities among elementary learners due to teacher-centered instruction and insufficient scaffolding of inquiry-based activities (Bahri et al., 2021; Sidiq et al., 2021). Qualitative interviews with teachers and students also corroborate earlier research emphasizing that monotonous lectures, insufficient infrastructure, and minimal exposure to collaborative learning constrain both HOTS and communication skills (Okoye et al., 2021). Additionally, the limited time allocation for science (four hours per week) and inadequate teacher training further restrict opportunities for deep cognitive engagement, a pattern also identified by (Orak & Al-khresheh, 2021). Despite these challenges, students demonstrate enthusiasm toward more interactive, technology-integrated, and creative learning activities (Amrina et al., 2024). The presence of 71.5% of students within the medium-to-high category of collaboration skills highlights a significant latent potential for pedagogical innovation. These convergent findings affirm the relevance of developing the MetaSC model, which capitalizes on students' collaborative readiness while addressing the deficiencies in higher-order cognitive processes through constructivist, metacognitive, and socially complex learning design.

This study advocates for a project-based learning (PBL) approach, augmented by technology and organized collaboration, to enhance Higher Order Thinking Skills (HOTS) and collaborative abilities among fourth-grade students in eight elementary schools in Sukoharjo Regency. This initiative specifically targets deficiencies in creative and communication skills within science education, aligning with evidence that PBL fosters student engagement, critical thinking, and creativity (Chang et al., 2024; Ghoniem & Ghoniem, 2022). The MetaSC model can surmount infrastructure obstacles, including basic laboratories and insufficient teaching resources, as well as intricate higher-order thinking skills assessment issues, by utilizing technologies like digital learning platforms and social media to promote collaborative endeavors and innovative exploration (Rahmawati et al., 2020).

The MetaSC framework supports contextual and experiential learning aligned with real-world conditions, which has been shown to strengthen students' 21st-century competencies, including collaboration, creativity, and critical thinking (Hussein, 2021; Saad & Zainudin, 2022). Effective implementation, however, requires systematic teacher professional development focused on HOTS-oriented pedagogy, collaborative learning design, and the sharing of best practices through interdisciplinary engagement with educational stakeholders such as librarians and curriculum specialists (Cioc et al., 2022). Despite its promising implications, this study is limited by the relatively small qualitative sample (five teachers and seven students), the localized research setting of eight elementary schools in Sukoharjo Regency, and reliance on self-reported questionnaires, which may introduce response bias. Consequently, further large-scale studies are recommended to validate and adapt the MetaSC model across diverse educational contexts, thereby strengthening its empirical robustness and practical applicability in advancing science learning at the elementary level.

Conclusion and Suggestions

This research establishes the critical requirement for a Metacognition–Social Complexity (MetaSC) learning model to advance Higher Order Thinking Skills (HOTS) and collaboration in elementary science. Utilizing a mixed-method exploratory sequential design, the study identified systemic constraints across pedagogical approaches, infrastructure, and teacher preparedness that currently impede 21st-century skill development. The MetaSC model constitutes the study's primary theoretical innovation, synthesizing metacognitive regulation with social complexity principles within a project-based, technology-enhanced learning environment. This conceptual advancement repositions metacognition beyond an individual cognitive function, reframing it as a socially embedded process that emerges through collaborative inquiry.

From a practical standpoint, the research delivers an evidence-informed instructional framework aligned with both the objectives of Indonesia's Merdeka Curriculum and the contextual realities of its elementary classrooms. Future studies may concentrate on investigating the incorporation of modern technologies, like as AI or VR, inside MetaSC, while accounting for mediating variables like student motivation and teacher competency. Comprehensive evaluation employing classroom observations and authentic performance assessments will be essential to verify the model's efficacy and ensure its sustainable impact on students' cognitive and collaborative growth.

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