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Enhancing STEM Education in Early Childhood: Science Process Skills, Effective Questioning, and Science Concept Understanding of Kindergarten Teachers in Greater Bandung Area

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Abstract

Aligned with Indonesia's Education Roadmap 2025–2045 in improving Early Childhood Education (ECE) and promoting STEM learning in ECE to develop innovation and problem-solving skills in children from an early age, this study aims to examines the readiness of early childhood educators in the Greater Bandung area to implement STEM learning, focusing on three areas: science process skills (SPS), effective questioning, and science concept understanding. Utilizing a convergent parallel mixed-method design, data were collected from 17 purposively selected kindergartens through direct classroom observations, video and audio transcripts, and teacher interviews. The results show that kindergarten teachers in the Greater Bandung area demonstrate a "partial readiness" for STEM learning implementation. The result showed 58% teachers have incorporated four different SPS, particularly observation and experimenting, while skills such as classifying and measuring are less developed. Questioning practices were largely limited to basic strategies, with higher-order questions and peer collaboration rarely observed. In addition, the presence of misconceptions and the lack of scientific explanations indicate gaps in teachers' science content knowledge. These findings point to the need for targeted professional development to strengthen early childhood educators' skills and confidence in delivering STEM learning in ECE settings.

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INTRODUCTION

In recent years, there has been a growing emphasis on the importance of early childhood education (ECE) in shaping the foundation of children's cognitive and academic development. Studies show that quality education during early childhood has long-term benefits for children's academic success (Campbell et al., 2018). Recognizing this, Indonesia has taken significant steps to improve access to early education, as outlined in the Indonesia Education Roadmap 2025-2045 (Ministry of National Development Planning, 2025). This roadmap includes the extension of compulsory education to 13 years, ensuring that all children receive structured learning from an early age.

Among the various approaches to enhancing early education quality, STEM education has gained global attention. Many countries have placed STEM at the centre of their education policies due to its role in boosting innovation and economic growth (Zhi Hong Wan, 2020). For example, the U.S. government allocated $279 million for STEM education initiatives in 2018, while Australia invested over $64 million to enhance STEM learning, particularly in digital technology (Department of Education, 2018; Johnson, 2012). Similarly, Indonesia has acknowledged the importance of STEM by integrating it into its education roadmap, aiming to improve the quality of education and prepare students for technological advancements.

STEM education is particularly beneficial for young children due to their natural curiosity, problem-solving abilities, and capacity for experiential learning. Research suggests that children as young as three years old can engage in engineering thinking, explore hypotheses, and transfer knowledge across different contexts (Lipard, 2017). Studies have also shown that engaging young children in STEM education fosters essential 21st-century skills, including creativity, critical thinking, collaboration, and communication (Bybee, 2013; National Research Council, 2014). Moreover, STEM-based inquiry learning encourages young learners to develop problem-solving abilities by allowing them to experiment, iterate, and refine their understanding of the world through hands-on experiences (Murcia et al., 2020). In addition, studies show that by the 4th grade, children who have had little exposure to STEM often struggle with basic math and science concepts (Pantoya, 2015). This shows that early STEM experiences not only increase students' interest in STEM fields but also equip them with foundational knowledge that prepares them for later academic success.

Despite its potential, the implementation of STEM education in early childhood education (ECE) faces several challenges. Studies have shown that many early childhood educators lack the necessary STEM knowledge and teaching skills, which affects their confidence in implementing STEM learning. Common issues include limited teaching materials, time constraints, and concerns about young children's cognitive readiness for integrated STEM learning (Jamil et al., 2018). In fact, STEM education in early childhood requires well-prepared teachers who possess strong pedagogical and content knowledge.

To address these challenges, a specialized training program for early childhood educators needs to be done. However, understanding teachers' current readiness is essential to ensure the program's success. What remains unknown is the specific level of readiness among Indonesian kindergarten teachers when evaluated simultaneously across three critical, interconnected dimensions: their ability to facilitate Science Process Skills, their mastery of effective questioning, and their capacity to identify and correct science misconceptions.

The problem is that without a clear understanding of teacher readiness in these three specific areas, professional development programs risk being ineffective or misaligned with actual classroom needs. This study is necessary to provide the empirical baseline required to design targeted training that addresses both pedagogical and content-specific gaps. The objectives of this research are: To evaluate the implementation of Science Process Skills in kindergarten science lessons; To analyze the frequency and quality of effective questioning strategies used by teachers; To identify the presence of science misconceptions in teacher explanations and their ability to address student misunderstandings.

METHOD

This study utilized a convergent parallel mixed-method design, combining quantitative and qualitative data. Data was collected through direct observation and transcript from video as well as audio recording of science lessons. Teacher interviews also had been conducted to complete the data. To provide a clearer overview of method, reseach design chart is presented in Figure 1.

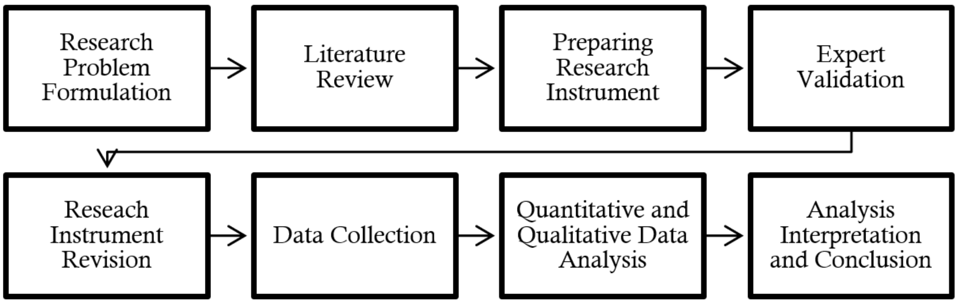

Figure 1. Research Design

Participants were selected using purposive sampling technique, focusing on 17 kindergartens located in Greater Bandung area. At each school a teaching team consisting of 1-3 teachers was observed during a single science lesson. For the purpose of data transcription and analysis, the study focused on the leading teacher of each team, as they were the primary facilitator of the classroom and provided the most substantial recorded data.

The instruments used in this study include observation checklist instruments identifying Science Process Skill, Effective questioning, and Science Concept Understanding, observer notes, and interview guideline. The instruments validated through expert judgment before implementation. Triangulation was done by comparing the findings from the classroom observations with the qualitative insights from the teacher interviews to validate the results.

For the quantitative analysis, the collected data were analyzed using descriptive statistical analysis. Frequency counts and distributions were analyzed for each observed indicator, then visualized through frequency graphs and comparative charts. Meanwhile for qualitative analysis, a thematic analysis was conducted on lesson transcripts and interview data to identify specific teacher misconceptions, challenges, and nuances of teacher-student interaction. Formal consent was obtained from all participating schools prior the data collection.

RESULT AND DISCUSSION

The results are organized into three main areas related to teachers' readiness to implement STEM learning in early childhood classrooms. The first subsection examines teachers' use of effective questioning techniques during classroom interactions. The second subsection focuses on the science process skills implemented in classroom activities. The final subsection discusses the presence of science misconceptions and the ways teachers addressed, or did not address. Together, these three areas offer a comprehensive picture of current classroom practices and highlight key challenges and implications for improving STEM teaching in early childhood education.

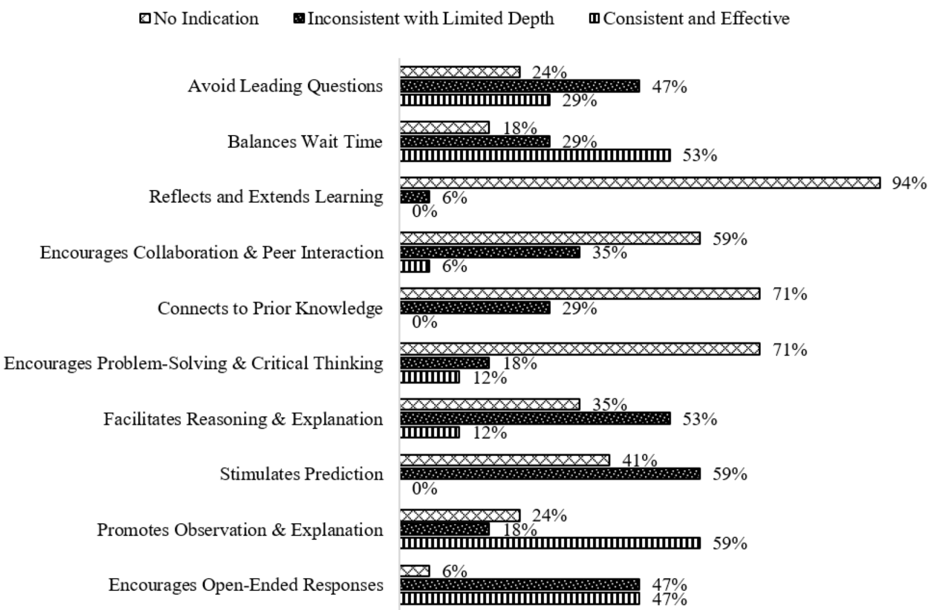

Figure 2. Effective questioning strategies implementation in class

1. Effective Questioning Techniques

Effective questioning strategy are identified based on validated frameworks from previous research, including the following: the Teacher Questioning Framework (Chin, 2007), Bloom's Taxonomy for Cognitive Levels (Anderson & Krathwohl, 2001), the Electronic Quality of Inquiry Protocol (EQUIP) Framework (Marshall et al., 2010), Flanders Interaction Analysis Categories (Flanders, 1970), the Classroom Assessment Scoring System (Pianta et al., 2008), and the Reformed Teaching Observation Protocol (Sawada et al., 2002). Based on previous research, ten strategies of effective questioning have been identified: (1) avoids leading question; (2) balances wait time; (3) reflects & extend learning; (4) encourages collaboration & peer interaction, (5) connects to prior knowledge, (6) encourages problem-solving & critical thinking, (7) facilitates reasoning & explanation, (8) stimulates prediction, (9) promotes observation & description, and (10) encourages open-ended responses.

These ten strategies were used to analyse classroom video transcripts from 17 selected kindergartens in the Greater Bandung area. The aim was to find out how well kindergarten teachers applied effective questioning strategies in their classrooms. Each strategy was assessed and grouped into one of three levels: no indication, inconsistent with limited depth, or consistent and effective.

No indication means that the teacher did not show any evidence of using that particular questioning strategy. Inconsistent with limited depth indicates that the teacher used that particular questioning strategy but still inconsistent and lacked comprehensive integration. In contrast, consistent and effective describes teachers who implemented the specific questioning strategy regularly and demonstrated a deep, purposeful application of the technique throughout their teaching in a way that clearly helped support children's learning.

Based on Figure 2, the strategies that were least implemented by teachers across the 17 selected kindergartens in the Greater Bandung area were those categorized as higher-order thinking prompts, namely Reflects and Extends Learning (no indication in 94% of schools), Connects to Prior Knowledge (no indication in 71% of schools), and Encourage Problem-Solving & Critical Thinking (no indication in 71% of schools). Unlike closed or confirmatory questions, these strategies ask teachers to stay responsive to unpredictable responses and helping children build their thinking step by step rather than steering them toward a predetermined answer. The absence of these strategies can limit conceptual retention and transfer, positioning children as passive recipients of explanation rather than active reasoners, and overall a missed opportunity to build the cognitive habits that science learning depends. Based on observation and interview, most of the teachers often feel uncertain about how to guide young children through reasoning tasks, particularly when children's responses are unpredictable. This result aligns with a study done by Purnamasari et. al (2020) which suggests that early childhood teachers may not place sufficient emphasis on, or feel confident in, using strategies that promote higher-order thinking. Additionally, early childhood educators in Indonesia typically graduate from Early Childhood Education (ECE) programs that may offer limited exposure to scientific content or questioning techniques rooted in inquiry and critical thinking (Novianti and Febrialismanto, 2020), meaning many teachers enter classrooms without having practiced these strategies in structured ways. Purnamasari et al. (2020) further emphasize the importance of professional development for ECE teachers, particularly in enhancing their communication strategies to better facilitate critical thinking in early learning environments.

The strategy of Encouraging Collaboration and Peer Interaction (No. indication in 59% of schools) also appeared to be among the least frequently implemented effective questioning techniques. This is particularly striking given that all 17 schools had formally adopted either the learning centers model *(model pembelajaran sentra)* or the activity areas model *(model pembelajaran area)*, as mandated by the current national curriculum, which organizes children into small groups. In theory, these structural arrangements should naturally support peer interaction. In practice, however, the physical grouping of children did not translate into meaningful collaborative learning, as teachers rarely used questioning to prompt children to talk to, listen to, or build on each other's ideas. This gap between structural intent and classroom reality is not unique to the schools in this study because it aligns with an observational study conducted in ten kindergartens in Palembang by Rantina and Boeriswati (2023) which found that even though most schools had implemented an interest center-based learning model, classroom activities were still largely teacher-centered. Rather than encouraging peer-to-peer collaboration, the learning process tended to focus on teacher-student interaction, with children primarily following instructions instead of working together to solve problems or complete tasks collaboratively. Both findings shown that adopting a collaborative learning model on paper does not automatically shift the teacher's role or questioning habits in practice. The model changes the room arrangement but it does not automatically changes how teachers talk to children. Nonetheless, building opportunities for peer collaboration is essential, not only for nurturing social-emotional development, but also for children's sense of belonging, and cooperation skill (Tejada & Hammer, 2024).

On the other hand, the strategies with the highest percentage of consistent and effective implementation are Balances Wait Time (consistent and effective use in 53% of schools) and Promotes Observation and Description (consistent and effective use in 35% of schools. This finding suggests that these two strategies may already be more familiar or accessible to teachers in early childhood settings. Balancing wait time is a relatively simple adjustment in teacher behavior that does not require additional materials or complex planning. Meanwhile, promoting observation and description aligns closely with young children's natural tendencies (such as seeing, touching, and describing their surroundings). making it more intuitive for teachers to implement. As noted by Tanck (2025) these characteristics likely contribute to the feasibility and consistent adoption of these strategies compared to more cognitively demanding questioning techniques.

Taken together, the distribution of effective questioning implementation across the 17 schools reveals a clear pattern: strategies that are concrete, low-preparation, and aligned with how young children naturally engage with the world tend to be used consistently, while those that require teachers to follow and extend children's thinking in open-ended ways remain largely absent. Closing this gap will require sustained professional development that helps teachers build the confidence and practical skills to navigate the unpredictable, open-ended conversations that higher-order questioning depends on.

2. Science Process Skills (SPS)

STEM learning focuses on integrating Science, Technology, Engineering, and Mathematics to help students understand and solve real-world problems (Bybee, 2013). Within this process, Science in STEM is not limited to students acquiring scientific knowledge and facts; it also emphasizes how students engage in the scientific process to address challenges. Consequently, all activities involved in the scientific process require students to develop strong Science Process Skills. This highlights the importance of training students to engage with the scientific process from an early age through STEM projects. By doing so, students can gradually build their Science Process Skills, enabling them to tackle increasingly complex problems in the future (Ningtyas et al., 2024).

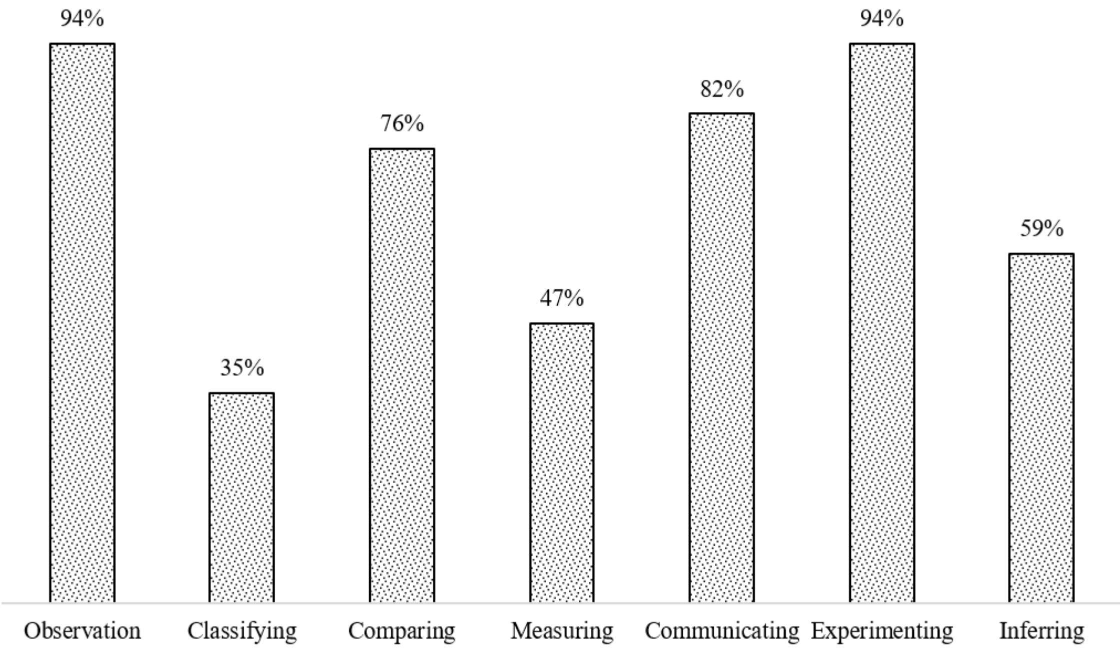

Figure 3. Science process skills implemented in class

According to Izzudin (2019), the Science Process Skills most appropriate for early childhood education include Observation, Classifying, Comparing, Measuring, Communicating, Experimenting, and Inferring. These skills can be grouped into two main categories: Basic Science Process Skills, which consist of Observation, Classifying, Comparing, Measuring, and Communicating; and Integrated Science Process Skills, which include Experimenting and Inferring. In this research, SPS that appear in science learning in the class taught by teachers in 17 selected kindergartens in the Greater Bandung area are identified.

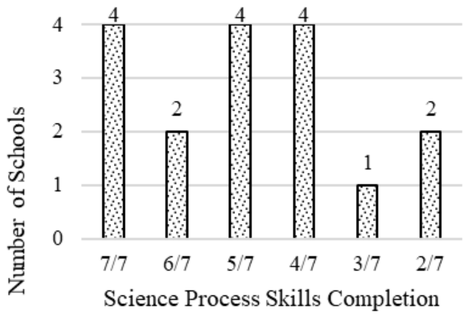

Figure 4. Science process skills implementation in class

The implementation of SPS in the observed schools as can be seen in Figure 3 were varied, but notably, 10/17 or over 58% of the classrooms had incorporated more than four different SPS in their learning activities. This is a positive indication, as it suggests that most teachers are already providing opportunities for children to engage in activities that help develop their SPS. This might be rooted from Indonesia's national curriculum for ECE that encourages the use of variety of student-centered model including Beyond Centers and Circle Time (BCCT), which naturally involve a variety of manipulative, sensory, and exploratory tasks (Maimunah, 2023). These kinds of activities typically embed multiple SPS such as observing, classifying, and communicating.

Based on the observation, the other seven schools that showed lower SPS in their learning were conducting science demonstration activities led by the teachers, instead letting student to do the experiments and hands-on activities themselves. Although demonstrations can be engaging and informative, they limit children's direct involvement in the very processes that define scientific thinking such as handling materials, making their own observations, forming comparisons, and drawing conclusions from firsthand experience. As a result, the children did not have opportunities to fully practice all components of SPS. Although curiosity, questioning, and exploration emerge naturally in young children from observing demonstration, all SPS require scaffolding, guided practice, and repeated opportunities in order to mature into sophisticated scientific thinking, teacher demonstrations alone may not substitute hands-on involvement that allows children to practice all SPS (Yilmaz et al., 2024).

Based on Figure 4, the Science Process Skills that showed the highest percentage of appearance in the classrooms were Observation and Experimenting, each with a 94% appearance rate. This can be attributed to the fact that nearly all of the selected kindergartens incorporated experimentation as part of their science learning activities. Experiment-based activities are likely popular among teachers because they help maintain children's focus and engagement during lessons. Furthermore, as students engage in experiments, they naturally carry out observations of the results and phenomena, which explains why the observation skill also appeared with such a high frequency. This finding also aligns with the observation that 59% of classrooms consistently used effective questioning techniques that promote observation and explanation, suggesting that teachers are not only providing hands-on experiments but also actively guiding students to notice, reflect on, and communicate what they observe.

Meanwhile, Science Process Skills that showed moderate levels of appearance but still present room for improvement were Inferring, Comparing, and Communicating, with respective appearance rates of 59%, 76%, and 82%. These skills could be strengthened by effective questioning (Chin, 2007) like encouraging students to draw simple conclusions based on their observations (inferring), prompting them to describe similarities and differences between objects or results (comparing), and providing more opportunities for students to share their ideas and findings verbally or through drawings (communicating).

On the other hand, the Science Process Skills that appeared in fewer than half of the observed classrooms were Classifying and Measuring, with respective appearance rates of 35% and 47%. This is particularly noteworthy, as both classifying and measuring are considered basic science process skills that ideally should be developed first before introducing more complex skills such as experimenting and inferring Izzudin (2019). The data therefore suggest an inversion of the intended sequence, children are regularly experimenting, but without the underlying skills that would allow them to do so with precision or analytical intent. This may be due to teachers focusing more on the hands-on action of experimenting. When teachers prioritize the experiential momentum of an experiment, more structured work such as sorting and measuring can easily get bypassed. Additionally, classifying and measuring require more structured guidance and specific tools, which might present practical challenges in a busy early childhood classroom setting (Outhwaite et al., 2024). To improve the integration of these skills, teachers could be encouraged to incorporate more effective questioning techniques (Chin, 2007) in the class especially ones that promote observation & desciption and facilitates reasoning & explanation. The other suggestion would be designing simple activities that incorporate sorting objects based on attributes (such as size, color, or texture) and to introduce basic measurement tasks using age-appropriate, familiar tools like rulers, measuring cups, or even non-standard units (e.g., hand spans).

3. Science Misconceptions

Misconceptions in early childhood education can arise when children enter formal learning environments with prior knowledge and personal understandings of the world that often differ from scientifically accepted explanations (Abell & Lederman, 2007). These early ideas are typically formed through everyday experiences, cultural or religious teachings, and informal observations, and while they reflect children's attempts to make sense of their environment, they can sometimes lead to incorrect or incomplete understandings of scientific concepts (Alawiyah et al., 2018).

Early childhood is an ideal time to nurture scientific thinking and correct misunderstandings before they become ingrained (Theobald, 2021). Therefore, teachers play a crucial role in identifying, explaining, and addressing these misconceptions to support accurate concept development (Izzati & Rochmah, 2020). This involves not only delivering correct scientific information but also actively engaging children in discussions and explorations that challenge their incorrect ideas and promote conceptual change in practice, which can be achieved by STEM learning. Importantly, these activities must be aligned with early childhood developmental needs so that discussions and explorations remain playful, engaging, and appropriate for young learners.

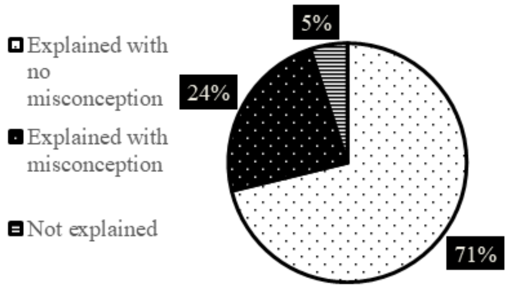

Figure 5. Misconception in teacher's science concept explanation in class

Based on Figure 5, there are still 24% of schools that were found to explain scientific concepts with misconceptions, while 5% did not explain the scientific concepts related to the classroom activities at all. From the observation, this may be due to a tendency among teachers to prioritize student engagement over scientific accuracy, a pattern that aligns with research showing that many educators underestimate young children's ability to grasp scientific concepts causing teachers to focus primarily on keeping children engaged in the learning process, while paying less attention to the importance of balancing it with accurate and meaningful scientific concepts (Tanık-Önal & Sönmez-Eryasar, 2022). It could also stem from limited content knowledge, as many early childhood education (ECE) teachers in Indonesia are trained in early childhood pedagogy but not in science-specific disciplines (Astuti at al., 2020). Additionally, a lack of access to reliable resources may contribute to these challenges.

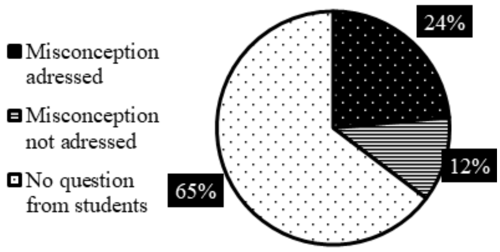

Figure 6. Frequency of teachers adressing misconception from students' question

These findings highlight the importance of providing enrichment opportunities and targeted professional development for ECE teachers, particularly in strengthening their understanding of scientific concepts and content knowledge appropriate for young learners.

Addressing misconceptions was particularly difficult to observe, as shown in Figure 6, where 65% of the science lessons did not include student questions or visible signs of misconceptions that would require clarification from the teacher. This finding may reflect that the lesson design or teacher questioning did not create space for children to surface their thinking in the first place. In the remaining lessons, misconceptions were addressed in 24% of the cases, while in 12% they were left uncorrected. When misconceptions go unaddressed in early childhood classrooms, it tend to persist and become increasingly resistant to correction as children grow older, often interfering with their ability to build accurate understanding in later science learning (Abell & Lederman, 2007). Based on the observation and interview, one possible explanation why it happened is that teachers were often preoccupied with managing and assisting students during hands-on experimental activities, which were the dominant approach used in most lessons. A qualitative study done by Duban et al. (2019) reported that when doing lab experiments, much of the teachers' effort went into managing materials, logistics, and student safety, which reduced the time and cognitive space to engage deeply with student thinking and misconceptions.

CONCLUSION

This study reveals that kindergarten teachers in the Greater Bandung area demonstrate a "partial readiness" for STEM learning implementation based on science process skills (SPS), effective questioning, and science concept understanding. The findings indicate that while there is high engagement in experiential activities, there is a significant lack of the analytical scaffolding required to turn these activities into rigorous STEM learning. The findings also showed 58% of teachers have integrated more than four SPS, especially observation and experimenting,. oOther skills such as classifying and measuring remain underdeveloped, likely due to their structured and resource-dependent nature. In terms of effective questioning, teachers tend to use simpler strategies like balancing wait time and promoting observation, while higher-order questioning techniques that foster reflection, problem-solving, and peer collaboration are still rarely applied. Additionally, misconceptions in scientific explanations persist, reflecting the need for stronger content knowledge and pedagog ical confidence in science. Overall, these findings suggest that early childhood educators demonstrate promising engagement in science learning but still require targeted support to implement STEM education comprehensively and effectively, while also ensuring that the activities remain developmentally appropriate, playful, and engaging for young learners.

In light of these findings, a specialized training program for early childhood educators is essential. The training should be designed to address the identified gaps by focusing on three core areas: (1) developing and integrating customized, age-appropriate materials to enhance teachers' mastery and facilitation of all Science Process Skills, especially classifying and measuring; (2) embedding playful yet purposeful examples and activities that strengthen teachers' ability to use effective questioning strategies promoting higher-order thinking, reflection, and collaboration; and (3) providing clear and engaging instructional resources to deepen teachers' understanding of scientific concepts and prevent misconceptions in classroom instruction. By aligning the training content with these readiness gaps, it can be assured that the program builds both pedagogical and content competence, empowering teachers to create inquiry-based, accurate, and engaging STEM learning environments for young children. This alignment will be critical for achieving the broader goal of improving the quality of STEM education in early childhood settings across Indonesia.

The regional scope of this study limited to 17 kindergartens in the Greater Bandung area, which may not be representative of all Indonesian ECE settings. Future research should expand this investigation to a larger, more diverse geographic sample across Indonesia to identify national trends. Additionally, longitudinal studies are needed to evaluate the long-term impact of targeted STEM professional development on teacher confidence and student learning outcomes.

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