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META-ANALYSIS OF THE EFFECTIVENESS OF THE INQUIRY-BASED LEARNING MODEL IN FOSTERING EARLY CHILDHOOD SCIENCE LITERACY

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Abstract
Based on the 2022 PISA assessment, Indonesia's science literacy score has experienced a further decline compared to 2018. This research aims to extrapolate the fundamental principles proven effective in enhancing science literacy across various educational levels, and then reflect upon and adapt them to the learning and developmental context of Early Childhood Education (ECE), which is distinctly different from higher levels. This study employs a systematic literature review method with a quantitative approach, namely meta-analysis. The results indicate that seven out of the eight analyzed studies demonstrated Cohen's d values categorized as large effects. For instance, the study by Haerani et al. (2020) recorded a high Cohen's d value of 5.17. These findings strengthen the theoretical foundation for adapting the inquiry-based learning model to ECE through three main pillars: (1) simplifying the inquiry process into observation-exploration-communication stages that align with children's cognitive development, (2) transforming learning into contextual play activities through the exploration of everyday environments, and (3) utilizing realia (real objects/media) that facilitate sensorimotor learning.
Keyword: Science Literacy, Inquiry, Early Childhood

INTRODUCTION
Science learning is implemented in the educational process using a scientific approach. Science learning directs the teaching and learning process to enhance science literacy. Science literacy provides the knowledge and understanding of scientific concepts and processes necessary for personal decision-making, participation, and productivity. This aligns with the statement by PISA (Program for International Student Assessment), which reveals that science literacy is the ability to use scientific knowledge, identify questions, and draw evidence-based conclusions in order to understand and make decisions (Sarwi et al., 2020).
PISA itself measures three main domains: literacy, mathematics, and science. The PISA assessment aims to evaluate education systems by measuring student performance (Widowati et

al., 2019). Data from PISA science literacy results from 2000 to 2018 show that the science literacy of students in Indonesia remains low. According to the science literacy data, the students' ranking in 2000 was 38th out of 41 surveyed countries with a score of 393; in 2003, it was 38th out of 41 countries with a score of 395; in 2006, it was 50th out of 57 countries with a score of 393; in 2009, it was 57th out of 65 countries with a score of 383; in 2012, it was 64th out of 65 countries with a score of 382; in 2015, it was 62nd out of 72 countries with a score of 403; and in 2018, it was 70th out of 78 countries with a score of 396. Indonesia's science score decreased again by 13 points from 396 in 2018 to 383 in 2022 (Kompas.com, 2024).

This decline in science literacy scores is certainly a crucial issue to investigate. Science literacy plays a vital role in life. It is not only about mastering scientific knowledge but also encompasses critical thinking skills, the ability to interpret data, and a scientific attitude in addressing various problems (Sutiani et al., 2021). The low science literacy of Indonesian students is caused by various factors. From the learning perspective, the science learning process in schools still largely focuses on rote memorization of concepts and one-way delivery of information (Adnan et al., 2021). Teachers' limited understanding of the concept of science literacy also impacts the low quality of learning that supports the development of students' scientific skills (Jaya, 2021). Based on this, building the foundation of science literacy cannot be postponed and must begin early.

Early Childhood Education (ECE) holds a strategic and crucial position. This phase is known as the *golden age*, where children's cognitive, social, and emotional development occurs rapidly (Juwita et al., 2023). Most importantly, children at this age naturally possess immense curiosity about their surroundings, making young children like active little scientists exploring their world (Tamba et al., 2024). The right approach during this phase will not only instill a positive attitude towards science but also form a sustainable scientific mindset.

The reality on the ground often does not align with this ideal potential. Science learning practices in many ECE institutions are still confined to conventional methods, such as lectures, memorization, and the use of rigid worksheets. Such approaches tend to reduce science to passive information, which can ultimately stifle children's natural curiosity (Ramadani et al., 2025). Consequently, the essence of science as a challenging and enjoyable inquiry process is neglected.

The inquiry-based learning model offers itself as a relevant and promising solution. This model positions children as active subjects who construct their own knowledge through the stages of observing, formulating questions, investigating, and reflecting on findings (Anisa et al., 2025). Specifically in the ECE context, inquiry is realized through science play activities (Wulandari et al., 2022), where children learn about basic scientific concepts such as cause-and-effect, force, and the properties of matter through direct, concrete, and meaningful experiences (Widyaningrum et al., 2024). Through the inquiry model, students not only master scientific concepts but also develop critical thinking abilities, problem-solving skills, and a scientific attitude, which are the core of science literacy (Muyassaroh & Mukhlis, 2023).

Along with the growing awareness of the importance of the inquiry approach, numerous empirical studies have been conducted in Indonesia in recent years, testing the effectiveness of the inquiry learning model both guided and free inquiry in the context of improving science literacy. These studies, scattered across various scientific journals, generally conclude that the inquiry model has a positive impact (Hardani, 2020). However, research focusing specifically and comprehensively on its effectiveness at the ECE level remains very limited.

Based on this gap, this meta-analysis research was conducted, analyzing and synthesizing findings from 8 research articles on inquiry from various educational levels. The effective principles of the inquiry model across different educational levels can be adapted to foster science literacy in early childhood. This research does not stop at synthesis alone; it aims to extrapolate and reflect on the existing evidence to formulate implications and an adaptation framework for the ECE context (Rukmaningsih et al., 2020). This study serves to bridge empirical findings from higher educational levels with the practical needs and development of children at the ECE level.

Based on the above explanation, the researcher is compelled to conduct a study entitled "Meta-Analysis of the Effectiveness of the Inquiry-Based Learning Model in Fostering Early Childhood Science Literacy." This research synthesizes findings on the effectiveness of the inquiry model in enhancing science literacy from various educational levels. The goal is to extrapolate the fundamental principles proven to be effective and then reflect upon and adapt them to the learning and developmental context of Early Childhood, which is distinctly different from higher levels.

METHODOLOGY

This research employs a systematic literature review method with a quantitative approach in the form of a meta-analysis. This type of research was chosen because it aims to summarize, analyze, and statistically synthesize existing quantitative research findings to obtain stronger and more comprehensive conclusions.

Meta-analysis allows researchers not only to conduct a narrative review but also to calculate the overall effect size of the implementation of the inquiry-based learning model on improving students' science literacy. This study combines findings from 8 research articles across various educational levels concerning the effectiveness of the inquiry-based learning model in enhancing science literacy. The deliberate selection of articles from various educational levels was conducted to obtain a more comprehensive map of the effective principles of the inquiry model, thereby enabling the process of extrapolation and adaptation to the ECE context to be carried out on a more robust evidential foundation.

The data sources in this study are secondary data derived from 10 published quantitative research articles. The process of collecting these articles followed several stages:

1. **Literature Search:** Articles were searched through digital databases such as Google Scholar, SINTA (Science and Technology Index), and university repositories in Indonesia. Keywords used in the search included: "inquiry model," "science literacy," "science learning outcomes," "early childhood education," "experiment," "pretest-posttest."
2. **Article Selection:** Selection was carried out based on predetermined inclusion and exclusion criteria.

Table 1. Article Inclusion and Exclusion Criteria

Component	Inclusion Criteria	Exclusion Criteria
Population	Learners from all educational levels (Early Childhood Education, Elementary, Junior High, Senior High, University).	Populations outside the context of formal/informal education (e.g., training for teachers, parents, or non-human samples).
Intervention	Studies that implemented the inquiry-based learning model in its various forms (e.g., guided, open,	Studies that tested learning models other than inquiry (e.g., project-based learning, direct instruction without inquiry elements) or that mixed inquiry with other

Component	Inclusion Criteria	Exclusion Criteria
	structured inquiry) in science learning or related topics.	models where its effect could not be isolated.
Comparison	Studies that compared a group using the inquiry model with a control/comparison group (e.g., conventional learning, another model).	Studies without a control/comparison group (e.g., pure qualitative descriptive studies without pre-post tests, activity reports without outcome evaluation).
Outcomes	Studies that measured at least one aspect of science literacy, such as: conceptual understanding, science process skills, scientific attitudes, or curiosity.	Studies that only measured non-science learning outcomes (e.g., mathematics or language achievement) or that did not measure any science literacy-related outcomes.
Study Design	Experimental or quasi-experimental studies with a clear design (pretest-posttest control group, etc.). Complete empirical research articles published in reputable journals (national/international) or proceedings.	Non-empirical studies (e.g., literature reviews, conceptual articles, opinion pieces). Unpublished research reports (undergraduate theses, master's theses, dissertations) to maintain publication quality. Studies with an unclear methodology description.
Contextual (Key Focus)	Studies whose principles, strategies, or effectiveness findings have the potential to be reflected upon and adapted to the Early Childhood Education learning context (are concrete, involve exploration, manipulatives, etc.).	Studies where the inquiry implementation is highly technical and abstract, making it impossible to adapt to the play context and pre-operational cognitive development of young children (e.g., complex virtual lab-based inquiry at the university level).

Data analysis in this meta-analysis was conducted through several quantitative stages to calculate the magnitude of the effect, or effect size, of each study, and then summarize them.

1. **Data Extraction**

   The following quantitative data were extracted and tabulated from each article:
   - Researcher's name and year of publication
   - Number of samples or students (n)
   - Pretest mean score ($\bar{x}_1$)
   - Posttest mean score ($\bar{x}_2$)

- Pretest standard deviation value (s_1) or posttest standard deviation value (s_2)

2. **Effect Size Calculation**
   Effect size is a quantitative index that measures the strength or magnitude of a treatment or phenomenon. Given that your data consists of pretest and posttest results, the relevant effect size to calculate is **Cohen's d**. The formula used is as follows:

$$d = \frac{M_{post} - M_{pre}}{SD_{pooled}}$$

- d = Effect size value (Cohen's d)
- M_{post} = Mean posttest score
- M_{pre} = Mean pretest score
- SD_{pooled} = Pooled standard deviation

   For a one-group pretest-posttest research design, the pooled standard deviation is often simplified by using the standard deviation of the pretest group (s_pre) as the basis for comparison, as it represents the variation in student scores before the treatment is given. Thus, a more practical formula to use is:

3. **Interpretation of the Effect Size Value**
   After the effect size (d) value from each article is calculated, that value is interpreted to determine the magnitude of the influence of the inquiry-based learning model. The interpretation category commonly used according to Cohen (1988) is as follows:

Table 2. Effect Size (Cohen's d) Interpretation Categories

No	Effect Size (d) Value	Effect Category
1	$d < 0.2$	Very Small / Negligible
2	$0.2 \leq d < 0.5$	Small
3	$0.5 \leq d < 0.8$	Medium
4	$d \geq 0.8$	Large

RESULTS AND DISCUSSION

Inquiry provides students with the opportunity to practice the scientific process directly. Through the stages of inquiry, students are guided to observe phenomena, formulate problems, propose hypotheses, conduct investigations, collect data, analyze results, and draw conclusions. Several research findings utilized in this analysis are as follows:

1. The Effect of the Guided Inquiry Learning Model on Students' Science Literacy Ability at SMP Negeri 35 Palembang (Erdani et al., 2020).
2. The Effect of the Free Inquiry Learning Model on Improving Science Literacy in Junior High School (A. S. Wulandari et al., 2023).

3. The Effect of the Free Inquiry Model on Science Literacy Skills (Haerani et al., 2020).
4. The Effect of the Guided Inquiry Model Assisted by Wordwall Educational Games on the Science Literacy of Elementary School Students (Widyaningrum et al., 2024b)
5. Implementation of the Inquiry Learning Model to Improve Science Literacy of Students at SD Negeri 02 Tekorejo (Gustinasari & Mahrus, 2025)
6. The Effect of the Inquiry Learning Model with Realia Media on the Science Literacy of Children Aged 4-5 Years (Febriani et al., 2023)
7. The Effect of the Guided Inquiry Learning Model Assisted by Multidimensional Thinking Diagrams in Science Learning on Students' Science Literacy (Fuadina et al., 2022)
8. The Effect of the Guided Inquiry Learning Model on Improving the Science Literacy of Grade X Students at MAN 1 Kota Bima for the 2022/2023 Academic Year (Fahrudin, 2020)

Based on the description above, a total of 8 primary studies were included in this analysis. These studies examine the effect of the inquiry-based learning model on student science literacy in elementary and junior high schools. Each study reported pretest and posttest scores, which were used to calculate the effect size. Table 1 presents a standard summary of the analyzed studies.

Table 3. Study Summary

No	Study	Condition	Mean	N	Std. Deviation
1	Erdani et al., 2020	Before	66.9	28	6.64
		After	83	28	6.49
2	Wulandari et al., 2023	Before	39.4	357	13.54
		After	84.2	357	10.78
3	Haerani et al., 2020	Before	20.8	37	10.182
		After	67.5	37	7.717
4	Widyaningrum et al., 2024	Before	64.2	20	8.12
		After	81.2	20	5.74
5	Gustinasari & Mahrus, 2025	Before	58.2	38	16.68
		After	66.1	38	10.87
6	Febriani et al., 2023	Before	11.73	15	1.28
		After	16	15	1.363
7	Fuadina et al., 2022	Before	69.87	32	7.33
		After	86.21	32	6.89
8	Fahrudin, 2020	Before	32.87	40	8.711
		After	38.5	40	1.97

Subsequently, an effect size analysis was conducted. Based on the pretest and posttest results data, as well as the standard deviation data, the effect size was calculated using Cohen's d. The results of the calculation are as follows:

Table 4. Cohen's d Results

No	Study	Mean Difference	Pooled Std. Deviation	Cohen's d	Effect Size Interpretation Categories

1	Erdani et al., 2020	16.1	6.57	2.45	Large
2	Wulandari et al., 2023	44.8	12.24	3.66	Large
3	Haerani et al., 2020	46.7	9.03	5.17	Large
4	Widyaningrum et al., 2024	17	7.03	2.42	Large
5	Gustinasari & Mahrus, 2025	7.9	14.08	0.56	Medium
6	Febriani et al., 2023	4.27	1.32	3.23	Large
7	Fuadina et al., 2022	16.34	7.11	2.3	Large
8	Fahrudin, 2020	5.63	6.32	0.89	Large

Based on the statistical synthesis of eight primary studies, this meta-analysis reveals a consistent and encouraging finding. The interventions studied resulted in an impact that is not only positive but also substantive on the measured outcomes. Beyond mere statistical significance, the magnitude of this impact is the main highlight, where seven out of the eight analyzed studies showed Cohen's d values categorized as large effects. As an illustration, the study by Haerani et al., (2020) recorded a high Cohen's d value of 5.17. This high value not only confirms the strength of the intervention but also suggests that the achievement gap between the experimental and control groups had almost no overlap, indicating that the intervention can be considered a dominant determining factor within the context of that particular study.

However, amidst this consistency of large effects, there exists a variation in the magnitude of the effect sizes that warrants more careful examination. These findings actually provide insights into the contexts of intervention implementation. Striking differences, for instance between d=5.17 (Haerani et al., 2020) and d=0.56 (Gustinasari & Mahrus, 2025), allow for reflection on the heterogeneity in methodological and population characteristics. Factors such as the duration and intensity of the intervention, facilitator qualifications, sample characteristics (e.g., baseline ability levels), and the sensitivity of the measurement instruments used are strongly suspected to be the root causes of this disparity. Therefore, the study by Gustinasari & Mahrus (2025), which reported a medium effect, becomes a valuable starting point; although its magnitude is lower, this finding confirms that the intervention still has a meaningful practical impact even under potentially less ideal conditions, while also affirming that its effectiveness is not absolute and can be moderated by other variables.

In line with the above explanation, the consistency of the other seven studies in producing large effects forms a robust and undeniable pattern of evidence, thereby strengthening the external validity and generalizability of the findings regarding the intervention's potency. The strength of this pattern remains unshaken by the presence of one study with a medium effect, which can instead be viewed as an indicator of the boundaries or specific conditions under which the intervention's effectiveness might be moderated. The results of the study by Febriani et al., 2023, on the effect of the inquiry learning model with realia media on the science literacy of children aged 4-5 years, also showed a large effect, as seen from the Cohen's d result of 3.23.

Based on the synthesis of all findings, the empirically proven effectiveness of the inquiry model across various educational levels provides a strong foundation for its adaptation in ECE. However, its implementation requires a specifically tailored approach that aligns with the developmental characteristics of young children. First, it is necessary to simplify the complex steps of inquiry into simple, easy-to-follow stages for children, for example through a cycle of "Observe, Try, and Tell." Second, an emphasis on the aspect of play is key, where the inquiry process must be packaged in the form of enjoyable play that does not feel formal. Third, integration with children's daily lives is crucial to ensure meaningful learning, such as exploring scientific concepts through cooking, gardening, or water play. This approach not only fosters early science literacy but also develops basic science process skills like observation, prediction, and communicating findings through methods suited to the child's developmental stage, for instance through stories, drawings, or direct demonstrations.

Although this meta-analysis indicates the promising effectiveness of the inquiry model, its implementation in ECE settings requires deep consideration of several critical aspects. The first aspect is educator readiness, which necessitates not only a conceptual understanding of the inquiry model but also practical skills in applying it within the context of children's play. The second aspect is resource availability, including safe, accessible, and locally relevant tools and materials. The third aspect is the development of an authentic assessment system capable of measuring complex learning processes without sacrificing the element of play. Therefore, further research is essential to develop inquiry protocols specific to ECE, create appropriate assessment instruments, and explore the supporting and hindering factors for its implementation within Indonesia's diverse contexts, considering the variety of cultures, socio-economic backgrounds, and educational resources available.

CONCLUSION

Based on the synthesis of eight experimental studies, it can be concluded that the inquiry-based learning model is proven effective in enhancing science literacy, with seven studies showing an effect size in the large category. These findings strengthen the theoretical foundation for adapting the inquiry model to Early Childhood Education (ECE) through three main pillars: (1) simplifying the inquiry process into observation-exploration-communication stages that align with children's cognitive development, (2) transforming learning into contextual play activities through the exploration of everyday environments, and (3) utilizing realia (real objects) that facilitate sensorimotor learning. Its implementation requires systemic support in the form of enhancing educators' capacity to design inquiry scaffolding, developing safe and affordable learning resources, and creating authentic assessment instruments capable of measuring both the learning process and outcomes. Therefore, further research is needed on the design of inquiry protocols specifically for the Indonesian ECE context, taking into account cultural and socio-economic diversity, to realize science learning practices that are both meaningful and developmentally appropriate for young children.

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