



Analyzing Gender and Cultural Disparities in Science Literacy and Numeracy: Socioeconomic, Linguistic, and Educational Perspectives

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Abstract: The current research examines differences between genders and cultures concerning scientific literacy and numeracy skills of Indonesian secondary school students residing in Sundaland, Indonesia. This quantitative study used hierarchical linear modeling (HLM) and analyzed results from literacy tests, questionnaires, and interviews conducted among the stratified sample. According to the analysis, Javanese students achieved the best results in the test; Balinese respondents scored the lowest due to unequal infrastructure and limited access to technology. Moreover, males showed greater results in numeracy, whereas females demonstrated their advantage in scientific literacy. In addition, the use of the mother tongue helped students achieve a better understanding of the concepts; Batak and Minangkabau respondents with long-standing cultural learning traditions showed higher results. Thus, this paper supports the idea that inclusive educational policy is a key factor for closing the literacy gap in ethnically diverse countries. Ethnomathematics and multicultural education practices should be used more often for improving academic performance in Indonesia. Even though this work has some limitations, including the geographic location of respondents and the lack of longitudinal studies, the author managed to conduct a valuable study on the issue under consideration. It will contribute to the development across diverse populations.

Keywords: cultural disparities; gender disparities; linguistic diversity; numeracy literacy; science literacy; socioeconomic perspectives

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INTRODUCTION

The development of a country is highly dependent on the quality of its human resources, in terms of education, competitiveness, and adaptability to the dynamics of global change. It can be assessed in terms of formal educational levels, critical thinking skills, technical expertise, and the ability to collaborate and innovate in tackling global challenges. Literacy has also become a crucial prerequisite for critical thinking, problem-solving, and innovations in the digital age (Iswara et al., 2022; Kim & Park, 2020; van Laar et al., 2020). A robust literacy culture fosters critical analysis, effective communication, collaboration, and creativity—important aspects of socio-economic growth founded on knowledge (Mariane et al., 2023). An example of the importance of a strong literacy culture in boosting innovation and knowledge-based economies is Finland's digital literacy campaign. The focus of the Finnish literacy project on developing critical and collaborative skills helped promote active public participation in technology innovation and knowledge economy activities. Given the dynamics of the Fourth Industrial Revolution and the emergence of Society 5.0, education should provide individuals with the adaptive skills necessary to cope with socio-economic and technological changes. Six important aspects of twenty-first-century literacy. (Anwar, 2021; Chalkiadaki, 2018; Coşkun et al., 2019). There are six major dimensions of 21st-century literacy: reading and writing, numerical, scientific, financial, digital, and cultural and civic literacies (Konopko, 2015). Literacy is an important means of nurturing a range of competencies, including information comprehension, data problem-solving, financial management, navigating technology, and engaging socially. Such pillars of literacy denote the proficiency level of individuals, their ability to think and behave in accordance with data, and their active participation in the digital world. Literacy becomes a tool for developing the 21st-century skills learners need in an ever-evolving world.

The 4C skills, which include critical thinking, communication, collaboration, and creativity, are vital when it comes to the resolution of global issues (Dilekçi & Karatay, 2023; Thornhill-Miller et al., 2023; Yulianto, Umami, Anwar, et al., 2024). According to the Framework for 21st Century Learning (Amador et al., 2007), the use of 4C skills improves academic performance and prepares students for future jobs in the labor market (González-Salamanca et al., 2020). It fosters critical thinking, effective communication, collaboration, and creativity when tackling difficult challenges (Dilekçi & Karatay, 2023; Alifah, 2023). Nonetheless, there is a lack of scientific and numerical literacy in the acquisition of those 4C skills in Indonesia (González-Salamanca et al., 2020; van Laar et al., 2020). For example, an experimental study by Kartal (2020) showed that an application-based approach improves students' skills in evidence-based analytical thinking. Moreover, according to Lee et al. (2024),

cooperation during data analysis problem-solving tasks promotes numerical literacy. Scientific and numerical literacy is very important for improving critical thinking and creativity through evidence-based analysis and creative problem-solving (Kartal, 2020). On the other hand, scientific literacy promotes the ability to critically assess hypotheses and make decisions based on facts and figures, while numerical literacy helps understand numbers and interpret statistics (Lieskovský & Sunyík, 2022; Qiao et al., 2024; Reyna & Brainerd, 2023). While scientific literacy enhances the ability to formulate arguments about scientific ideas, numerical literacy is critical for solving data-driven problems through group discussions (Haviz et al., 2020). It is one of the best strategies for improving Indonesia's education system. However, this fusion of competencies and literacy depends on the nation under review, with high-performing nations successfully implementing effective teaching approaches.

Countries that perform exceptionally well on PISA tests, such as Singapore and Finland, have successfully infused scientific literacy and numeracy into 4Cs learning by embracing inquiry-based and project-based learning. Singapore, for instance, embraces collaborative student experimentation in laboratories where students explore scientific concepts. Conversely, Finland encourages students to develop practical and problem-based projects that require advanced mathematical calculations (Chistiyakov et al., 2023; Martawijaya et al., 2023; Stehle & Peters-Burton, 2019; Yulianto, Umami, Anwar, et al., 2024). On the other hand, Indonesia is still grappling with challenges in adopting 4Cs learning in its education system due to excessive emphasis on memorization, inadequate exploration, and a lack of open discussion (Ismawati et al., 2023). According to Yulianto et al. (2024), about 70% of teachers find it challenging to deliver learning activities based on higher-order thinking skills (HOTS). Besides, data from Kemendikbud (2023) indicates that rural schools lag behind urban schools regarding technological infrastructure by at least 50%. The 2013 curriculum, which integrates 4Cs principles, remains inefficient due to inadequate teacher training in applying HOTS, disparities in digital access (Larasati & Al Mighwar, 2023), and uneven pedagogical practices between urban and rural schools (Kemendikbud, 2023). The persistent barriers to implementing 4C-based learning under the 2013 Curriculum, such as teacher unpreparedness, limited digital access, and the dominance of rote learning, have catalyzed national efforts to renew the curriculum.

Curriculum reform in Indonesia via the Merdeka Curriculum addresses the shortcomings of the existing 2013 curriculum, particularly its inability to address challenges emerging from digital technology, globalization, and the need for critical and collaborative thinking skills in the 21st century. In particular, this curriculum focuses on competency-based learning, flexibility, and character building using the Pancasila Student Profile (Larasati & Al Mighwar, 2023) together with the promotion of 4Cs, namely critical thinking, creativity, communication, and collaboration (Stehle & Peters-Burton, 2019; Yulianto, Umami, & Mony, 2024). However, even with the flexible learning offered in the curriculum, implementing it is difficult due to teachers' insufficient preparedness, uneven distribution of digital technologies, and limited access in rural areas. According to a study conducted by the Ministry of Education and Culture (Kemendikbud, 2023), only 40% of teachers have sufficient knowledge of how to implement new approaches to learning, and 60% of schools in remote areas lack adequate connectivity. At the same time, many teachers face difficulties in applying new methods such as project- and inquiry-based learning, which are among the main principles of the Merdeka Curriculum. The disparity in readiness is evident between urban schools, which are more adaptable, and schools in remote areas that lack resources. These internal challenges are reflected in Indonesia's learning outcomes at the international level, particularly in large-scale assessments such as PISA. The gap between curriculum intent and classroom reality is evident in the nation's low performance in literacy and 21st-century skills.

Indonesia is encountering various issues related to literacy-based learning and the development of 21st-century skills due to its poor PISA score (369.3), which is caused by poor-quality instruction, limited access to technological advancements, and an imbalance between urban and rural regions (OECD, 2023). On the other hand, Singapore (PISA 559.7) stands out for incorporating educational technology through the implementation of online learning resources, adopting problem-solving curricula like the Mathematics Problem-Solving Curriculum, and providing ongoing professional development for teachers through NIE programs (PISA 2022 Assessment and Analytical Framework, 2023). Malaysia (PISA 424.7) and Thailand (PISA 394.0) have applied a STEM approach to improve scientific literacy and numeracy skills (OECD, 2023). Indonesia's delayed performance is associated with poor teaching standards, limited technological use, and disparities between urban and rural education. The dependence on rote memorization and examination-based assessment impedes logical reasoning, critical thinking, and application of scientific principles (Ismawati et al., 2023). The weak scientific literacy and numeracy call for reforming the "Kurikulum Merdeka" by improving pedagogical techniques through project-based learning, expanding technological opportunities through online learning resources such as "Rumah Belajar," and training teachers using the "Guru Penggerak" initiative. The curriculum development process should emphasize the acquisition of analytical skills among learners instead of rote memorization for examinations (Ongesa, 2020). Considering the above factors and the need for curriculum transformation, it is imperative to focus on scientific literacy and numeracy as the primary literacies that enable critical thinking and the innovative skills valued in modern education systems. Scientific and numerical literacy become the basis for a 21st-century education, contributing to the cultivation of critical thinking and problem-solving skills in evidence

and the development of students' innovation capabilities using science knowledge, data analytics, and technology tools for coming up with innovative solutions for global issues (Haviz et al., 2020; Kartal, 2020). According to experts in this field, scientific literacy is the competence related to scientific knowledge, the ability to use it to solve different problems, and the ability to assess information based on evidence (OECD, 2023). At the same time, numerical literacy involves understanding and interpreting numbers and data to make informed decisions (Goldstein et al., 2024). Despite all that, 56 out of 81 countries, among which is Indonesia, continue showing results lower than the international average level in scientific and numerical literacy due to the prevailing education system based on rote learning, where students have to memorize facts and formulae without understanding their meaning and using them to solve problems in reality (Ismawati et al., 2023; OECD, 2023; Wulandari & Jailani, 2017). Conversely, countries with high performance on PISA tests apply inquiry, problem-based, and problem-solving approaches (Stehle & Peters-Burton, 2019). In Indonesia, the lack of exploratory learning and limited resources further exacerbate the literacy gap (Lidinillah et al., 2022). Beyond systemic and infrastructural barriers, demographic factors, particularly gender, also play a critical role in shaping disparities in scientific and numerical literacy.

The existence of inequalities in literacy based on gender is still evident, especially in low- and middle-income countries. Specifically, in Ghana, the gender gap increases as education progresses (Takyi et al., 2021). As primary school enrollments increase, girls remain more vulnerable to dropping out of school and exhibit lower literacy levels (Psaki et al., 2022). The gap in access to technology between male and female students persists in Latin America, leading to inequalities in education, even in online courses (Armando et al., 2022). Generally, boys have an advantage in math, whereas girls excel in reading comprehension. These inequalities are attributed to social and cultural stereotypes that shape gender role perceptions from birth, where boys are considered good at math subjects while girls are more talented in languages (Borgonovi & Greiff, 2020; Breda & Napp, 2019; Rapp & Borgonovi, 2019; Reilly et al., 2019). According to Gender Schema Theory, societal pressures drive boys toward STEM education while encouraging girls in the verbal domain (Barone & Assirelli, 2020).

In contrast, the Expectancy-Value Theory suggests that psychological and sociological factors underlie this problem, grounded in the relationship between the two aspects (Sahoo & Klasen, 2021; Verdugo-Castro et al., 2022). Cross-national studies reveal that gender differences in reading proficiency and attitudes toward mathematics are more pronounced in countries with high gender equality, reflecting a complex interaction between genetic, environmental, and cultural factors (Balducci, 2023). The above-stated inequality underscores the impact that gender roles have on the educational and professional success of learners from early years (Herbaut & Barone, 2021; Sahoo & Klasen, 2021). Ignoring the specific needs and preferences of boys and girls when creating pedagogical approaches intensifies differences in their reading and numeracy skills. Methods of discussion are found to improve literacy among females, whereas problem-solving tasks and laboratory work help males in acquiring numeracy skills (Bussell, 2021; Driscoll et al., 2024; Hadyaoui & Cheniti-Belcadhi, 2024; Malik & Ubaidillah, 2021). Gender-specific curriculum reforms must be implemented to reduce inequalities between male and female students. Providing mentorship opportunities to female learners in STEM will positively impact their skills in math and science, as such initiatives have proven highly effective in Sweden and Finland, where gender differences in STEM participation were significantly smaller (Prieto-Rodriguez et al., 2020). Apart from gender-related issues, literacy skills depend on the culture and language of learners, especially in multi-cultural and multi-lingual regions like Sundaland in Indonesia.

Sundaland, which encompasses Sumatra, Java, Kalimantan, and Bali, is a region characterized by great cultural and linguistic diversity. The diverse culture in this area includes local languages such as Javanese, Sundanese, and Dayak, as well as various forms of art, such as wayang kulit and Reog Ponorogo dance. The isolation of this area due to rising water levels (Hanebuth & Stattegger, 2003) and the presence of over 700 ethnic groups in this area have greatly impacted social structures, learning practices, and academic literacy (Faiziyah et al., 2020). For example, in cases of geographic isolation, learning is largely community-based and indigenous-knowledge driven, whereas in developed areas, there is an emphasis on technological tools. The multilevel perspective of developmental dyslexia focuses on culture in the process of transforming information processing into literacy practices (Lachmann & Bergström, 2023). Linguistic awareness is the key to acquiring cross-cultural literacy skills (Francis et al., 2023). Though the importance of culturally-based approaches to academic literacy is increasingly recognized, more evidence is needed regarding the relation between pedagogy and academic achievement (Bassett & Macnaught, 2024). According to the Interdependence Hypothesis, the ability to speak one's mother tongue improves second-language literacy (Lachmann & Bergström, 2023). For instance, a study conducted among bilingual groups in Yogyakarta found that students well versed in Javanese were better able to understand concepts taught in Indonesian than students who did not have a proper understanding of their native tongue (Irwanto et al., 2024). Nonetheless, Indonesia's monolingual approach to education, which focuses on Indonesian, neglects the benefits of bilingualism and multilingualism (Walker et al., 2019). Additionally, the increased focus on English acts as a barrier to protecting local languages (Zein, 2019). The monolingual tendency not only fails to tap into the academic potential associated with students' linguistic backgrounds but also alienates them from the languages they speak at home. The idea of bilingual

education has proved very effective in addressing the challenges of globalization. However, it suffers from outdated pedagogy, such as boring lectures without student participation, and poor teaching techniques. Bilingual literacy within higher education is therefore required (Walker et al., 2019). Multilingual education not only retains the local languages but also uses English as a common language (Zein, 2019). As seen in the case of the Basque Country in Spain, the education program incorporated the languages of Basque, Spanish, and English, resulting in better literacy skills among students.

On the other hand, students from diverse ethnic backgrounds and those speaking local languages face several difficulties. For example, international examinations like PISA, which are based on a global context, may fail to accurately measure students' literacy due to Indonesia's multilingual education system (OECD, 2023). A community-based approach to conducting assessments will be vital to making them more contextual. The approach involves involving parents, community elders, and local teachers in creating culturally appropriate learning materials and organizing study groups where students communicate in their indigenous languages to promote their understanding. Such challenges in linguistics are necessarily intertwined with the larger issues of cultural diversity within the Indonesian archipelago, where differences in culture, language, and educational principles inform regional learning practices.

Indonesian culture has produced a diverse learning system shaped by cultural values, traditions, and socio-economic conditions. For instance, Islamic-oriented education through dayahs, Islamic schools, and public schools in the Aceh and Minangkabau regions (Akbar et al., 2021; Basri, 2015) helps maintain cultural identity. Nevertheless, such a learning process mainly focuses on rote learning and normative teaching revolving around Islamic moral and ethical values, thereby preventing learners from exploring innovative solutions and developing critical thinking skills. Indeed, this learning process aligns with Vygotsky's Sociocultural Learning Theory, which emphasizes the role of cognitive interactions in fostering creativity and problem-solving. The technology and analysis-based approach used in Java is consistent with the principles of Constructivist Learning Theory (Akbar et al., 2021; Basri, 2015). It comprises the introduction of e-learning sites, data-based evaluation tools, and software for conducting science experiments. Moreover, CTL in the Kalimantan region (Hamudy & Rifki, 2024; OECD, 2023) helps address the challenges associated with educational infrastructure. Finally, Culturally Responsive Teaching in Bali combines cultural elements such as the Tri Pramana philosophy, the East-West method, the Subak irrigation system, and the flipped classroom learning strategy, using the "Kelas Maya Jejak Bali" site (Suardana et al., 2023; Yoda, 2017). Socioeconomic factors and infrastructure inequality contribute to literacy disparities in Sundaland. Major cities like Medan and Padang have better access to educational facilities, while remote areas face shortages of technology and teaching staff (Sartono et al., 2024). Data from BPS (2023) and PISA 2018 highlight literacy gaps exacerbated by traditional norms that restrict female education (Jabeen et al., 2020). The Sekolah Garis Depan program aims to fill these gaps, but its success depends on the incentives provided to teachers and on adapting the curriculum to local culture (BPS, 2023). For example, in isolated parts of Kalimantan, the program increased school attendance by 20% within 2 years of implementation. Nonetheless, it still struggles to improve the teaching of science and mathematics due to insufficient laboratory facilities (Hamudy & Rifki, 2024). Research comparing Indonesia's educational system with those of other multicultural countries, such as Switzerland and Canada, may prove insightful in formulating more competitive and inclusive education policies. Although regional educational systems influence the macro-structure of schools in Indonesia, ethnicity and language play a greater role in shaping children's literacy skills at the micro-cultural level. To understand this aspect, it is necessary to investigate how different ethnicities in Sundaland develop literacy skills shaped by their cultures, languages, and knowledge systems.

Literacy among the major ethnicities in Sundaland, including the Batak, Malays, Minangkabau, Betawi, Javanese, and other groups, indicates that culture and language play significant roles in literacy in Indonesia—for example, the Javanese value hierarchical learning, while the Sundanese emphasize interactive discussion in class. The Batak group performs better in logical analysis because of their argumentative culture, while the Minangkabau incorporates religion in their educational practices. The practice of contextual learning in Bali blends traditional arts with curricular subjects (Suardana et al., 2023). Cultural diversity poses a challenge for literacy learning because Bahasa Indonesia is the primary language of instruction and learning in Indonesia. Learners who have been learning in their mother tongues perform well in understanding basic concepts but face problems when learning through formal language due to syntax difficulties and sophisticated vocabulary. (Bermejo et al., 2021; Daly et al., 2023). The theory of Interdependence holds that literacy in one language promotes literacy in another. Such a paper emphasizes the importance of developing inclusive policies, including teacher training, the preparation of bilingual curricula, and the provision of learning aids in regional languages, aimed at addressing gaps between diverse ethnic groups. The research on differences in science and numeracy literacy levels between boys and girls from various cultures in high schools in Sundaland considers ethnicity, socio-economic status, linguistic background, and local education traditions. This study will add to the body of knowledge on inclusive and adaptable education policies. This study is important for educational science because it offers an integrated approach to linguistic-cultural inclusiveness based on hierarchical linear modeling, a method seldom used in Indonesia.

METHODS

The research methodology used in this study involves quantitative research employing a cross-sectional comparative design, aimed at generating empirical evidence on disparities in gender, culture, ethnicity, socioeconomic status, and language diversity without conducting experiments. A quantitative approach was chosen to assess statistical disparities and correlations in multilevel data, consistent with the theoretical framework of literacy disparity studies in multiculturally rich areas (Lee & Stankov, 2018; Reilly et al., 2019). The study underscores the importance of inclusive education in promoting scientific literacy and numeracy in Sundaland, comprising Sumatra, Java, Kalimantan, and Bali. In this study, a cross-sectional comparative design will be used to map disparities without any experimental design. This design is quite common in literacy-disparity studies conducted in multiculturally rich societies (Lee & Stankov, 2018; Reilly et al., 2019). This is because it helps identify correlations among gender, ethnicity, and socio-linguistic factors, among others, across varied student samples. The selection of this area was based on its high level of diversity as depicted in the OECD (2023) report on educational diversification in Southeast Asia (Lee & Stankov, 2018; Reilly et al., 2019). The research focuses on the learning gaps caused by gender, culture, ethnicity, socioeconomic factors, and linguistic differences among learners. The first aspect under consideration is gender, which influences how students perceive knowledge and learn. Another factor is culture and ethnicity, which will affect the educational values of certain communities. Also, the socioeconomic status will dictate the degree of access to good educational facilities. Lastly, linguistic diversity will either promote literacy or become an obstacle to learning success, depending on whether mother tongue instruction is encouraged. The use of a cross-sectional comparative research methodology will enable the research to measure disparities in relation to gender, culture, and language without manipulation.

The participants for this study were selected through Multistage Random Sampling, with equal distribution of samples across geographical regions, gender, race, and language. Specifically, Stratified Random Sampling was used in the first stage to categorize participants by four major geographical regions of Sundaland: Sumatra, Java, Kalimantan, and Bali (Cahill & Bostic, 2025). The multi-stage random sampling design, including stratified sampling, cluster sampling, and simple random sampling, was conducted according to the methods described by Creswell & Creswell (2018) and Fraenkel & Wallen (2019). In the second stage, Cluster Random Sampling was used to select schools at random based on accreditation level (Excellent, Very Good, Good), school ownership (private/public), and geographical area (rural/urban). In the third stage, Simple Random Sampling was used to select participants from the schools selected in the second stage, considering gender and culture as well. The final sample consisted of 2.250 participants, randomly selected from a population of 4.853.305 high school students in Sundaland (BPS, 2023).

The sampling process for the various ethnicities used the following three steps to achieve proportional representation and ensure reliable data collection on the social and cultural dynamics of different ethnicities. The first step involves stratification by region and ethnicity, with the proportions of both majorities and minorities in each region known with reference to data from the Indonesian Central Bureau of Statistics (BPS). The second step involved the Cluster Random Sampling method, in which some of the selected schools within a certain district or city are known to have a significant number of ethnic groups. Such a district or city was selected because it had high levels of social interaction and cultural diversity, as exhibited among the Batak, Minangkabau, and Malay groups in Sumatra, and the Dayak and Banjar groups in Kalimantan. The third and last step involved Simple Random Sampling, in which students were selected randomly from the selected schools, with an even distribution of proportions between the two genders and among ethnicities. For example, a case where the Dayak population is 50 percent, and the Banjar population is 40 percent in a certain school.

Table 1. Distribution of Ethnic Groups in the Research Sample

Region	Final Sample	Predominant Ethnic Groups	Sample per Ethnic Group
Java	1.317 students	Javanese (70%), Sundanese (20%), Betawi (5%), Madurese (5%)	Javanese: 922, Sundanese: 263, Betawi: 66, Madurese: 66
Sumatra	518 students	Batak (40%), Minangkabau (35%), Malay (15%), Acehese & Lampung (10%)	Batak: 207, Minangkabau: 181, Malay: 78, Acehese & Lampung: 52
Kalimantan	225 students	Dayak (50%), Banjar (40%), Malay & Buginese (10%)	Dayak: 113, Banjar: 90, Malay & Buginese: 22
Bali	101 students	Balinese (85%), Sasak & Javanese (15%)	Balinese: 86, Sasak & Javanese: 15
Total	2.250 students	Adjusted to Local Population	

The instrument used in this research relies on PISA, TIMSS, and the UNESCO Global Framework on Literacy, as they are the most comprehensive international standards for literacy. In particular, PISA measures literacy in terms of real-life application, TIMSS focuses on curriculum-related literacy, and UNESCO addresses functional and contextual literacy. This instrument is not based solely on a pre-existing set of questions but has

been modified, adapted, and validated to be appropriate for the Indonesian education system. This process involves identifying the most important aspects of literacy according to PISA, TIMSS, and UNESCO, and adjusting them to reflect Indonesian reality. Namely, PISA focuses on problem-solving literacy, TIMSS on national curriculum-based literacy, and UNESCO on functional and contextual literacy. In this case, about 60% of the test was based on questions from PISA and TIMSS, and the remaining 40% were developed in-house in accordance with UNESCO's recommendations to reflect specific social, economic, and linguistic aspects of the country. For example, numeracy involves analyzing energy use across various regions in Indonesia, while science literacy involves assessing the impact of climate change on the local environment. Bilingualism (Bahasa Indonesia and Javanese, Sundanese, Minangkabau, and Banjarese) is used to assess the influence of native languages on literacy comprehension.

The classification used in this research is based on a rubric designed according to the competency levels of the Program for International Student Assessment (PISA), which was selected for its emphasis on scientific literacy and international problem-solving competence. The test instrument includes 40% multiple-choice questions on basic concepts, 35% short-answer questions on numeracy applications, and 25% case-study questions on critical thinking skills, based on the PISA framework for scientific literacy. The content validation process was conducted with UPI experts through an extensive analysis of each item to confirm alignment with the PISA and TIMSS frameworks, as well as item difficulty and content relevance. The Aiken's V achieved was 0.87, representing highly relevant questions in terms of international literacy indicators. For the construct validity, the Confirmatory Factor Analysis (CFA) was implemented with AMOS and yielded the following results: $\chi^2/df = 2.85$ (≤ 5.0), CFI = 0.93 (≥ 0.90), RMSEA = 0.047 (≤ 0.08), and SRMR = 0.035 (≤ 0.08), showing excellent model fit. Cronbach's alpha and McDonald's omega reliability scores were very high: Multiple Choice ($\alpha = 0.84$; $\omega = 0.86$); Short Answer ($\alpha = 0.81$; $\omega = 0.83$); Case Study Short Answer (Alpha = 0.81, Omega = 0.83), Case Study (Alpha = 0.89, Omega = 0.91), and the overall instrument (Alpha = 0.85, Omega = 0.87). These two metrics were utilized because Cronbach's Alpha measures internal consistency, while McDonald's Omega provides a more accurate estimate for instruments with complex factor structures. Inter-rater reliability was assessed with Cohen's Kappa = 0.78 (good agreement) and ICC = 0.82 (high consistency), ensuring that the interview analysis using Thematic Analysis was free from subjective bias.

The subjects of the current study were prospective mathematics, biology, physics, and chemistry teachers from the Faculty of Science Education at La Tansa Mashiro University and Universitas Terbuka, Indonesia. The choice of these universities was based on their excellent reputations for providing high-quality education and for developing strong relationships with other educational institutions in the region. The testing tools comprised literacy tests for students in science and numeracy. Data collection was conducted through literature reviews of national reports, BPS reports, Kemendikbudristek data, and surveys and interviews. In particular, the survey was designed to measure six elements of literacy: motivation, studying, parental participation, educational facilities, learning processes, and learning environments, according to [Yulianto et al. \(2024\)](#). Semi-structured interviews with randomly selected high school teachers and students were conducted to verify the quantitative results and analyze the relationships among literacy variables. Altogether, 14 questions regarding learning approaches at home and at school were raised, along with socio-cultural factors affecting literacy levels.

In this paper, we will investigate gender and cultural differences in scientific and numerical literacy, taking into account region, ethnicity, social status, and language diversity. Normality will be estimated using either the Kolmogorov-Smirnov test for large samples or the Shapiro-Wilk test for small samples. To test for equality of variances, Levene's Test will be used. A normality test is important because it ensures normality of the data, whereas the other test is used to verify equality of variances between samples. An ANOVA test is performed if all prerequisites are met; otherwise, the Kruskal-Wallis test is followed by Dunn-Bonferroni or a Pairwise Mann-Whitney U test. A two-way ANOVA is performed when the effects of gender and ethnicity are considered. For the ANCOVA test, we need to control for potential factors that affect scientific and numerical literacy. Moreover, multiple linear regression analysis will be used to explore the contribution of independent variables to scientific and numerical literacy. Multicollinearity will be assessed using the Variance Inflation Factor (VIF). Hierarchical Linear Modeling (HLM) is used to investigate the multilevel impact on individuals, schools, and local policies on educational achievement. The data have been analyzed using Hierarchical Linear Modeling (HLM) to estimate multilevel impacts at the individual, institutional, and regional policy levels. HLM has been recommended for analyzing nested educational data structures where students are grouped within schools and regions. Thematic analysis is used to uncover relationships among variables, integrating quantitative and qualitative data through data reduction, data presentation, and verification. The validity of the findings is established through data triangulation, which involves employing multiple data sources, methods of analysis, and theories. Data triangulation involves comparing findings from quantitative and qualitative data using methods of data reduction, data presentation, and data verification. In addition, the findings are compared with the existing literature to assess their consistency and reliability. The results of the analysis will be shown in tables, charts, and narratives. Software such as SPSS for ANOVA and linear regression, HLM for hierarchical

analysis, and R and Python for data visualization will be used. This research provides insight into scientific and numerical literacy in Indonesia, their cultural and ethnic diversity (Batak, Minangkabau, Sundanese, Javanese, Balinese, Dayak, Banjar), and their socioeconomic background.

RESULT AND DISCUSSION

A descriptive analysis of 2,520 students from Sumatra, Java, Kalimantan, and Bali, conducted between 2022 and 2024, examines disparities in science and numeracy literacy by region, ethnicity, and gender. The primary objective is to understand the distribution of literacy scores before performing inferential statistical tests. The data are categorized by gender (male and female), ethnic background, and the mean and standard deviation ($\bar{X} \pm SD$) of test results. The results are presented in Table 1.

Table 1. Descriptive Statistics of Science and Numeracy Literacy

Region	Ethnicity	Science Literacy ($\bar{X} \pm SD$)		Numeracy Literacy ($\bar{X} \pm SD$)	
		Male	Female	Male	Female
Sumatra	Batak	66.00 $\pm$ 2.70	67.13 $\pm$ 2.89	63.29 $\pm$ 4.19	64.14 $\pm$ 3.63
	Minangkabau	63.98 $\pm$ 3.02	64.32 $\pm$ 2.64	64.20 $\pm$ 3.96	64.65 $\pm$ 4.12
	Malay	64.85 $\pm$ 2.71	64.77 $\pm$ 2.83	65.61 $\pm$ 3.22	61.10 $\pm$ 3.71
	Aceh	66.80 $\pm$ 2.90	64.55 $\pm$ 3.51	67.02 $\pm$ 3.75	66.79 $\pm$ 3.40
Java	Javanese	69.18 $\pm$ 2.98	67.08 $\pm$ 3.76	67.13 $\pm$ 2.90	66.51 $\pm$ 3.61
	Sundanese	64.04 $\pm$ 3.20	68.96 $\pm$ 2.99	64.33 $\pm$ 4.16	64.68 $\pm$ 3.62
	Betawi	62.90 $\pm$ 3.20	66.36 $\pm$ 2.57	64.74 $\pm$ 3.10	69.20 $\pm$ 2.99
	Madura	62.80 $\pm$ 2.90	64.06 $\pm$ 3.23	66.98 $\pm$ 3.77	66.45 $\pm$ 3.88
Kalimantan	Dayak	66.52 $\pm$ 2.60	66.14 $\pm$ 2.72	63.70 $\pm$ 4.19	62.55 $\pm$ 3.58
	Banjar	63.43 $\pm$ 4.45	63.36 $\pm$ 4.34	64.61 $\pm$ 2.66	63.55 $\pm$ 2.76
	Malay	62.63 $\pm$ 4.90	62.00 $\pm$ 4.01	64.50 $\pm$ 3.30	61.98 $\pm$ 3.99
	Bugis	63.91 $\pm$ 4.30	63.50 $\pm$ 3.73	63.45 $\pm$ 4.53	62.41 $\pm$ 4.76
Bali	Balinese	63.41 $\pm$ 3.86	63.12 $\pm$ 4.07	64.50 $\pm$ 3.30	62.80 $\pm$ 4.01
	Javanese	62.50 $\pm$ 3.92	62.90 $\pm$ 3.20	67.10 $\pm$ 3.77	65.68 $\pm$ 3.20
	Sasak	62.45 $\pm$ 3.16	63.57 $\pm$ 3.55	62.14 $\pm$ 4.41	62.35 $\pm$ 3.69

Validity tests, such as the Kolmogorov-Smirnov (KS) Test, Shapiro-Wilk Test, and Levene's Test, were conducted on science and numeracy literacy scores by region, ethnicity, and gender to assess the accuracy of the analysis. Normality was indicated in most groups ($p > 0.05$), permitting the application of a parametric method, as the data had a normal distribution, to obtain a true and precise estimate. For example, Batak (Male, Science Literacy) $p = 0.947$, Javanese (Female, Science Literacy) $p = 0.763$, and Dayak (Male, Science Literacy) $p = 0.198$. Nevertheless, certain groups showed a slight deviation, including Bugis (Female, Science Literacy), $p = 0.253$; Sasak (Female, Numeracy Literacy), $p = 0.465$; and Malay (Female, Numeracy Literacy), $p = 0.275$. Nonetheless, further testing using Q-Q Plots and Boxplots confirmed the lack of significance of the aforementioned deviations by comparing the observed data with the theoretical distribution and identifying outliers and deviations from the norm. In addition, the Kruskal-Wallis test was used for cases with substantial deviation from the norm as an alternative to the two-way ANOVA. The homogeneity of variance test using Levene's Test indicated balanced variance across groups ($p = 0.391$ for science literacy and $p = 0.446$ for numeracy literacy), allowing the analysis of performance differences by region, ethnicity, and gender using a Two-Way ANOVA.

In assessing disparities in science and numeracy literacy across the Sundaland region, significant differences in performance were noted, attributed to disparities in education quality, resource availability, and socio-economic factors. The highest performers were from Java, while the lowest performing region was Bali. To assess the statistical significance of the differences, a Two-Way ANOVA was preferred due to the potential interaction between the two variables. The statistics used included the sum of squares, degrees of freedom, mean squares, F-value, and p-value. To adjust for factors such as language and socio-economic status, the ANCOVA technique was preferred. Finally, an HLM approach was used to examine intergroup differences and hierarchical effects of individual-, school-, and regional-level policies on literacy performance. From the analyses in Table 2, the Two-Way ANOVA shows that there are significant variations in both scientific literacy ($F = 86.083$, $p = 0.000$) and numeracy ($F = 63.051$, $p = 0.000$) across Sundaland, with the highest and lowest figures recorded in Java and Bali, respectively. The figures in this case refer to results from tests of scientific literacy and numeracy conducted across different schools in Sundaland. There were significant differences in gender, with female students showing greater variation than males ($F = 111.545$, $p = 0.000$; vs. $F = 38.415$, $p = 0.000$). Figure 1 indicates gender sensitivity among the regions.

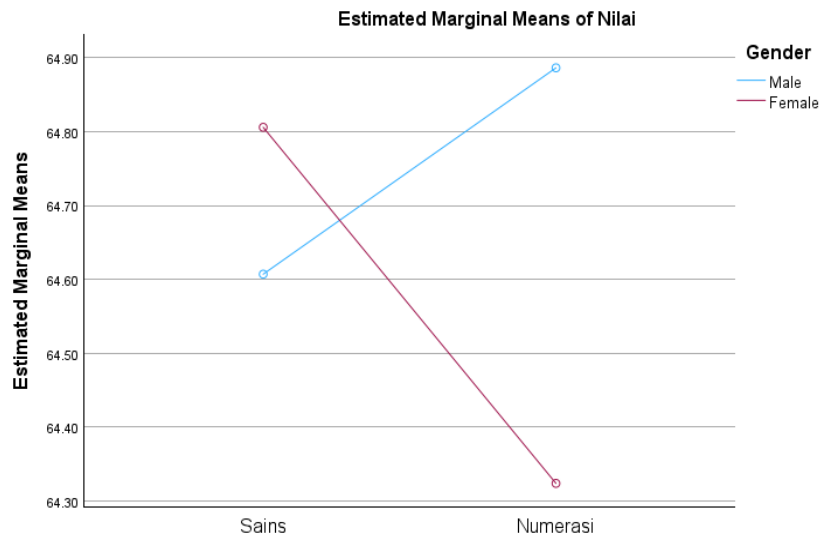


Figure 1. Science and Numeracy Proficiency by Gender Across Four Regions

The Post-Hoc Tukey Test and ANCOVA were used to control for confounders such as socioeconomic status, school accreditation, and the availability of educational facilities for students across all areas. Using the Post-Hoc Tukey Test, significant differences were found in the science literacy and numeracy levels of different regions. The results of the post-hoc Tukey test presented in Table 3 indicate significant differences in mathematical literacy achievement among students across all regions. Significant differences were identified between Java and Sumatra ($p = 0.002$), Java and Kalimantan ($p = 0.000$), as well as Java and Bali ($p = 0.000$). Likewise, significant differences were also found between Sumatra and Kalimantan ($p = 0.015$) and between Sumatra and Bali ($p = 0.000$). In addition, the comparison between Kalimantan and Bali showed a statistically significant difference ($p = 0.010$). Overall, these findings demonstrate that each region exhibits distinct characteristics in students' mathematical literacy performance. As indicated by the Post-Hoc Tukey Test results, there are significant differences in science literacy and numeracy across regions. In particular, Java showed significant differences from Sumatra ($p = 0.002$), Kalimantan ($p = 0.000$), and Bali ($p = 0.000$). Similarly, Sumatra had significant differences with Kalimantan ($p = 0.015$) and Bali ($p = 0.000$). Kalimantan also had significant differences from Bali ($p = 0.010$). The p -value is < 0.05 , indicating significant differences among the regions considered above. Variations in literacy and numeracy levels within Sundaland have been attributed to differences in access to learning materials, teacher competence, and technology. In this regard, Java stands out owing to its better infrastructure, whereas Bali does not perform well due to a lack of learning facilities and the prevailing culture. Other variables, such as SES, mother tongue, and school certification, have contributed to the differences. Although variations between regions persist even after controlling for SES and school certification, this suggests that cultural factors also matter.

Table 2. ANCOVA for Controlling Confounding Variables

Region	School Accreditation	SES	Mother Tongue	Adjusted Mean		F-value	p-value
				Science Literacy	Numeracy		
Java	Excellent	High	Javanese	71.20 ± 2.50	70.00 ± 2.85	18.40	0.000*
	Very Good	Medium	Javanese	68.50 ± 2.75	67.20 ± 3.10	15.80	0.001*
	Good	Low	Javanese	66.10 ± 3.20	65.00 ± 3.60	13.20	0.003*
Sumatra	Excellent	High	Minangkabau	68.50 ± 2.60	67.40 ± 3.00	15.70	0.001*
	Very Good	Medium	Minangkabau	66.80 ± 2.80	65.90 ± 3.20	12.90	0.002*
	Good	Low	Minangkabau	64.70 ± 3.40	63.80 ± 3.80	11.10	0.005*
Kalimantan	Excellent	High	Dayak	66.90 ± 2.85	65.80 ± 3.40	14.50	0.003*
	Very Good	Medium	Dayak	64.80 ± 3.10	63.70 ± 3.70	12.20	0.005*
	Good	Low	Dayak	62.70 ± 3.80	61.90 ± 4.10	10.50	0.008*
Bali	Excellent	High	Balinese	65.40 ± 3.20	64.50 ± 3.80	13.10	0.004*
	Very Good	Medium	Balinese	63.80 ± 3.50	62.90 ± 4.00	11.70	0.006*
	Good	Low	Balinese	62.10 ± 3.90	61.20 ± 4.30	9.90	0.010*

Table 2 from questionnaires and structured interviews indicates that accreditation, socioeconomic status (SES), and mother tongue affect scientific literacy and numeracy among Sundaland students. Java performs best in terms of scientific literacy (71.20 ± 2.50) and numeracy (70.00 ± 2.85), owing to its higher accreditation rate, higher SES, and use of the Javanese language ($F = 18.40$; $p = 0.000$). The second best performer is Sumatra, with the Minangkabau language ($F = 15.70$; $p = 0.001$); then follows Kalimantan, with the Dayak language ($F = 14.50$; $p = 0.003$); and finally, Bali, which uses the Balinese language and is at the bottom of the list ($F = 13.10$; $p = 0.004$). HLM shows how individual characteristics affect literacy and numeracy, with individual factors represented by gender influence on learning, cognitive analysis skills, and mother tongue on conceptual understanding. Institutional-level factors include high accreditation, the use of technology for interactive learning, and effective teaching methods for conceptual understanding. Policy-level factors include bilingualism, government involvement in providing proper facilities, and equitable access for optimal literacy.

The Hierarchical Linear Modeling (HLM) analysis revealed significant differences across regions at the individual, institutional, and regional levels. At Level 1 (individual factors), Java demonstrated the highest mean scores in gender (1.80 ± 0.25), cognitive ability (3.10 ± 0.20), and mother tongue (1.30 ± 0.18), while Bali generally showed the lowest values, particularly for gender (1.00 ± 0.40) and cognitive ability (2.30 ± 0.28). Kalimantan recorded the highest score for mother tongue (1.40 ± 0.25). All Level 1 variables were statistically significant, with p -values ranging from 0.000 to 0.002. At Level 2 (institutional factors), Java consistently achieved the highest scores in accreditation (3.80 ± 0.35), teaching quality (3.20 ± 0.30), and technology integration (3.50 ± 0.28), whereas Bali showed the lowest institutional performance across most indicators. These differences were also statistically significant ($p = 0.000$ – 0.002). At Level 3 (regional factors), Kalimantan exhibited the highest mean scores in bilingual program implementation (3.40 ± 0.55), government support (3.10 ± 0.50), and access to educational resources (2.90 ± 0.48), followed closely by Java and Bali. Overall, the findings indicate that regional disparities significantly influence educational outcomes and institutional performance across Indonesia, as evidenced by all variables showing statistically significant differences ($p < 0.05$). Hierarchical Linear Modeling (HLM) indicates that Level 1 (Individual) contributes through gender, which has a significant effect on numeracy across all regions ($p = 0.001$). The effects are strongest in Java (1.80 ± 0.25) and weakest in Bali (1.00 ± 0.40). Cognitive variables are the main contributors, especially in Java (3.10 ± 0.20 ; $p = 0.000$), and the effect of the native language background is strongest in Kalimantan (1.40 ± 0.25 ; $p = 0.002$). For Level 2 (Institution), the effects of school accreditation and teacher quality are significant, especially in Java (3.80 ± 0.35 ; $p = 0.000$), and the use of technology in the teaching and learning process makes the greatest contribution in Java (3.50 ± 0.28 ; $p = 0.002$). The contribution at Level 3 (Regional) is from the bilingual program for local languages and government policies on education. Bilingual programs have the strongest effect on numeracy achievement in Kalimantan (3.40 ± 0.55 ; $p = 0.000^*$), followed by government support and educational resources, also in Kalimantan (3.10 ± 0.50 ; $p = 0.001^*$).

The differences in science and numeracy literacy among Sundaland countries, including Sumatra, Java, Kalimantan, and Bali, are multifaceted and depend on various socioeconomic factors, education systems, cultural backgrounds, and multilingualism. As the center of Indonesian education, Java shows better results concerning science and numeracy literacy, thanks to technological advancement, modern science labs, and regular teacher training programs (Coşkun et al., 2019; Ismawati et al., 2023). Despite this achievement, the divide between the city and the countryside remains. In Sumatra, especially among the Batak and Minangkabau ethnic groups, which have advanced educational traditions and strong community support, students perform better academically. However, in isolated locations, infrastructure and teaching materials are limited but may be overcome through ethnomathematics and the use of native languages in education (Lidinillah et al., 2022). The digital divide, lack of educational infrastructure, and language differences continue to hinder students' access to STEM literacy in Kalimantan (Hafni & Aiyub, 2021; Psaki et al., 2022).

On the other hand, even though Bali is known to be a tourist site, there exist difficulties in integrating science and numeracy literacy within their education systems that have culture at their core. The philosophy of Tri Hita Karana can, however, serve as a holistic approach to boosting sustainable STEM literacy (Suardana et al., 2023). Consequently, the suggested strategies would be increased budget allocation for building educational facilities in rural areas, curriculum development using indigenous knowledge, continuous professional development for educators, and school-community partnerships to motivate learners. These strategies will ensure gender and cultural inequalities are reduced in an effort to achieve sustainable and holistic STEM literacy in the Sundaland region. Descriptive Analysis highlights notable variations in science and numeracy literacy across the Sundaland region, with differences by gender and geographic location. The highest scores were recorded in the province of Java, while Bali recorded the lowest. In the study, the Two-Way ANOVA test revealed the impact of gender and geographic region. Additionally, ANCOVA was used to control for extraneous variables such as language barriers and socio-economic status. Furthermore, Hierarchical Linear Modeling (HLM) was used to examine personal, school, and regional-level predictors.

According to the Independent t-test, there is no significant difference in science literacy between males and females ($t = -1.280$; $p = 0.201$). This suggests equal literacy skills among both genders. On the other hand,

males ($M = 64.89$, $SD = 3.99$) performed significantly better in numeracy than females ($M = 64.32$, $SD = 4.27$) ($t = 3.415$; $p = 0.001$). The Two-way ANOVA shows that the regional factor has a statistically significant effect on science literacy ($F=86.467$; $p=0.000$) and numeracy ($F=64.123$; $p=0.000$). In addition, the gender aspect also has a statistically significant effect on numeracy ($F=13.656$; $p=0.000$). Despite the relatively small effect of gender on science literacy, it is still statistically significant ($F=2.268$; $p=0.002$). The analysis indicates that the interaction between region and gender is statistically significant for both science literacy ($F=4.476$; $p=0.004$) and numeracy ($F=11.356$; $p=0.000$). To provide a deeper understanding of the influence of gender and region on scientific literacy and numeracy, data visualization in the form of interaction graphs is employed to illustrate how the differences in scientific literacy and numeracy scores between males and females vary across regions (Figures 2 and 3).

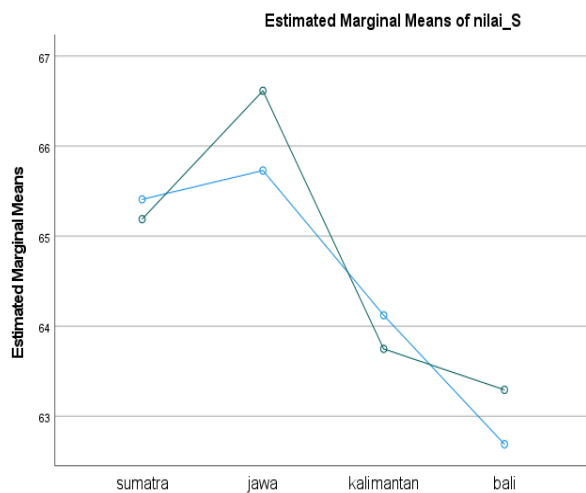


Figure 2. Science Proficiency by Gender

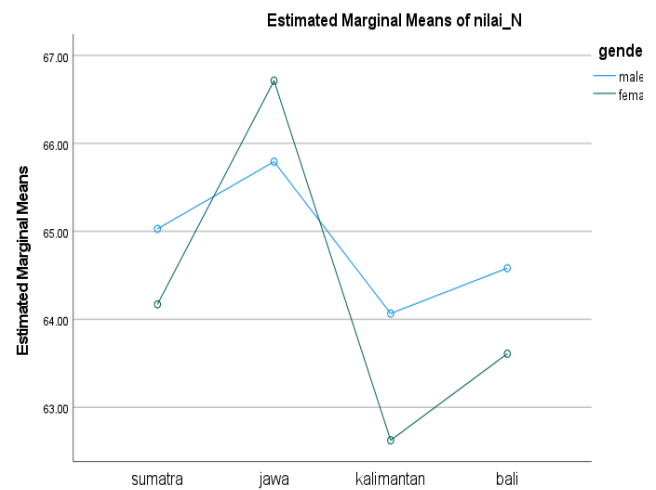


Figure 3. Numeracy Proficiency by Gender

The Tukey HSD Post-Hoc Test in Table 6 indicates significant differences in scientific literacy and numeracy by gender across the four Sundaland regions. In this regard, female respondents in Java and Bali were more scientifically literate than their counterparts in Sumatra ($p = 0.000$). Male students in Kalimantan demonstrated higher numeracy than their counterparts in other regions ($p = 0.000$). There is also a significant difference in females in Kalimantan and other regions ($p = 0.010$). The findings show the impact of gender and culture on academic performance, underscoring the need to establish policies that facilitate inclusivity in the education sector. It also indicates significant differences in scientific literacy and numeracy skills by gender and geographical location in Sundaland. Scientific literacy is significantly higher among women in Java and Bali, while numeracy skills are significantly higher among men. The same trend can be found in Kalimantan and Sumatra. Social conventions that shape societal expectations play a role in situations in which women are expected to perform well in literacy, while men are favored in numeracy. For the ANCOVA analysis, confounding factors such as school accreditation were taken into consideration, and Table 7 shows the Adjusted Mean, F-value, and p-value.

Table 3. ANCOVA for Controlling Confounding Variables Based on School Accreditation

Region	School Accreditation	Gender	SES	Adjusted Mean		F-value	p-value
				Science Literacy	Numeracy		
Sumatra	Excellent	M	High	68.10 ± 3.00	67.80 ± 3.60	14.20	0.001*
	Very Good	F	High	69.30 ± 2.80	65.50 ± 3.50	13.80	0.002*
	Good	M	Medium	66.50 ± 3.20	65.90 ± 3.70	12.60	0.002*
	Excellent	F	Medium	67.20 ± 3.10	63.80 ± 3.40	11.40	0.004*
	Very Good	M	Low	64.20 ± 3.40	64.00 ± 3.90	10.80	0.005*
		F	Low	65.50 ± 3.30	62.70 ± 3.60	9.90	0.007*
Java	Excellent	M	High	70.10 ± 3.20	68.50 ± 3.40	16.80	0.000*
	Very Good	F	High	71.40 ± 3.00	66.20 ± 3.60	15.50	0.000*
	Good	M	Medium	68.30 ± 3.10	67.00 ± 3.50	14.70	0.001*
	Excellent	F	Medium	69.60 ± 3.00	64.80 ± 3.40	13.20	0.002*
	Very Good	M	Low	66.00 ± 3.50	65.20 ± 3.80	11.50	0.003*
		F	Low	67.20 ± 3.30	63.90 ± 3.70	10.80	0.004*
Kalimantan	Excellent	M	High	65.50 ± 3.10	66.20 ± 4.00	12.30	0.005*
	Very Good	F	High	66.80 ± 2.90	63.80 ± 3.80	11.60	0.006*
	Good	M	Medium	64.10 ± 3.20	64.80 ± 3.90	10.80	0.008*
	Excellent	F	Medium	65.30 ± 3.10	62.20 ± 3.70	9.90	0.009*
	Very Good	M	Low	62.80 ± 3.50	63.10 ± 4.10	8.60	0.010*
		F	Low	64.00 ± 3.40	61.50 ± 3.80	7.80	0.012*
Bali	Excellent	M	High	63.90 ± 3.30	65.00 ± 3.90	11.20	0.010*
	Very Good	F	High	65.40 ± 3.10	62.80 ± 3.70	9.90	0.012*
	Good	M	Medium	62.70 ± 3.40	63.80 ± 4.00	8.70	0.015*
	Excellent	F	Medium	63.50 ± 3.20	61.70 ± 3.80	7.50	0.017*
	Very Good	M	Low	61.80 ± 3.60	62.20 ± 4.20	6.90	0.018*
		F	Low	62.50 ± 3.50	60.90 ± 4.00	6.40	0.020*

According to ANCOVA results, females perform better than males in scientific literacy in high-SES, best-accredited schools in Java (71.40 ± 3.00 ; $p = 0.000$). Meanwhile, males perform better than females in numeracy scores in Sumatra (67.80 ± 3.60 ; $p = 0.001$). This gender gap narrows in Very Good-accredited schools with medium SES, but males still perform better than females in numeracy. As for "Good" accredited schools with low SES, there is an evident deterioration in literacy and numeracy performance; however, the gender gap is noticeable, especially in Kalimantan and Bali. This study will further examine the gender gap in scientific literacy and numeracy in Sundaland by conducting Hierarchical Linear Modeling analysis through three hierarchical levels: 1) Individual variables, such as cognitive ability, native language, and region; 2) Institutional variables, including school accreditation, quality of education, and technology use; and 3) Region-specific variables, involving bilingualism, government intervention, and availability of educational materials.

The HLM results by gender indicate consistent differences between male and female students across the individual, institutional, and regional levels. At Level 1 (individual), female students demonstrated higher scores than male students in all variables, including Sundaland Region characteristics (female = 2.80 ± 0.28 ; male = 2.50 ± 0.30 ; $p = 0.002$), cognitive ability (female = 3.80 ± 0.25 ; male = 3.50 ± 0.28 ; $p = 0.000$), and mother tongue background (female = 2.10 ± 0.28 ; male = 1.80 ± 0.30 ; $p = 0.002$). At Level 2 (institutional), female students also showed significantly higher mean scores in school accreditation (female = 4.50 ± 0.38 ; male = 4.20 ± 0.40 ; $p = 0.000$), teaching quality (female = 4.00 ± 0.32 ; male = 3.70 ± 0.35 ; $p = 0.001$), and technology integration (female = 4.20 ± 0.30 ; male = 3.80 ± 0.33 ; $p = 0.002$). Similarly, at Level 3 (regional), female students outperformed male students in bilingual programs (female = 4.30 ± 0.45 ; male = 3.90 ± 0.50 ; $p = 0.000$), regional government support (female = 4.00 ± 0.42 ; male = 3.60 ± 0.48 ; $p = 0.001$), and access to educational resources (female = 3.80 ± 0.43 ; male = 3.40 ± 0.45 ; $p = 0.002$). Overall, the findings suggest that female students consistently achieved higher outcomes across all HLM dimensions, with all differences being statistically significant ($p < 0.05$). In HLM suggests that women have been performing considerably better than men in science literacy and numeracy in the Sundaland region ($p < 0.05$). On Level 1 (Individual), women had higher cognitive ability and were more affected by their knowledge of the mother tongue. On Level 2 (Institutional), they received greater benefits from school accreditation, quality education, and technological advancement. On Level 3 (Regional), women performed much better in bilingual classes, with support from local authorities, and with the availability of educational facilities. These could be attributed to improved learning processes, a high level of self-discipline, and social and educational environments that favor women in learning.

The influence of cultural differences on the gender divide in numeracy and science literacy is evident throughout the Sundaland region. In cities, there is greater technological advancement in numeracy and literacy skills because women can access science education more easily due to widespread technology use (Balducci,

2023; Breda & Napp, 2019). In rural settings, gender-based stereotypes and the low representation of female students in science hinder girls' ability to excel in both science and numeracy (Armando et al., 2022; Driscoll et al., 2024). The people of Java have demonstrated proficiency in numeracy and literacy through advanced educational facilities, technological advancements in learning, and gender equality advocacy through 21st-century skills programs. Nonetheless, men continue to outshine women in understanding technical concepts and conducting scientific experiments (Kamarulzaman et al., 2021). In Sumatra, women are ahead of their male counterparts in science literacy, especially in analytical and evaluative skills, due to an existing learning culture and community support (Harahap et al., 2020).

On the other hand, women in Kalimantan lack proficiency in science literacy due to the unavailability of science laboratories and the instructional language that conflicts with the culture, thereby making men better at numeracy (Hafni & Aiyub, 2021; Psaki et al., 2022). Unlike the findings of Takyi et al. (2021), which focus on the dominance of men in numeracy literacy in Ghana without accounting for ethnicity, this research provides a more insightful understanding through cultural learning methods and the use of the mother tongue. In the case of Bali, women have been disadvantaged in numeracy literacy due to the patriarchal cultural background and lack of engagement in STEM education. On the other hand, women in Bali excel in science literacy, especially in analyzing the environment for sustainability purposes, as per the Tri Hita Karana doctrine (Suardana et al., 2023). Thus, appropriate initiatives are needed to promote women's participation in STEM studies and to incorporate ethnomathematics into the curriculum (Barone & Assirelli, 2020; Verdugo-Castro et al., 2022).

The ANOVA results highlight significant differences in science literacy and numeracy across ethnic groups in Sundaland. The Batak and Javanese ethnicities excel in science literacy, while the Acehnese and Betawi excel in numeracy. Conversely, the Malay and Sasak ethnic groups scored the lowest in both aspects. ANOVA confirmed the significant influence of ethnicity on science literacy ($F = 38.377$; $p = 0.000$) and numeracy ($F = 32.407$; $p = 0.000$). Independent t-tests, ANCOVA, and Hierarchical Linear Modeling (HLM) further validated these findings by controlling for confounding variables and evaluating individual, school, and policy-related factors. These results affirm ethnicity as a primary determinant of students' science literacy and numeracy in Sundaland. The visualization of interactions in Figures 4 and 5 aims to provide a deeper understanding of differences in science and numeracy literacy across ethnic groups in Sundaland. Through the interaction graph, the distribution patterns of literacy and numeracy scores are more clearly visible, including the ethnic groups with the highest and lowest performance, as well as variations across regions. This visualization also helps determine whether the effect of ethnicity on science and numeracy literacy is consistent or varies across groups.

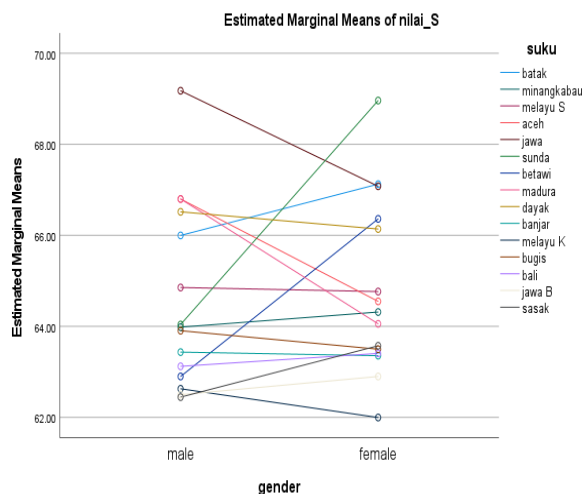


Figure 4. Science Proficiency by Gender and Ethnicity Across Four Regions

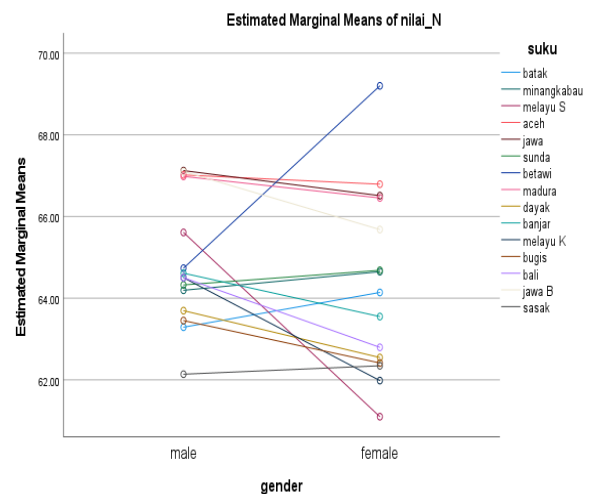


Figure 5. Numeracy Proficiency by Gender and Ethnicity Across Four Regions

The results of the Independent t-test indicate that females from the Batak, Sundanese, and Betawi ethnic groups achieved significantly higher science literacy scores compared to males ($p < 0.05$). Conversely, males from the Acehnese and Javanese ethnic groups outperformed females in science literacy ($p < 0.05$). In terms of numeracy skills, only Betawi females demonstrated a significant advantage over males ($p < 0.05$), while other ethnic groups showed no significant differences ($p > 0.05$).

Table 4. Tukey HSD Test for Science and Numeracy Literacy by Ethnicity

Ethnicity	Gender	Sumatra	Java	Kalimantan	Bali
Batak	M	-	1.75 (0.001)*	0.23 (1.000)	3.30 (0.000)*
	F	-	2.70 (0.000)*	1.29 (0.095)	2.53 (0.000)*
Minangkabau	M	2.41 (0.000)*	3.98 (0.000)*	2.18 (0.000)*	-0.89 (0.600)
	F	1.15 (0.227)	2.31 (0.000)*	-0.14 (1.000)	-1.38 (0.048)*
Malay S.	M	1.75 (0.001)*	3.32 (0.000)*	0.65 (0.936)	-2.41 (0.000)*
	F	2.70 (0.000)*	3.86 (0.000)*	1.41 (0.038)*	-2.57 (0.000)*
Aceh	M	0.89 (0.595)	2.45 (0.000)*	-0.17 (1.000)	-3.24 (0.000)*
	F	-0.04 (1.000)	1.12 (0.262)	-1.33 (0.072)	-3.72 (0.000)*
Javanese	M	-1.57 (0.005)*	-	1.70 (0.001)*	4.86 (0.000)*
	F	-1.16 (0.213)	-	2.45 (0.000)*	3.69 (0.000)*
Sunda	M	0.06 (1.000)	1.63 (0.003)*	0.90 (0.569)	-2.16 (0.000)*
	F	-1.19 (0.181)	-0.03 (1.000)	-0.91 (0.630)	-2.15 (0.000)*
Betawi	M	1.93 (0.000)*	3.50 (0.000)*	2.93 (0.000)*	-0.13 (1.000)
	F	-2.15 (0.000)*	-0.99 (0.490)	0.89 (0.668)	-0.35 (1.000)
Madura	M	1.13 (0.182)	2.70 (0.000)*	4.01 (0.000)*	0.95 (0.472)
	F	0.38 (1.000)	1.54 (0.012)*	2.35 (0.000)*	1.11 (0.281)
Dayak	M	0.23 (1.000)	1.80 (0.000)*	-	3.32 (0.000)*
	F	1.29 (0.095)	2.45 (0.000)*	-	1.39 (0.046)*
Banjar	M	3.17 (0.000)*	4.73 (0.000)*	2.63 (0.000)*	-
	F	2.18 (0.000)*	3.34 (0.000)*	1.24 (0.131)	-
Malay K.	M	4.25 (0.000)*	5.81 (0.000)*	3.06 (0.000)*	0.57 (0.981)
	F	3.64 (0.000)*	4.80 (0.000)*	0.05 (1.000)	-1.19 (0.182)
Bugis	M	2.86 (0.000)*	4.43 (0.000)*	3.63 (0.000)*	0.25 (1.000)
	F	2.68 (0.000)*	3.84 (0.000)*	1.38 (0.047)*	0.14 (1.000)
Balinese	M	3.30 (0.000)*	4.86 (0.000)*	3.32 (0.000)*	-
	F	2.53 (0.000)*	3.69 (0.000)*	1.24 (0.131)	-
Javanese B.	M	3.86 (0.000)*	5.43 (0.000)*	3.63 (0.000)*	0.57 (0.981)
	F	1.34 (0.065)	2.50 (0.000)*	0.05 (1.000)	-
Sasak	M	3.55 (0.000)*	5.12 (0.000)*	3.32 (0.000)*	3.32 (0.000)*
	F	2.67 (0.000)*	3.84 (0.000)*	1.38 (0.047)*	0.14 (1.000)

Results from the Tukey HSD test show significant differences in literacy in science and numeracy among the ethnic groups of Sundaland, which are dependent on culture, learning environment, and gender. The Batak and Javanese ethnic groups show high competence in literacy in science, as reflected by Batak-Minangkabau (MD = 2.41, $p = 0.000$) and Javanese-Malay S. (MD = 3.32, $p = 0.000$). They benefit from an analytical learning culture and educational systems that enable them to excel. In numeracy, Dayak and Javanese are the ethnic groups with the highest competencies, as exemplified by Dayak-Banjar (MD = 2.93, $p = 0.000$) and Javanese-Betawi (MD = 3.50, $p = 0.000$). Their success in numeracy may be attributed to their use of contextual learning methods and incorporation of local technology. Differences based on gender are likewise apparent, whereby Batak and Javanese females excel in science literacy while Dayak and Javanese males are competent in numeracy, as indicated by Batak (F)-Malay S. (MD = 2.70, $p = 0.000$) and Javanese (M)-Sundanese (MD = 1.63, $p = 0.003$). The two ethnic groups, Malay K. and Sasak, are poor in both science and numeracy literacy, as shown by Dayak-Malay K (MD = 4.01, $p = 0.000$) and Javanese vs. Sasak (MD = 5.12, $p = 0.000$), due to limited educational access and language barriers. This disparity also correlates with socio-economic factors and educational infrastructure, where urban ethnic groups like the Javanese and Betawi outperform rural groups such as the Sasak and Malay K.

It also indicates significant differences in scientific literacy and numeracy among ethnicities in Sundaland ($p < 0.001$). The Javanese and Batak ethnic groups were generally performing better, suggesting an analytical culture and a higher level of education. The Dayak had the best performance in numeracy skills, while the Minangkabau, Southern Malay, Acehnese, Sasak, and Kalimantan Malay performed poorly, indicating low-quality education for these minorities. On the other hand, Betawi and Madurese performed inconsistently, suggesting the influence of environmental conditions and social networks on academic achievement. Gender differences are also important: Batak and Javanese women showed stable scores in scientific literacy, while Dayak males were best at numeracy. There was an observable gap between the Javanese-Balinese and the native Balinese in Bali, with the Former significantly outperforming the latter ($p < 0.000$). This result implies that incorporating local culture into modern teaching techniques can effectively enhance science education. In summary, ethnicity, gender, and socio-cultural environments are key factors influencing scientific literacy and numeracy levels. Thus,

it is vital to develop a culturally appropriate curriculum, improve teachers' competency, incorporate educational technologies, and mentor disadvantaged minorities.

Table 5. ANCOVA for Scientific Literacy and Numeracy Based on Ethnicity.

Region	Ethnicity	SES	Mother Tongue	Science Literacy	Numeracy	F-value	p-value
Sumatra	Batak	High	Batak	68.50 ± 2.60	67.40 ± 3.00	15.70	0.001
		Medium	Batak	66.30 ± 2.80	65.10 ± 3.20	13.20	0.002
		Low	Batak	64.20 ± 3.40	63.00 ± 3.80	11.50	0.005
	Minangkabau	High	Minangkabau	66.80 ± 2.80	65.90 ± 3.20	12.90	0.002
		Medium	Minangkabau	64.90 ± 3.10	63.80 ± 3.50	11.30	0.004
		Low	Minangkabau	62.70 ± 3.50	61.80 ± 3.90	9.80	0.007
Java	Javanese	High	Javanese	71.20 ± 2.50	70.00 ± 2.85	19.20	0.000*
		Medium	Javanese	68.50 ± 2.75	67.20 ± 3.10	15.80	0.001
		Low	Javanese	66.10 ± 3.20	65.00 ± 3.60	13.20	0.003
	Sundanese	High	Sunda	69.50 ± 2.80	68.20 ± 3.10	16.40	0.001
		Medium	Sunda	66.80 ± 3.00	65.50 ± 3.40	14.00	0.002
		Low	Sunda	64.70 ± 3.30	63.20 ± 3.70	11.90	0.004
	Betawi	High	Betawi	67.30 ± 3.10	66.10 ± 3.50	13.90	0.002
		Medium	Betawi	65.20 ± 3.30	64.10 ± 3.70	12.20	0.004
		Low	Betawi	63.00 ± 3.60	61.80 ± 4.00	9.80	0.007
	Madura	High	Madura	64.80 ± 3.40	63.70 ± 3.80	11.70	0.004
		Medium	Madura	62.90 ± 3.50	61.80 ± 4.00	10.20	0.006
		Low	Madura	61.20 ± 3.70	60.10 ± 4.20	8.90	0.009
Kalimantan	Dayak	High	Dayak	66.90 ± 2.85	65.80 ± 3.40	14.50	0.003
		Medium	Dayak	64.80 ± 3.10	63.70 ± 3.70	12.20	0.005
		Low	Dayak	62.70 ± 3.80	61.90 ± 4.10	10.50	0.008
	Banjar	High	Banjar	64.50 ± 3.10	63.20 ± 3.50	11.80	0.004
		Medium	Banjar	62.70 ± 3.40	61.40 ± 3.80	10.10	0.006
		Low	Banjar	60.80 ± 3.80	59.70 ± 4.10	8.70	0.009
Bali	Balinese	High	Balinese	65.40 ± 3.20	64.50 ± 3.80	13.10	0.004
		Medium	Balinese	63.80 ± 3.50	62.90 ± 4.00	11.70	0.006
		Low	Balinese	62.10 ± 3.90	61.20 ± 4.30	9.90	0.010
	Sasak	High	Sasak	62.10 ± 3.90	61.20 ± 4.30	9.90	0.010
		Medium	Sasak	60.80 ± 4.00	59.90 ± 4.40	8.70	0.012
		Low	Sasak	58.90 ± 4.20	57.80 ± 4.50	7.50	0.015

From Table 5, the results show notable differences in scientific literacy and numeracy among Sundaland's ethnic groups, depending on their SES and native language. The ethnic groups with high SES, which include Batak (Sumatra: 68.50 ± 2.60; 67.40 ± 3.00), Javanese (Java: 71.20 ± 2.50; 70.00 ± 2.85), Dayak (Kalimantan: 66.90 ± 2.85; 65.80 ± 3.40), and Balinese (Bali: 65.40 ± 3.20; 64.50 ± 3.80), had the best performance. On the other hand, ethnic groups with low SES living in remote areas, such as the Dayak and Sasak, were significantly affected because of a lack of access to education. The native language mediates literacy comprehension among ethnic groups. Hence, there is a need for culturally sensitive education policies to improve educational opportunities among ethnic groups with low SES.

The Hierarchical Linear Modeling (HLM) results revealed significant differences in scientific literacy and numeracy across ethnic groups at the individual, institutional, and regional levels. At Level 1 (individual), the gender variable showed significant differences among ethnicities ($p = 0.001$), with the highest score observed among Javanese students (1.80 ± 0.25) and the lowest among Balinese students (1.20 ± 0.40). Cognitive ability also differed significantly ($p = 0.000$), where Javanese students achieved the highest score (3.20 ± 0.20), while Balinese students obtained the lowest score (2.50 ± 0.28). In addition, mother tongue background demonstrated significant variation ($p = 0.002$), with the highest score found among Dayak students (1.40 ± 0.25). At Level 2 (institutional), school accreditation showed significant differences ($p = 0.000$), with the highest score reported in schools attended by Javanese students (3.80 ± 0.35) and the lowest among Balinese students (2.80 ± 0.50). Teaching quality also varied significantly ($p = 0.001$), with Javanese students reporting the highest score (3.30 ± 0.30). Similarly, technology integration demonstrated significant differences ($p = 0.002$), where Javanese students achieved the highest score (3.60 ± 0.28). At Level 3 (regional), bilingual programs showed significant variation ($p = 0.000$), with the highest score observed among Dayak students (3.40 ± 0.55). Regional government support also differed significantly ($p = 0.001$), with the highest value found in the Dayak group (3.20 ± 0.50). Furthermore, access to educational resources demonstrated significant differences ($p = 0.002$), with Dayak students obtaining the highest score (2.90 ± 0.48). Overall, these findings indicate that individual, institutional, and regional factors contribute substantially to variations in scientific literacy and

numeracy across ethnic groups in Indonesia. According to HLM analysis, there are notable differences in scientific literacy and numeracy among Sundaland residents, depending on individuals, institutions, and ethnicity. Javanese ethnicity had relatively higher scores in cognition, native language, school certification, teaching methods, and technology. Consequently, the Javanese ethnicity is the highest performing in educational aspects. In addition, Batak and Minangkabau performed relatively well compared to other ethnicities with limited educational access. The Dayak performed better in the bilingual teaching program, while the Javanese ethnicity performed well in government intervention and access to educational materials. Hence, it indicates the importance of cultural factors, institutional support, and educational policies in improving literacy. It can be deduced that to improve literacy among different ethnic groups, there is a need to improve teaching quality, utilize technology, and use local languages.

In Sundaland, linguistic considerations determine the development of scientific and numeracy literacy among the population. Linguistic variations among ethnicities influence comprehension of scientific and numerical content, especially when there is a difference in the language of instruction at school and the native language used in everyday communication (Bermejo et al., 2021). For instance, in Sumatra, the Batak and Minangkabau, two ethnic groups characterized by advanced literacy, achieve high academic performance. However, teaching in Bahasa Indonesia as the language of instruction may pose challenges for rural learners with low socioeconomic status (Hafni & Aiyub, 2021). On the other hand, in Java, the linguistic hierarchy of Javanese and Sundanese is an added difficulty due to the complexity of comprehending abstract concepts in STEM fields. In Kalimantan, learners face challenges due to differences in grammar structures between Dayak and Banjar and Bahasa Indonesia (Hamudy & Rifki, 2024). The absence of STEM-instructing teachers proficient in local languages further worsens learners' academic performance (Coşkun et al., 2019). Such results expand the scope of Gender Schema Theory by showing that the effect of gender schemas on the development of numeracy skills is stronger in areas with poor infrastructure. The symbolic nature of Balinese culture, as reflected in the Balinese language, contributes significantly to understanding ecological and environmental concepts.

Nevertheless, the lack of correspondence in scientific language between Bahasa Indonesia and other languages poses a problem for numeracy literacy (Suardana et al., 2023). Consequently, incorporating local languages in STEM education (Lidinillah et al., 2022), preparing bilingual educational materials (Walker et al., 2019), and conducting teacher training programs that take into account the linguistic background of the learners (Chalkiadaki, 2018) can help improve scientific and numeracy literacy in (Suardana et al., 2023). Therefore, integrating local languages into STEM education (Lidinillah et al., 2022), developing bilingual teaching materials (Walker et al., 2019), and providing teacher training that considers students' linguistic backgrounds (Chalkiadaki, 2018) are effective strategies for enhancing scientific literacy and numeracy in Sundaland.

Inclusive, contextually grounded educational policies have proven effective in enhancing scientific literacy and numeracy among various ethnic groups in Sundaland. In Bali, integrating Hindu values into environmental education fosters students' ecological awareness and contributes to a deeper understanding of scientific concepts (Suardana et al., 2023). Similarly, a project-based approach rooted in Minangkabau culture in Sumatra enhances students' analytical skills by contextualizing STEM concepts (Lidinillah et al., 2022). A parallel strategy is implemented in Java, where Sundanese ethnomathematics is integrated to improve students' numeracy skills (Iswara et al., 2022). In Kalimantan, collaboration between schools and the Dayak community within local wisdom-based programs has strengthened students' understanding of scientific and environmental concepts (Hamudy & Rifki, 2024). Thus, culturally responsive approaches, STEM integration, and strategies for empowering women in science are key to addressing literacy disparities in the Sundaland region. To reinforce the robustness of these findings, future longitudinal research is essential to assess the sustained impact of mother tongue use and the integration of local curricula on long-term literacy development.

The findings presented in the current study offer strategic insights for designing more inclusive, culturally oriented educational policy frameworks in Indonesia, especially in multi-ethnic regions like Sundaland. In particular, the research indicates that discrepancies in scientific and numeracy literacy levels depend not only on the personal characteristics of learners, such as gender and intelligence, but also on institutional determinants such as school accreditation, the quality of teaching, and technology integration, along with regional aspects such as bilingual education programs, governmental and institutional support, and availability of educational resources. As such, it is recommended to introduce culturally informed policies alongside a more problem- and project-based approach to education, and to ensure equal access to digital learning platforms in disadvantaged areas. Multilingual education and ethnomathematics should be regarded as key measures to address literacy differences between ethnic groups, develop local identities, and prepare students for the challenges of the 21st century.

Despite this research offering an all-encompassing picture of the problem at hand across both genders and various cultures, several methodological aspects warrant mention. Firstly, the geographical area covered by this research is very narrow and can be applied only to Eastern Indonesia, or even beyond national borders. Secondly, the research is conducted using quantitative data collected through a cross-sectional approach; thus, it is not possible to determine the long-term consequences of implementing inclusive education practices and

policies. Thirdly, although there was some data triangulation through both questionnaires and interviews, the qualitative analysis is rather limited, as it does not focus on the learning experiences of minority ethnic groups or children from distant regions. Fourthly, some important control factors, such as individual learning methods, community involvement, and teachers' training, were not thoroughly addressed during the course of the research. To enhance the effectiveness of future inclusive education policies and practices, the following suggestions are offered. First, future research should use a longitudinal design to measure students' literacy outcomes over time and to evaluate the sustainability of culturally and gender-based interventions. Second, future research should cover a broader range of areas, including Eastern Indonesia and remote indigenous populations, to investigate literacy dynamics among linguistically and culturally heterogeneous communities. Third, there should be equal emphasis on integrating quantitative and qualitative research methodologies to appreciate better the difficulties students and educators face in overcoming literacy barriers. Fourth, teacher training programs should be organized to emphasize inclusive teaching strategies, the use of local languages in teaching, and curriculum adaptation to community needs. Fifth, future international cooperation is highly recommended, especially with multicultural countries such as Finland, Canada, and New Zealand, to establish benchmarks for implementing sustainable, multilingual education policies.

CONCLUSION

This study argues that scientific literacy and numeracy in Sundaland are significantly shaped by the interplay among gender, culture, and language. Java is successful owing to its easy access to quality education, while Bali shows the poorest performance because of poor infrastructure. Males perform better in numeracy, while females demonstrate higher scientific literacy. Learning in one's own language increases conceptual understanding, which makes it critical for the government to develop policies that accommodate linguistic differences among people of Sundaland. The interplay between individual characteristics, such as gender and cognitive skills, and institutional and regional factors, such as school accreditation, teaching skills, bilingual programs, and government policies, plays an important role in literacy. The Batak and Minangkabau ethnicities have proven to be excellent at literacy because of their learning culture. However, Dayak and Banjar face difficulties achieving higher literacy levels due to linguistic constraints and weak social support networks. Therefore, literacy in a diverse community requires educational policies that ensure equal literacy for all individuals while adhering to national education standards. Ethnomathematics should be incorporated into the curriculum, and teacher capacity should be increased in culturally responsive teaching. Applying these findings is expected to enhance policy effectiveness, increase student literacy achievement, and strengthen social cohesion through culturally responsive and inclusive education systems in Indonesia.

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