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Penulis	:	Dwi Yulianto, Muhamad Sukri Situmeang, Yusup Junaedi, Syahrul Anwar dan Moh Rizal Umami

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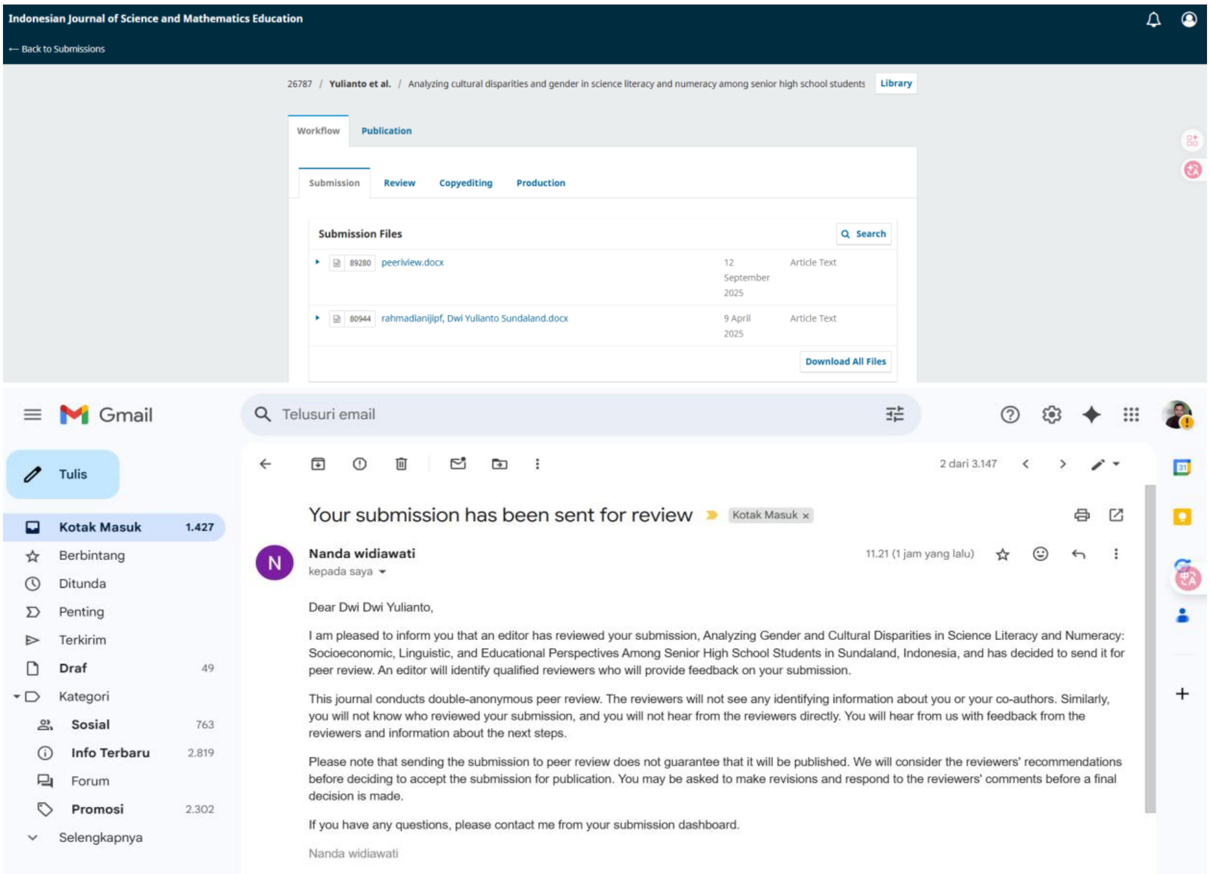

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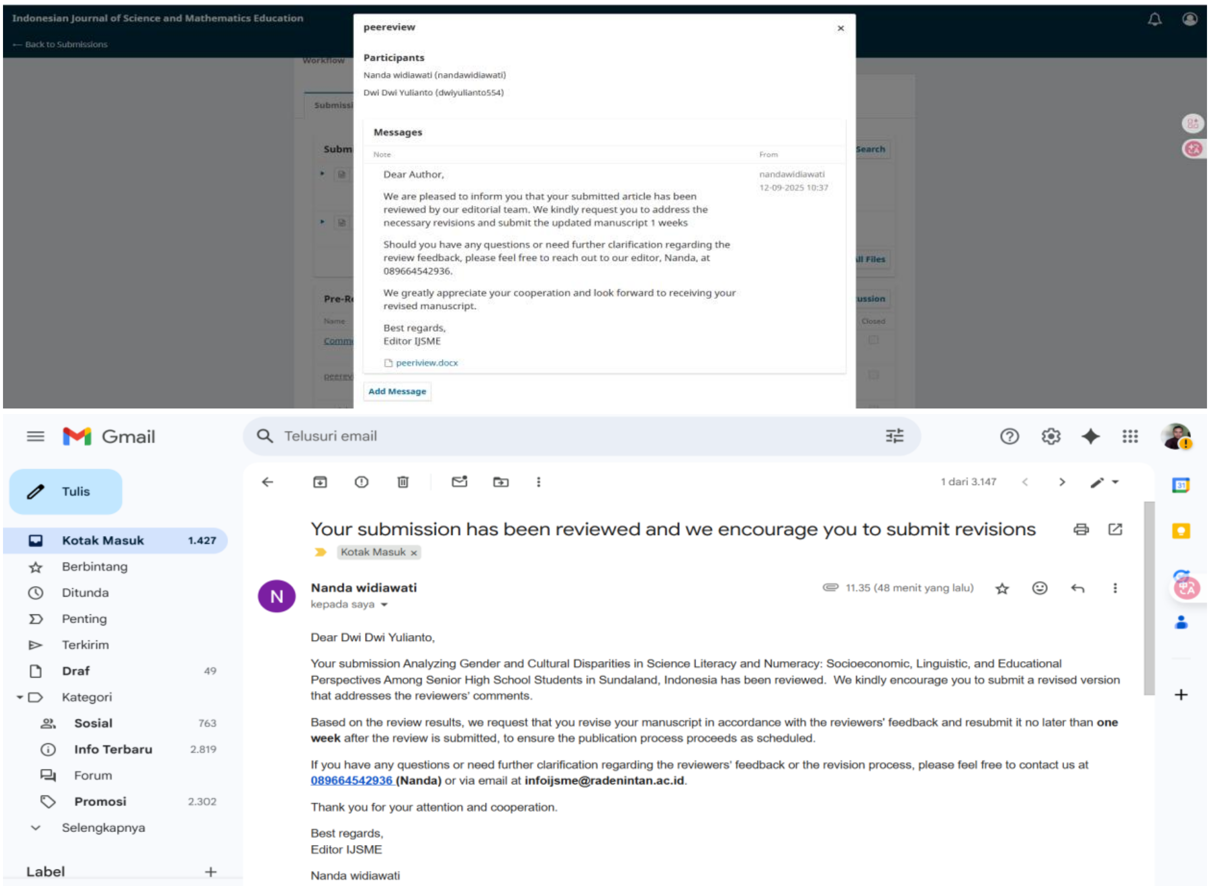

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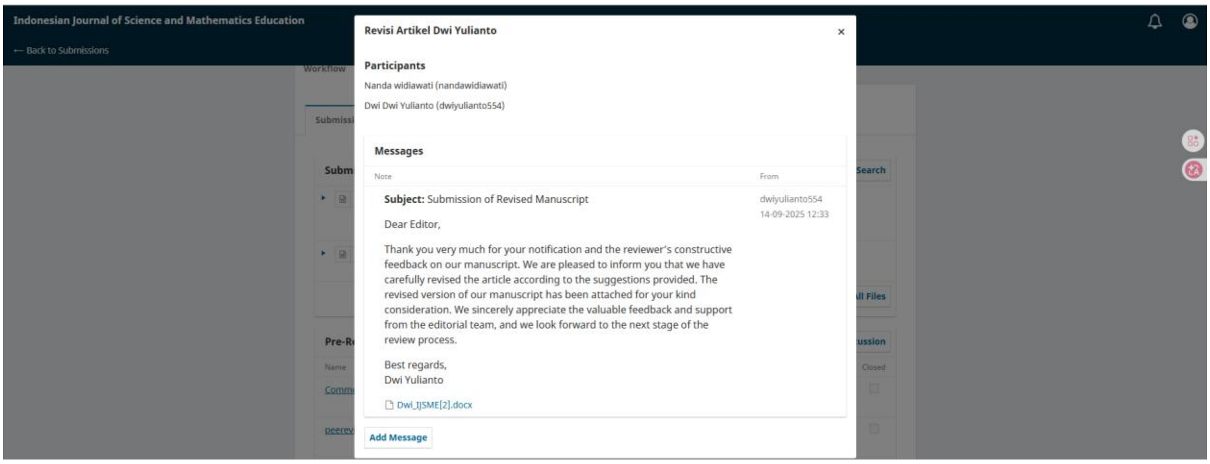

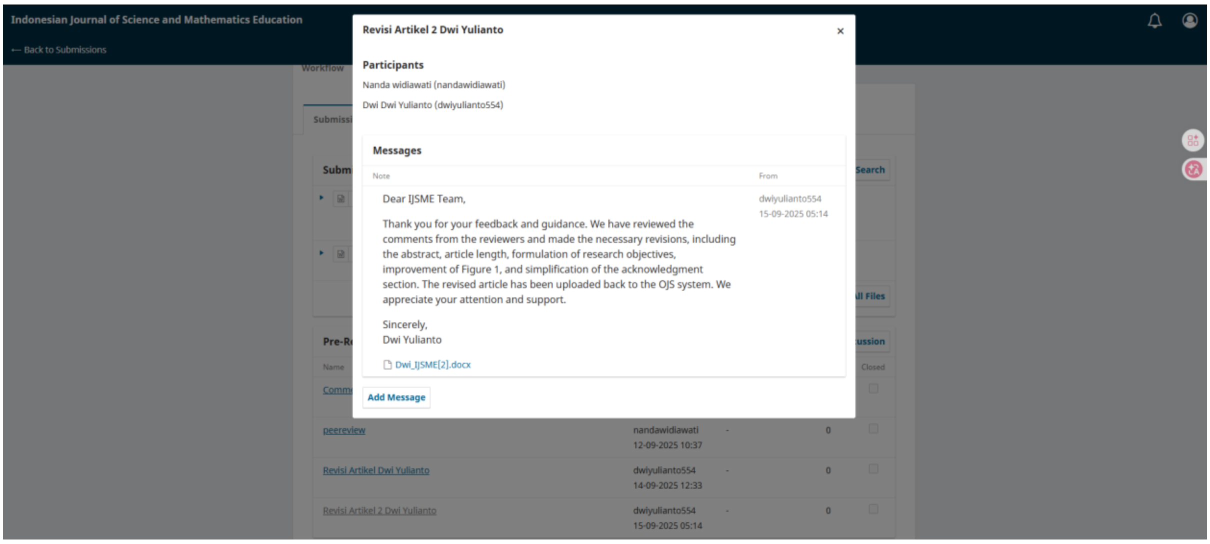

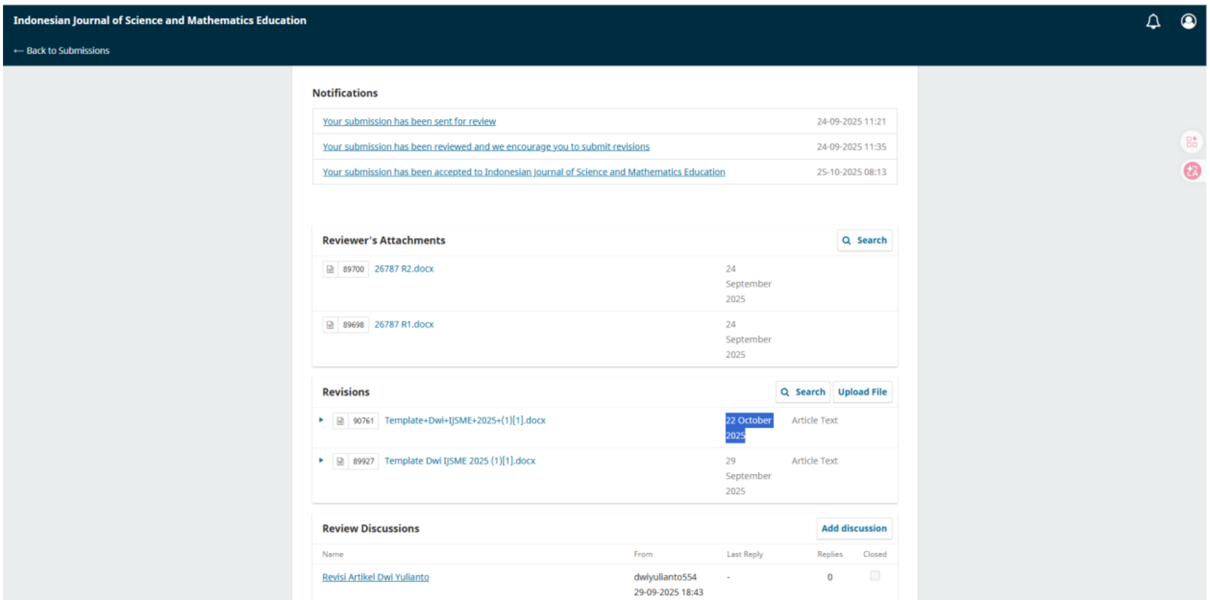

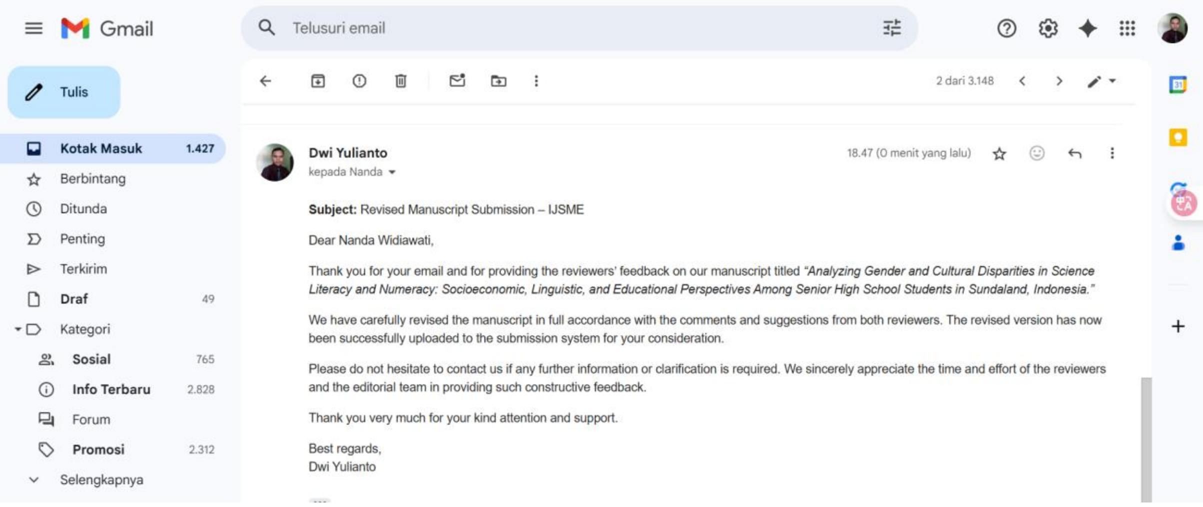

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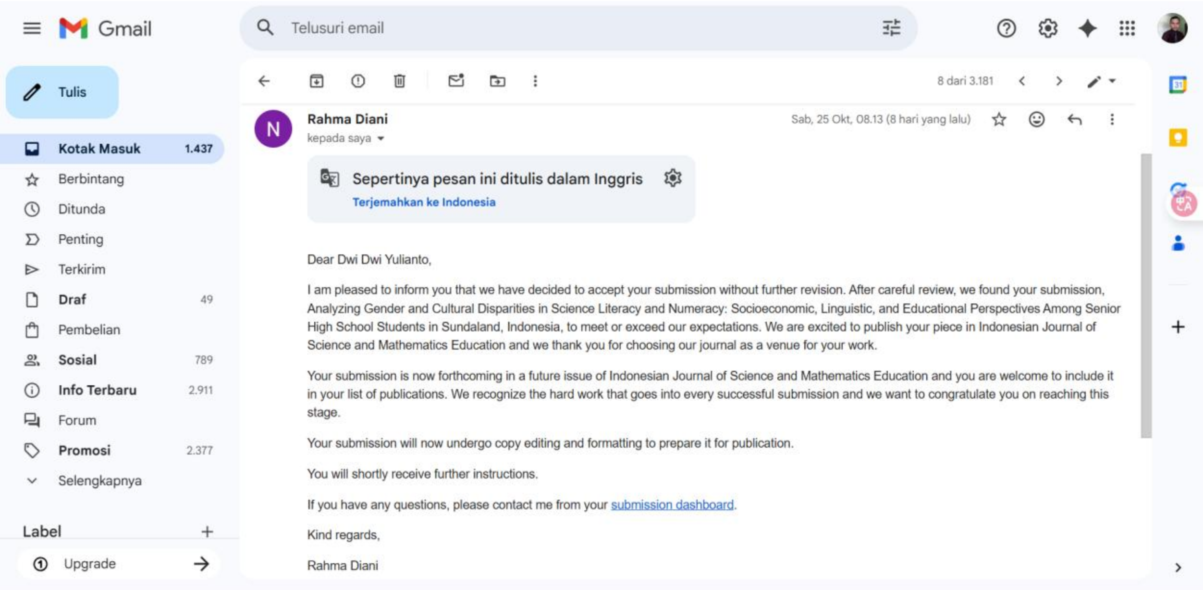

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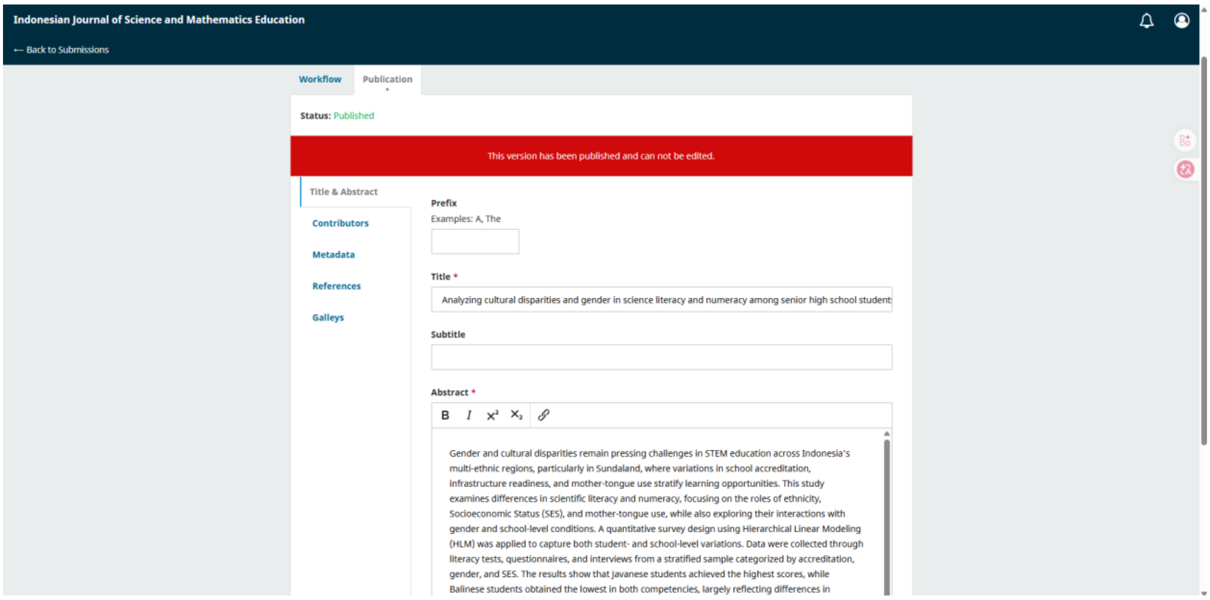

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Analyzing cultural disparities and gender in science literacy and numeracy among senior high school students in Sundaland, Indonesia

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Analyzing cultural disparities and gender in science literacy and numeracy among senior high school students in Sundaland, Indonesia

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ABSTRACT

Gender and cultural disparities remain pressing challenges in STEM education across Indonesia's multi-ethnic regions, particularly in Sundaland, where variations in school accreditation, infrastructure readiness, and mother-tongue use stratify learning opportunities. This study examines differences in scientific literacy and numeracy, focusing on the roles of ethnicity, Socioeconomic Status (SES), and mother-tongue use, while also exploring their interactions with gender and school-level conditions. A quantitative survey design using Hierarchical Linear Modeling (HLM) was applied to capture both student- and school-level variations. Data were collected through literacy tests, questionnaires, and interviews from a stratified sample categorized by accreditation, gender, and SES. The results show that Javanese students achieved the highest scores, while Balinese students obtained the lowest in both competencies, largely reflecting differences in infrastructure and technological support. Male students outperformed in numeracy, whereas females excelled in scientific literacy. Mother-tongue use enhanced conceptual understanding, particularly among Batak and Minangkabau students with strong learning traditions. The

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Cultural Disparities, Gender Disparities, Numeracy Literacy, Science Literacy.

ABSTRACT

This study investigates gender and cultural disparities in scientific literacy and numeracy among high school students in Sundaland, Indonesia, a multi-ethnic region marked by unequal school resources, language practices, and socioeconomic opportunities. Employing Hierarchical Linear Modeling (HLM), the research aims to (1) measure gender and cultural disparities, (2) estimate the direct and interactive effects of ethnicity, socioeconomic status (SES), and mother-tongue use, and (3) examine whether these relationships are moderated by gender and school-level factors such as accreditation and infrastructure. Data were collected through literacy tests, questionnaires, and interviews from a stratified sample categorized by accreditation, gender, and SES. The results show that Javanese students achieved the highest scores, while Balinese students obtained the lowest in both competencies, largely reflecting differences in infrastructure and technological support. Male students outperformed in numeracy, whereas females excelled in scientific literacy. Mother-tongue use enhanced conceptual understanding, particularly among Batak and Minangkabau students with strong learning traditions. These results underscore the need for inclusive, culturally responsive policies to address literacy gaps in multi-ethnic contexts. Ethnomathematics initiatives and multilingual education are recommended to promote learning equity. Future research should explore the long-term impacts of inclusive policies and community-based programs on student motivation and STEM achievement.

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Analisis Disparitas Kultural dan Gender dalam Literasi Sains dan Numerasi pada Siswa Sekolah Menengah Atas di Sundaland, Indonesia

Kata Kunci:

Kesenjangan Kultural, Kesenjangan Gender, Literasi Numerasi, Literasi Sains.

ABSTRAK

Penelitian ini mengkaji disparitas gender dan budaya dalam literasi sains dan numerasi pada siswa SMA di wilayah Sunda Land, Indonesia, yang ditandai oleh ketimpangan sumber daya sekolah, praktik bahasa, dan peluang sosial-ekonomi. Dengan menggunakan Hierarchical Linear Modeling (HLM), penelitian ini bertujuan untuk: (1) mengukur disparitas gender dan budaya, (2) mengestimasi pengaruh langsung dan interaktif dari etnisitas, status sosial-ekonomi (SES), serta penggunaan bahasa ibu, dan (3) menguji apakah hubungan tersebut dimoderasi oleh faktor gender dan tingkat sekolah, seperti akreditasi dan infrastruktur. Data dikumpulkan melalui tes literasi, kuesioner, dan wawancara dari sampel berstrata berdasarkan akreditasi, gender, dan SES. Hasil penelitian menunjukkan bahwa siswa Jawa meraih skor tertinggi, sedangkan siswa Bali memperoleh skor terendah pada kedua kompetensi, yang sebagian besar mencerminkan perbedaan infrastruktur dan dukungan teknologi. Siswa laki-laki lebih unggul dalam numerasi, sedangkan siswa perempuan lebih baik dalam literasi sains. Penggunaan bahasa ibu meningkatkan pemahaman konseptual, khususnya pada siswa Batak dan Minangkabau yang memiliki tradisi belajar kuat. Temuan ini menegaskan pentingnya kebijakan inklusif dan responsif budaya untuk mengatasi kesenjangan literasi di konteks multi-etnis. Inisiatif etnomatematika dan pendidikan multibahasa

direkomendasikan guna mendorong pemerataan pembelajaran. Penelitian selanjutnya diharapkan mengeksplorasi dampak jangka panjang kebijakan inklusif dan program berbasis komunitas terhadap motivasi belajar serta pencapaian STEM siswa.

Contribution to the literature

- Intersectional focus: Analyzes how gender, ethnicity, and language shape disparities in science and numeracy literacy among high school students in Sundaland, Indonesia.
- Methodological contribution: Applies a multi-level quantitative framework (HLM, ANCOVA) combined with qualitative insights to examine educational inequalities.
- Assessment design: Uses bilingual instruments adapted from PISA, TIMSS, and UNESCO, highlighting the role of mother-tongue instruction in strengthening conceptual understanding.
- Policy relevance: Provides context-specific recommendations for inclusive education, grounded in sociocultural theory, equity principles, and multilingual pedagogy.

1. INTRODUCTION

The progress of a nation relies on the quality of its human resources, educated, competitive, and adaptive to global change, reflected in education, critical thinking, collaboration, and innovation. Literacy underpins critical thinking, problem-solving, and creativity in the digital era [1]. Finland's digital literacy program, which emphasizes critical and collaborative skills, has enhanced technological innovation and economic participation. In the context of the Fourth Industrial Revolution and Society 5.0, education must equip learners with adaptive skills [2]. Twenty-first-century literacy encompasses six dimensions: reading–writing, numeracy, science, finance, digital, and cultural–civic [3], fostering information processing, problem-solving, technology use, and social engagement.

The 4C skills, Critical Thinking, Communication, Collaboration, and Creativity, are central to addressing global challenges [4]. The Framework for 21st Century Learning [5] demonstrates that 4Cs enhance academic achievement and workforce readiness [6]. However, the integration of scientific and numerical literacy in Indonesia remains limited [7]. Research highlights the role of experiment-based learning in strengthening evidence-based analysis [8] and collaboration in data-driven problem-solving [9]. Scientific literacy emphasizes hypothesis evaluation and evidence-based decision-making [10], while numerical literacy supports data-driven teamwork and statistical interpretation [11]. Together, these literacies enhance critical thinking, creativity, and problem-solving in education [12].

Countries excelling in PISA, such as Singapore and Finland, integrate scientific literacy and numeracy with 4Cs through inquiry- and project-based learning [9]. Indonesia, by contrast, struggles due to rote teaching methods, limited exploration, and insufficient discussion [13]. Seventy percent of teachers face challenges implementing higher-order thinking skills (HOTS) [9], while rural schools have 50% less technological access [14]. The 2013 Curriculum, which adopts 4Cs, is constrained by unequal access, weak teacher training, and pedagogical disparities [9]. The Merdeka Curriculum seeks to address these gaps by emphasizing competency-based learning, flexibility, and character development through the Pancasila Student Profile [28]. Nonetheless, challenges persist in teacher

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readiness, project-based pedagogy, and digital infrastructure, particularly in rural schools [15].

Indonesia's literacy challenges are reflected in its low PISA score (369.3), resulting from poor teaching quality, limited technology, and urban–rural disparities. In contrast, Singapore (559.7) succeeds through digital platforms, problem-solving curricula, and continuous teacher training, while Malaysia (424.7) and Thailand (394.0) adopt STEM-based approaches [15]. Educational reform is needed to strengthen pedagogy via project-based learning, expand digital access, and enhance teacher training programs [13]. Scientific and numerical literacy are crucial for critical thinking, problem-solving, and innovation [12]. Yet, 56 of 81 countries, including Indonesia, remain below average due to rote learning and exam-focused systems [15]. Finland and Singapore demonstrate success through inquiry- and problem-based approaches [16], while limited exploratory learning and resources in Indonesia exacerbate the literacy gap [17].

Gender disparities persist, with males generally excelling in numeracy and females in reading comprehension, shaped by cultural norms and stereotypes [18]. Gender Schema Theory [19] and Expectancy-Value Theory [20], explain these differences. Cross-national studies reveal that gender gaps are often more pronounced in high-equality countries [21]. Effective pedagogy must consider gender-specific learning styles: discussion-based methods enhance girls' reading literacy, whereas problem-solving activities support boys' numeracy development [22]. Gender-inclusive reforms and mentorship programs have successfully reduced STEM gaps in Sweden and Finland [23].

Sundaland (Sumatra, Java, Kalimantan, Bali) illustrates how cultural and linguistic diversity shapes literacy [24]. Local languages, traditions, and socio-economic contexts influence learning practices. The Interdependence Hypothesis posits that strong mother-tongue skills support second-language literacy [25]. However, Indonesia's monolingual policies and the dominance of English threaten local languages [26]. Community-based bilingual education could help address these challenges, as demonstrated by the Basque Country model. Educational practices vary across regions: rote Islamic-based learning in Aceh and Minangkabau [27]; constructivist approaches in Java; Contextual Teaching and Learning (CTL) in Kalimantan [28]; and culturally responsive teaching in Bali [29]. Literacy disparities are compounded by socio-economic inequalities, with rural areas lacking facilities and qualified teachers [30]. Programs such as *Sekolah Garis Depan* have improved attendance but still face challenges in maintaining educational quality [28].

Ethnic groups further shape literacy: Javanese emphasize hierarchical learning [31], Sundanese favor interactive discussions [32], Batak prioritize logic and analysis [34], and the Minangkabau integrate religious education [34]. Linguistic diversity complicates the transition from mother tongue to Indonesian [35],[36]. While prior studies have addressed literacy, 4C skills, and gender disparities, few have examined scientific and numerical literacy in Indonesia's multicultural context using multi-level and bilingual approaches. Therefore, this study seeks to fill this gap by analyzing disparities in Sundaland based on region, gender, ethnicity, and socio-cultural factors.

This study investigates scientific literacy and numeracy among Sundaland's high school students, focusing on region, gender, ethnicity, school accreditation, socio-economic status, and mother tongue. It aims to identify regional, gender, and ethnic differences, as well as institutional and socio-cultural factors influencing outcomes, to inform inclusive and adaptive educational policies for multicultural settings. Despite growing interest in multilingual and culturally responsive education, empirical gaps remain. Few studies combine multi-level quantitative (HLM, ANCOVA) and qualitative evidence to model student-, school-, and community-level drivers. Bilingual, culturally adapted assessments are rare, despite their importance for STEM learning. Given Indonesia's persistently low PISA performance and disparities, timely evidence is crucial for targeted and scalable interventions. Accordingly, this study investigates disparities in scientific literacy and numeracy among Sundaland's high school students, focusing on region, gender, ethnicity, accreditation, socio-economic status, and mother tongue.

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2. METHOD

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This study underscores the urgency of inclusive education policies to enhance scientific literacy and numeracy in Sundaland (Sumatra, Java, Kalimantan, Bali), a region marked by high cultural, ethnic, and linguistic diversity [37]. It analyzes literacy disparities linked to gender, culture, ethnicity, socioeconomic status, and linguistic diversity. Gender shapes learning approaches; culture and ethnicity influence educational values; socioeconomic status determines resource access; and linguistic diversity can facilitate or hinder literacy depending on mother-tongue instruction. Using a cross-sectional comparative design, the study maps these disparities empirically, offering a comprehensive view of factors driving literacy inequality (Figure 1).

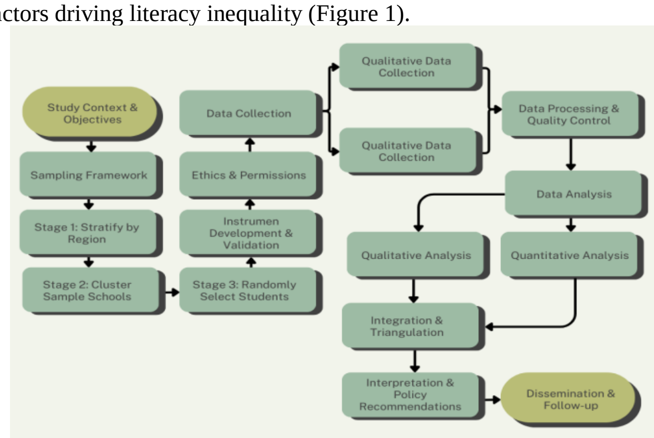

Figure 1. Research flowchart

Population and Research Sample

According to the latest data from the Indonesian Ministry of Education's Pusdatin [14] and the Central Bureau of Statistics [38], Indonesia has 4.853.305 high school students. This study focuses on students from the Sundaland region, distributed as follows:

Table 1. High School Student Population by Geographic Region and Gender

Region	Regional Proportion	Total Population	Urban Population	Rural Population	Male	Female
Java	58.5%	2,840,721	2,045,319	795,402	1,422,161	1,418,560
Sumatra	23%	1,117,249	581,674	535,575	561,812	555,437
Kalimantan	10%	484,191	208,201	275,990	242,895	241,296
Bali	4.5%	211,144	141,467	69,677	105,789	105,355
Total Sundaland	100%	4,853,305	2,976,661	1,876,644	2,332,657	2,320,648

Table 2. Student Population by School Accreditation

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	58,5%	955.847	785.326	304.146	312.879	256.138	226.385
Sumatra	23%	287.423	195.952	98.299	205.612	182.415	147.548

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Kalimantan	10%	90.612	76.785	40.804	97.336	105.421	73.233
Bali	4,5%	75.248	45.398	20.821	30.489	25.366	13.822
Total Sundaland	100%	1.409.130	1.103.461	464.070	646.316	569.340	461.988

A total of 2.250 students were selected through Multistage Random Sampling to ensure proportional representation by region, gender, ethnicity, and language, with Stratified Random Sampling dividing regions [39], Cluster Random Sampling selecting schools [40], and Simple Random Sampling, choosing students within schools [41].

Table 3. Sample Data of Students Based on Geographic Region and Gender

Region	Regional Proportion	High School Student Sample	Geographical Sample		Gender	
			Urban	Rural	M	F
Jawa	58.5%	1.317	948	369	659	658
Sumatra	23%	518	269	249	260	258
Kalimantan	10%	225	97	128	113	112
Bali	4.5%	101	68	33	51	50
Total Sundaland	100%	2.250	1.382	779	1.083	1.067

Table 4. Sample Data Based on School Accreditation

Region	High School Student Sample	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	1.317	464	382	156	154	125	36
Sumatra	518	184	135	68	93	78	50
Kalimantan	225	61	52	35	48	54	26
Bali	101	34	22	14	16	12	3
Total Sundaland	2.250	743	591	273	311	269	115

Ethnic samples were selected through a three-stage process: stratification by region and ethnicity using BPS data, clustering schools representing Batak, Minangkabau, Malay (Sumatra), and Dayak/Banjar (Kalimantan), and proportional random sampling of students by gender and ethnicity (e.g., Dayak 50%, Banjar 40%).

Table 5. 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%), Acehnese & Lampung (10%)	Batak: 207, Minangkabau: 181, Malay: 78, Acehnese & 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	

Test Instrument

This study developed a scientific and numerical literacy instrument for Indonesia based on PISA, TIMSS, and UNESCO frameworks (60% adapted, 40% newly developed), e.g., numeracy on regional energy use and science on climate impacts, presented bilingually. Items followed a PISA-based rubric (low, medium, high) with 40% multiple-choice, 35% short-answer, and 25% case studies. Content validity (UPI experts) was Aiken's V = 0.87; construct validity (CFA, AMOS) $\chi^2/df = 2.85$, CFI = 0.93, RMSEA = 0.047, SRMR = 0.035; reliability high: MC ($\alpha = 0.84$, $\omega = 0.86$), SA ($\alpha = 0.81$, $\omega = 0.83$), CS ($\alpha = 0.89$, $\omega = 0.91$), overall ($\alpha = 0.85$, $\omega = 0.87$); inter-rater: Cohen's Kappa = 0.78, ICC = 0.82. Participants were prospective teachers from La Tansa Mashiro University and Universitas Terbuka. Data included national reports, BPS, Kemendikbudristek, and questionnaires assessing six literacy aspects [9], and 14-question semi-structured interviews validating quantitative findings and socio-cultural literacy influences.

Data Analysis

This study examines gender and cultural disparities in scientific and numerical literacy across regions, ethnicities, socioeconomic status, and language. Normality (Kolmogorov-Smirnov/Shapiro-Wilk) and homogeneity (Levene) are tested. Analyses include ANOVA/Kruskal-Wallis, Two-Way ANOVA, ANCOVA, multiple regression (VIF), and Hierarchical Linear Modeling. Thematic analysis with triangulation validates patterns. Results are presented via SPSS, HLM, R, or Python.

3. RESULTS AND DISCUSSION

A descriptive analysis of 2.520 students (2022–2024) from Sumatra, Java, Kalimantan, and Bali examined science and numeracy literacy disparities by region, ethnicity, and gender, reporting mean ± SD for each group.

Table 5. Descriptive Statistics of Science and Numeracy Literacy

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

Kolmogorov-Smirnov and Levene's tests were applied to validate science and numeracy literacy scores across regions, ethnicities, and genders. Most groups met normality assumptions ($p > 0.05$), Significant deviations were analyzed using Kruskal-Wallis as an alternative to Two-Way ANOVA. Levene's Test confirmed homogeneity of variance ($p = 0.391$ for science literacy; $p = 0.446$ for numeracy), permitting Two-Way ANOVA to analyze performance differences by region, ethnicity, and gender.

Science and Numeracy Literacy in Sundaland (Sumatra, Java, Kalimantan, Bali)

Science and numeracy literacy in Sundaland showed regional gaps, with the highest in Java and the lowest in Bali. Two-Way ANOVA tested regional × gender effects (sum of squares, df, mean squares, F, p), ANCOVA controlled for linguistic and socio-economic factors, and HLM assessed individual, school, and regional effects.

Table 6. Statistical Calculation Results

Variable	Sum of Squares	df	Mean Square	F-Value	p-Value

Science Literacy	3562.506	3	1187.502	86.083	0.000
Numeracy	3022.581	3	1007.527	63.051	0.000
Male	1750.147	3	583.382	38.415	0.000
Female	4872.81	3	1624.27	111.545	0.000

Table 6 shows that Two-Way ANOVA revealed significant regional differences in scientific literacy ($F = 86.083$, $p = 0.000$) and numeracy ($F = 63.051$, $p = 0.000$), with Java highest and Bali lowest, reflecting educational disparities in Sundaland schools. Gender differences were also significant, with females showing greater variability ($F = 111.545$, $p = 0.000$) than males ($F = 38.415$, $p = 0.000$), indicating sensitivity to regional influences. ANOVA interaction plots confirm these findings.

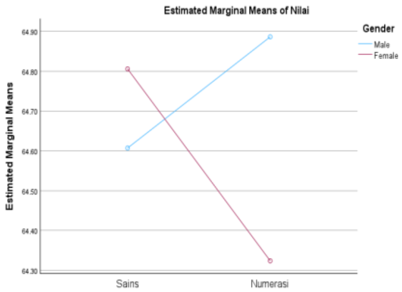

Figure 3. Science and Numeracy Proficiency by Gender Across Four Regions.

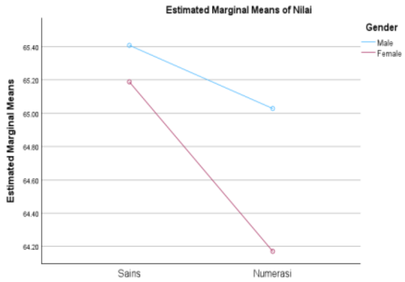

Figure 4. Science and Numeracy Proficiency by Gender in Sumatra.

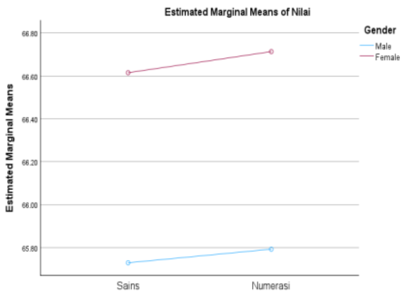

Figure 5. Science and Numeracy Proficiency by Gender in Java

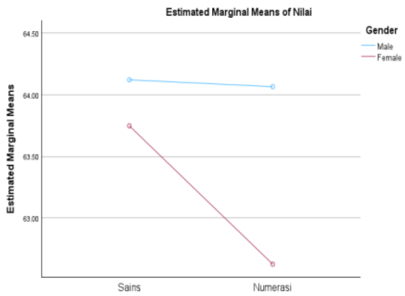

Figure 6. Science and Numeracy Proficiency by Gender in Kalimantan

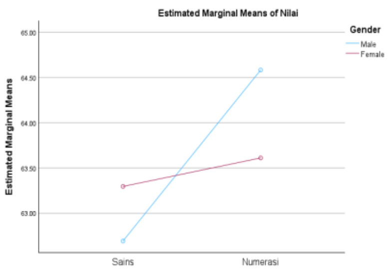

Figure 7. Science and Numeracy Proficiency by Gender in Bali

ANCOVA and Post-Hoc Tukey Test, controlling for SES, school accreditation, and access, revealed significant regional differences in science literacy and numeracy (Table 7). Java differed from Sumatra ($p = 0.002$), Kalimantan ($p = 0.000$), and Bali ($p = 0.000$); Sumatra from Kalimantan (p = 0.015) and Bali (p = 0.000); Kalimantan from Bali (p = 0.010), with all p < 0.05, indicating geography influences literacy.

Table 7. Post-Hoc Tukey Test (Identification of Sources of Differences)

Wilayah	Java	Sumatra	Kalimantan	Bali
Java	-	p = 0.002	p = 0.000	p = 0.000
Sumatra	p = 0.002	-	p = 0.015	p = 0.000
Kalimantan	p = 0.000	p = 0.015	-	p = 0.010
Bali	p = 0.000	p = 0.000	p = 0.010	-

Science literacy and numeracy in Sundaland vary significantly due to differences in educational resources, teaching quality, technology, SES, mother tongue use, school accreditation, and cultural factors, with Java excelling and Bali lagging despite controlling for SES and accreditation.

Table 8. ANCOVA for Controlling Confounding Variables

Region	School Accreditation	SES	Mother Tongue	Adjusted Mean		F-value	p-value
				Science	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*

ANCOVA (Table 8) indicates that school accreditation, SES, and mother tongue affect scientific literacy and numeracy in Sundaland, with Java highest (71.20 ± 2.50; 70.00 ± 2.85, F = 18.40; p = 0.000) due to superior accreditation, SES, and Javanese language, followed by Sumatra (Minangkabau, F = 15.70; p = 0.001), Kalimantan (Dayak, F = 14.50; p = 0.003), and Bali (Balinese, F = 13.10; p = 0.004), while HLM shows that individual factors (gender, cognition, mother tongue), institutional factors (accreditation, technology, teaching methods), and policy factors (bilingual programs, government support, equitable access) collectively shape literacy outcomes.

Table 9. HLM Results by Region

Level	Variabel	Sumatra	Jawa	Kalimantan	Bali	p-value
Level 1 (Individual)	Gender	1.50 ± 0.30	1.80 ± 0.25	1.20 ± 0.35	1.00 ± 0.40	0.001*
	Cognitive Ability	2.80 ± 0.25	3.10 ± 0.20	2.50 ± 0.30	2.30 ± 0.28	0.000*
	Mother Tongue	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002*
Level 2 (Institution)	Accreditation	3.40 ± 0.40	3.80 ± 0.35	2.90 ± 0.45	2.70 ± 0.50	0.000*
	Teaching Quality	2.60 ± 0.35	3.20 ± 0.30	2.50 ± 0.40	2.30 ± 0.38	0.001*
	Technology Integration	2.90 ± 0.30	3.50 ± 0.28	2.80 ± 0.35	2.50 ± 0.40	0.002*
Level 3 (Region)	Bilingual Program	2.80 ± 0.50	3.10 ± 0.45	3.40 ± 0.55	3.20 ± 0.50	0.000*
	Government Support	2.70 ± 0.48	3.00 ± 0.42	3.10 ± 0.50	2.90 ± 0.45	0.001*
	Access to Educational Resources	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002*

HLM analysis (Table 9) shows gender significantly affects numeracy (p = 0.001), with the highest in Java (1.80 ± 0.25) and the lowest in Bali (1.00 ± 0.40). Cognitive factors dominate in Java (3.10 ± 0.20; p = 0.000), mother tongue in Kalimantan (1.40 ± 0.25; p = 0.002). At the institutional level, school accreditation and teaching quality are key in Java (3.80 ± 0.35; p = 0.000), with technology use also significant (3.50 ± 0.28; p = 0.002). Regionally, bilingual programs in Kalimantan most influence numeracy (3.40 ± 0.55; p = 0.000*), followed by government support and educational resources (3.10 ± 0.50; p = 0.001*). Numeracy in Sundaland is shaped by individual, institutional, and regional factors.

Gender Differences in Science and Numeracy Literacy in the Sundaland Region.

Descriptive analysis reveals gender and regional disparities in Sundaland literacy: Java scored highest, Bali lowest. Two-Way ANOVA assessed gender and region effects, ANCOVA controlled linguistic and socioeconomic factors, and HLM examined individual, school, and policy influences. Independent t-tests (Table 9) show no significant gender difference in science literacy (t = -1.280; p = 0.201), but males outperformed females in numeracy (M = 64.89, SD = 3.99 vs. M = 64.32, SD = 4.27; t = 3.415; p = 0.001), confirming gender effects on numeracy in Sundaland.

Table 9. Results of the Independent t-test

Variable	Males	Females	t-value	p-value
Science Literacy	64,61 (SD = 3,97)	64,81 (SD = 3,83)	-1,280	0,201
Numeracy	64,89 (SD = 3,99)	64,32 (SD = 4,27)	3,415	0,001

Table 10 indicates that region strongly affects science literacy (F = 86.467; p = 0.000) and numeracy (F = 64.123; p = 0.000). Gender significantly impacts numeracy (F = 13.656; p = 0.000) and, to a lesser extent, science literacy (F = 2.268; p = 0.002). Significant region × gender interactions for science literacy (F = 4.476; p = 0.004) and numeracy (F = 11.356; p = 0.000) reveal that gender effects vary across regions.

Table 10. Two-Way ANOVA Results

Source of Variation	Science Literacy	Numeracy
Region	F = 86,467; p = 0,000	F = 64,123; p = 0,000
Gender	F = 2,268; p = 0,002	F = 13,656; p = 0,000
Region * Gender	F = 4,476; p = 0,004	F = 11,356; p = 0,000

To examine gender and regional effects on scientific literacy and numeracy, interaction graphs visualize score differences between males and females across regions.

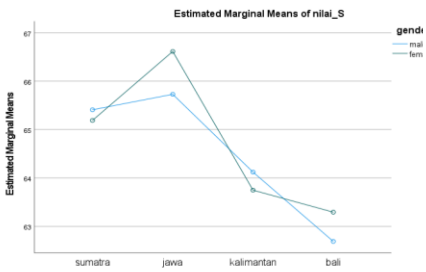

Figure 8. Science Proficiency by Gender

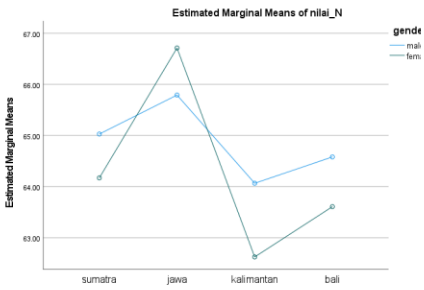

Figure 9. Numeracy Proficiency by Gender

The Tukey HSD Post-Hoc test (Table 11) shows gender and regional disparities in Sundaland, with females excelling in scientific literacy and males in numeracy, influenced by social norms, economic factors, and educational infrastructure, highlighting the need for inclusive, context-specific policies.

Table 11. Tukey HSD Post-Hoc Test (Identifying Sources of Gender Differences)

Group Comparison	Gender	Sumatra M	Sumatra F	Jawa M	Jawa F	Kalimantan M	Kalimantan F	Bali M	Bali F
Sumatra	M	-	p = 0.458	p = 0.279	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
	F	p = 0.458	-	p = 0.051	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Jawa	M	p = 0.279	p = 0.051	-	p = 0.000	p = 0.000	p = 0.000	p = 0.008	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	-	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Kalimantan	M	p = 0.000	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010	p = 0.000	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-	p = 0.000	p = 0.000
Bali	M	p = 0.000	p = 0.000	p = 0.008	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-

Tukey HSD (Table 12) showed gender differences in Sundaland females in Java and Bali outperformed Sumatra males in scientific literacy (p = 0.000), Kalimantan males led in numeracy (p = 0.000), and Kalimantan females differed from others (p = 0.010) highlighting gender and cultural effects on performance, with ANCOVA controlling for school accreditation detailed in Table 13 (Adjusted Means, F-values, p-values).

Table 12. ANCOVA for Controlling Confounding Variables Based on School Accreditation

Group Comparison	School Accreditation	Gender	SES	Adjusted Mean: Science Literacy	Adjusted Mean: Numeracy	F-value	p-value
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*
Jawa	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*

Group Comparison	School Accreditation	Gender	SES	Adjusted Mean		F-value	p-value
				Science Literacy	Numeracy		
	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*

ANCOVA shows females lead in scientific literacy at high-SES, top-accredited Java schools (71.40 ± 3.00; $p = 0.000$) and males in numeracy in Sumatra (67.80 ± 3.60; $p = 0.001$), with the gender gap narrowing in medium-SES, "Very Good" schools but persisting in low-SES, "Good" schools in Kalimantan and Bali, while HLM across Sundaland examines gender differences at individual (cognitive ability, mother tongue, regional factors), institutional (accreditation, teaching quality, technology), and regional (bilingual programs, government support, resource access) levels (Table 13).

Table 13. HLM Results by Gender

Level	Variable	Male	Female	p-value
Level 1 (Individual)	Sundaland Region	2.50 ± 0.30	2.80 ± 0.28	0.002*
	Cognitive Ability	3.50 ± 0.28	3.80 ± 0.25	0.000*
	Mother Tongue Background	1.80 ± 0.30	2.10 ± 0.28	0.002*
Level 2 (Institutional)	School Accreditation	4.20 ± 0.40	4.50 ± 0.38	0.000*
	Teaching Quality	3.70 ± 0.35	4.00 ± 0.32	0.001*
	Technology Integration	3.80 ± 0.33	4.20 ± 0.30	0.002*
Level 3 (Regional)	Bilingual Program	3.90 ± 0.50	4.30 ± 0.45	0.000*
	Regional Government Support	3.60 ± 0.48	4.00 ± 0.42	0.001*
	Access to Educational Resources	3.40 ± 0.45	3.80 ± 0.43	0.002*

Table 13 HLM results indicate that females significantly outperform males in Sundaland science literacy and numeracy ($p < 0.05$), with advantages shaped by mother tongue (Level 1), school accreditation, teaching quality, and technology integration (Level 2), as well as bilingual programs, government support, and resource access (Level 3), reinforced by adaptive learning, discipline, and supportive social and educational policies.

Differences in Science Literacy and Numeracy Based on Ethnicity in Sundaland

Table 14 reveals significant ethnic disparities in Sundaland students' science literacy and numeracy. Batak and Javanese lead in science literacy, Acehnese and Betawi in numeracy, while Malay and Sasak rank lowest in both. ANOVA confirms ethnicity's significant effect on science literacy ($F = 38.377$; $p = 0.000$) and numeracy ($F = 32.407$; $p = 0.000$). Results are robust under independent t-tests, ANCOVA, and HLM, controlling for individual, school, and policy factors, highlighting ethnicity as a principal determinant of students' performance.

Table 14. ANOVA Results

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups (Science Literacy)	6758.749	14	482.768	38.377	0.000
Within Groups	31511.714	2505	12.58		
Between Groups (Numeracy)	6628.616	14	473.473	32.407	0.000
Within Groups	36598.464	2505	14.61		

The interaction visualization elucidates ethnic disparities in science and numeracy literacy in Sundaland, revealing groups with extreme performance, regional variations, and the consistency of ethnicity's influence across populations.

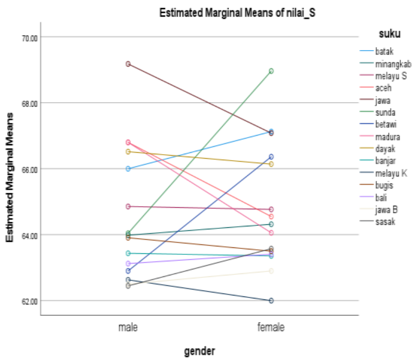

Figure 10. Science Proficiency by Gender and Ethnicity Across Four Regions.

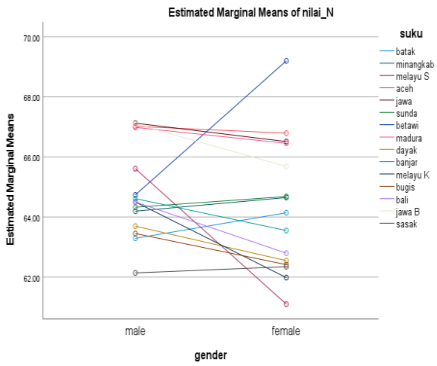

Figure 11. Numeracy Proficiency by Gender and Ethnicity Across Four Regions

Table 15: Batak, Sundanese, Betawi females > males in science literacy; Acehnese, Javanese males > females ($p < 0.05$). In numeracy, only Betawi females > males; others ns ($p > 0.05$).

Table 15. Independent t-test Based on Gender Across Various Ethnic Groups in Sundaland

Etnis	Gender	Science Literacy	t-value	p-value	Numeracy	t-value	p-value
Batak	M	66.00 (2.70)	-2.608	0.010	63.29 (4.19)	-1.407	0.161
	F	67.13 (2.89)			64.14 (3.63)		
Aceh	M	66.80 (2.90)	4.527	0.000	67.02 (3.75)	0.411	0.681
	F	64.55 (3.51)			66.79 (3.40)		
Javanese	M	67.02 (3.75)	4.011	0.000	67.13 (2.90)	1.215	0.226
	F	66.79 (3.40)			66.51 (3.61)		
Sunda	M	64.04 (3.20)	-10.299	0.000	64.33 (4.16)	-0.596	0.552
	F	68.96 (2.99)			64.68 (3.62)		
Betawi	M	62.90 (3.20)	-7.728	0.000	64.74 (3.10)	-9.505	0.000
	F	66.36 (2.57)			69.20 (2.99)		

Tukey HSD (Tabel 15) mengungkap disparitas etnis dan gender di literasi sains dan numerasi Sundaland: Javanese dan Batak unggul di sains (Batak vs. Minangkabau, MD = 2,41, p = 0,000; Javanese vs. Malay S., MD = 3,32, p = 0,000), Dayak dan Javanese di numerasi (Dayak vs. Banjar, MD = 2,93, p = 0,000; Javanese vs. Betawi, MD = 3,50, p = 0,000); gender memengaruhi: perempuan Batak/Javanese di sains, laki-laki Dayak/Javanese di numerasi (Batak F vs. Malay S., MD = 2,70, p = 0,000; Javanese M vs. Sundanese, MD = 1,63, p = 0,003); Malay K. dan Sasak terendah (Dayak vs. Malay K., MD = 4,01, p = 0,000; Javanese vs. Sasak, MD = 5,12, p = 0,000), mencerminkan ketimpangan sosial-ekonomi, pendidikan, dan infrastruktur.

Table 16. Tukey HSD Test for Science and Numeracy Literacy by Ethnicity

Etnis	Gender	Sumatra	Jawa	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)*

Etnis	Gender	Sumatra	Jawa	Kalimantan	Bali
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)

Table 17 (Tukey HSD) shows significant differences in scientific literacy and numeracy among Sundaland ethnic groups ($p < 0.001$), with Javanese and Batak highest, Dayak excelling in numeracy, some groups lagging due to limited education, gender differences present, and Javanese-Balinese outperforming native Balinese in Bali ($p < 0.000$), highlighting the influence of ethnicity, gender, and socio-cultural context and the need for culturally responsive curricula, teacher development, and targeted support.

Table 17. ANCOVA for Scientific Literacy and Numeracy Based on Ethnicity.

Wilayah	Etnis	SES	Bahasa Ibu	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

Wilayah	Etnis	SES	Bahasa Ibu	Science Literacy	Numeracy	F-value	p-value
		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

ANCOVA analysis (Table 18) indicates that scientific literacy and numeracy in Sundaland vary significantly by ethnic group, mediated by mother tongue and socioeconomic status (SES), with high-SES groups Batak in Sumatra (68.50 ± 2.60; 67.40 ± 3.00), Javanese in Java (71.20 ± 2.50; 70.00 ± 2.85), Dayak in Kalimantan (66.90 ± 2.85; 65.80 ± 3.40), and Balinese in Bali (65.40 ± 3.20; 64.50 ± 3.80) scoring highest, while low-SES groups in remote areas (Dayak, Sasak) score lower due to limited educational access, highlighting the need for culturally inclusive policies.

Table 19. HLM for Differences in Scientific Literacy and Numeracy by Ethnicity

Level	Variable	Batak	Minang kabau	Javanese	Dayak	Balinese	p-value
Level 1 (Individual)	Gender	1.60 ± 0.28	1.50 ± 0.30	1.80 ± 0.25	1.40 ± 0.35	1.20 ± 0.40	0.001
	Cognitive Ability	2.90 ± 0.24	2.80 ± 0.26	3.20 ± 0.20	2.70 ± 0.30	2.50 ± 0.28	0.000
	Mother Tongue Background	1.20 ± 0.18	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002
Level 2 (Institutional)	School Accreditation	3.50 ± 0.38	3.40 ± 0.40	3.80 ± 0.35	3.00 ± 0.45	2.80 ± 0.50	0.000
	Teaching Quality	2.70 ± 0.30	2.60 ± 0.35	3.30 ± 0.30	2.60 ± 0.40	2.40 ± 0.38	0.001
	Technology Integration	3.00 ± 0.28	2.90 ± 0.30	3.60 ± 0.28	2.90 ± 0.35	2.60 ± 0.40	0.002
Level 3 (Regional)	Bilingual Program	2.90 ± 0.45	2.80 ± 0.50	3.20 ± 0.45	3.40 ± 0.55	3.10 ± 0.50	0.000
	Regional Government Support	2.80 ± 0.42	2.70 ± 0.48	3.00 ± 0.42	3.20 ± 0.50	2.90 ± 0.45	0.001
	Access to Educational Resources	2.60 ± 0.40	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002

HLM analysis shows Sundaland’s scientific literacy and numeracy vary by individual, institutional, and ethnic factors. Javanese scored highest in cognition, language, accreditation, teaching, and technology; Batak and Minangkabau followed, Dayak and Balinese lagged. Dayak excelled in bilingual programs, Javanese in government support. Results stress culture, policy, and institutional roles, highlighting teaching quality, technology, and local language use as keys to bridging ethnic literacy gaps.

Discussion

Science and numeracy literacy in Sundaland (Sumatra, Java, Kalimantan, Bali) is shaped by socioeconomic factors, educational infrastructure, culture, and linguistic diversity. Java, as the educational hub, performs best due to technology, modern labs, and teacher training [14], [42], [43], though urban–rural gaps persist. In Sumatra, Batak and Minangkabau communities benefit from strong learning cultures and community support [44], but remote areas face resource limitations, mitigated by ethnomathematics and local language use [17]. Kalimantan suffers from digital inequality, poor infrastructure, and language barriers [45]. These findings align with prior research on the role of ethnomathematics and project-based learning in improving numeracy and higher-order thinking skills [1],[17], suggesting that locally rooted pedagogical models can be effective in reducing urban-rural disparities.

Gender gaps in literacy reflect cultural and linguistic influences. Urban women excel due to technology and STEM access [46], [43], while rural women face stereotypes and underrepresentation [21], [22]. In Java, women outperform in numeracy but men dominate technical skills [14]. In Sumatra, Batak and Minangkabau women excel in science literacy [44]. Kalimantan women lag due to limited labs and instruction-language mismatch [45]. In Bali, patriarchal norms hinder numeracy, yet women excel in environmental science aligned with Tri Hita Karana [29]. This pattern is consistent with global evidence showing female advantage in literacy and contextual variations in STEM participation [46], [21], while the persistence of patriarchal constraints in Bali highlights a divergence from intervention-based findings in other contexts [22], underscoring the salience of cultural norms in shaping gendered educational outcomes.

Language significantly affects STEM comprehension. In Sumatra, rural students struggle with Bahasa Indonesia despite Batak and Minangkabau literacy cultures [44], [47]. Javanese and Sundanese hierarchies complicate abstract STEM concepts [48]. In Kalimantan, Dayak and Banjar grammatical differences hinder comprehension [28], while Bali's Balinese language aids ecological understanding but clashes with scientific terminology [29]. Solutions include local-language integration, bilingual materials, and teacher training [17], [49]. These findings corroborate previous studies showing that the language of instruction substantially shapes mathematical and scientific reasoning [36], and extend this evidence by illustrating how linguistic hierarchies in Javanese and Sundanese further complicate comprehension of abstract STEM concepts.

Inclusive, context-based policies improve literacy. Bali integrates Hindu values into environmental education [29], Sumatra applies project-based Minangkabau approaches [17], Java uses Sundanese ethnomathematics [1], and Kalimantan collaborates with Dayak communities [28]. The effectiveness of integrating cultural values into STEM pedagogy is in line with theoretical frameworks emphasizing 21st-century competencies and education for sustainable development [6], [16], thereby confirming that culturally responsive approaches can serve as scalable models for inclusive education in diverse societies.

Implications

Findings highlight that literacy disparities are shaped by gender, cognition, school quality, accreditation, technology, bilingual programs, local policies, and resources. Recommendations include culturally responsive, gender-sensitive policies, PBL curricula, digital learning expansion, multilingual education, and ethnomathematics to bridge interethnic gaps and strengthen local identity.

Limitations

Limitations include geographic restriction to Sundaland, cross-sectional design excluding long-term impact, limited qualitative depth on minority students, and unexamined variables like learning styles, community support, and teacher quality.

Suggestions

Future research should: (1) adopt longitudinal designs to track literacy over time; (2) expand to Eastern Indonesia and indigenous communities; (3) integrate mixed-methods for deeper insights; (4) provide teacher training in inclusive pedagogy and local languages; (5) pursue international collaboration with multicultural countries for benchmarking sustainable multilingual education.

4. CONCLUSION

This study finds that scientific literacy and numeracy in Sundaland are shaped by gender, culture, and linguistics. Java performs best due to educational access, Bali lowest due to infrastructure limits. Males excel in numeracy, females in scientific literacy, reflecting social norms. Mother tongue use enhances conceptual understanding, highlighting the need for linguistically inclusive policies. Literacy outcomes depend on individual (gender, cognitive abilities), institutional (school accreditation, teaching quality), and regional (bilingual programs, government support) factors. Batak and Minangkabau excel in strong learning cultures, while Dayak and Banjar face linguistic and social barriers. Addressing these disparities requires policies integrating ethnomathematics, culturally responsive teaching, and school-community-research collaboration. Further studies should evaluate multilingual education and inclusive policy impacts on literacy gaps in Indonesia.

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AUTHOR CONTRIBUTION STATEMENT

DY conceived the research design, led the writing process, and supervised the data analysis. YJ coordinated data collection in the Sundaland region and contributed to the statistical analysis. EAJ was responsible for the development and validation of research instruments and contributed to the literature review. SA conducted fieldwork, managed interviews, and participated in qualitative data interpretation. MRU assisted with model design, data visualization, and technical editing of the manuscript. JM contributed to the ethnographic context analysis and the discussion of regional educational disparities. All authors reviewed and approved the final version of the manuscript.

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Lampiran 2. Respon Reviewer 2

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Analyzing Cultural Disparities and Gender in Science Literacy and Numeracy Among Senior High School Students in Sundaland, Indonesia

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ABSTRACT

This study investigates gender and cultural disparities in scientific literacy and numeracy among high school students in Sundaland, Indonesia, a multi-ethnic region marked by unequal school resources, language practices, and socioeconomic opportunities. Employing Hierarchical Linear Modeling (HLM), the research aims to (1) measure gender and cultural disparities, (2) estimate the direct and interactive effects of ethnicity, socioeconomic status (SES), and mother-tongue use, and (3) examine whether these relationships are moderated by gender and school-level factors such as accreditation and infrastructure. Data were collected through literacy tests, questionnaires, and interviews from a stratified sample categorized by accreditation, gender, and SES. The results show that Javanese students achieved the highest scores, while Balinese students obtained the lowest in both competencies, largely reflecting differences in infrastructure and technological support. Male students outperformed in numeracy, whereas females excelled in scientific literacy. Mother-tongue use enhanced conceptual understanding, particularly among Batak and Minangkabau students with strong learning traditions. These results underscore the need for inclusive, culturally responsive policies to address literacy gaps in multi-ethnic contexts. Ethnomathematics initiatives and multilingual education are recommended to promote learning equity. Future research should explore the long-term impacts of inclusive policies and community-based programs on student motivation and STEM achievement.

Commented [A1]: I really appreciate you explaining your background here, but please revise it to explain the main points of the phenomenon in your background.

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Commented [A3]: Before this sentence, explain what research method this is using.

Analisis Disparitas Kultural dan Gender dalam Literasi Sains dan Numerasi pada Siswa Sekolah Menengah Atas di Sundaland, Indonesia

Kata Kunci:

Kesenjangan Kultural, Kesenjangan Gender, Literasi Numerasi, Literasi Sains.

ABSTRAK

Penelitian ini mengkaji disparitas gender dan budaya dalam literasi sains dan numerasi pada siswa SMA di wilayah Sunda Land, Indonesia, yang ditandai oleh ketimpangan sumber daya sekolah, praktik bahasa, dan peluang sosial-ekonomi. Dengan menggunakan Hierarchical Linear Modeling (HLM), penelitian ini bertujuan untuk: (1) mengukur disparitas gender dan budaya, (2) mengestimasi pengaruh langsung dan interaktif dari etnisitas, status sosial-ekonomi (SES), serta penggunaan bahasa ibu, dan (3) menguji apakah hubungan tersebut dimoderasi oleh faktor gender dan tingkat sekolah, seperti akreditasi dan infrastruktur. Data dikumpulkan melalui tes literasi, kuesioner, dan wawancara dari sampel berstrata berdasarkan akreditasi, gender, dan SES. Hasil penelitian menunjukkan bahwa siswa Jawa meraih skor tertinggi, sedangkan siswa Bali memperoleh skor terendah pada kedua kompetensi, yang sebagian besar mencerminkan perbedaan infrastruktur dan dukungan teknologi. Siswa laki-laki lebih unggul dalam numerasi, sedangkan siswa perempuan lebih baik dalam literasi sains. Penggunaan bahasa ibu meningkatkan pemahaman konseptual, khususnya pada siswa Batak dan Minangkabau yang memiliki tradisi belajar kuat. Temuan ini menegaskan pentingnya kebijakan inklusif dan responsif budaya untuk mengatasi kesenjangan literasi di konteks multi-etnis. Inisiatif etnomatematika dan pendidikan multibahasa

direkomendasikan guna mendorong pemerataan pembelajaran. Penelitian selanjutnya diharapkan mengeksplorasi dampak jangka panjang kebijakan inklusif dan program berbasis komunitas terhadap motivasi belajar serta pencapaian STEM siswa.

Contribution to the literature

- Intersectional focus: Analyzes how gender, ethnicity, and language shape disparities in science and numeracy literacy among high school students in Sundaland, Indonesia.
- Methodological contribution: Applies a multi-level quantitative framework (HLM, ANCOVA) combined with qualitative insights to examine educational inequalities.
- Assessment design: Uses bilingual instruments adapted from PISA, TIMSS, and UNESCO, highlighting the role of mother-tongue instruction in strengthening conceptual understanding.
- Policy relevance: Provides context-specific recommendations for inclusive education, grounded in sociocultural theory, equity principles, and multilingual pedagogy.

1. INTRODUCTION

The progress of a nation relies on the quality of its human resources, educated, competitive, and adaptive to global change, reflected in education, critical thinking, collaboration, and innovation. Literacy underpins critical thinking, problem-solving, and creativity in the digital era [1]. Finland's digital literacy program, which emphasizes critical and collaborative skills, has enhanced technological innovation and economic participation. In the context of the Fourth Industrial Revolution and Society 5.0, education must equip learners with adaptive skills [2]. Twenty-first-century literacy encompasses six dimensions: reading–writing, numeracy, science, finance, digital, and cultural–civic [3], fostering information processing, problem-solving, technology use, and social engagement.

The 4C skills, Critical Thinking, Communication, Collaboration, and Creativity, are central to addressing global challenges [4]. The Framework for 21st Century Learning [5] demonstrates that 4Cs enhance academic achievement and workforce readiness [6]. However, the integration of scientific and numerical literacy in Indonesia remains limited [7]. Research highlights the role of experiment-based learning in strengthening evidence-based analysis [8] and collaboration in data-driven problem-solving [9]. Scientific literacy emphasizes hypothesis evaluation and evidence-based decision-making [10], while numerical literacy supports data-driven teamwork and statistical interpretation [11]. Together, these literacies enhance critical thinking, creativity, and problem-solving in education [12].

Countries excelling in PISA, such as Singapore and Finland, integrate scientific literacy and numeracy with 4Cs through inquiry- and project-based learning [9]. Indonesia, by contrast, struggles due to rote teaching methods, limited exploration, and insufficient discussion [13]. Seventy percent of teachers face challenges implementing higher-order thinking skills (HOTS) [9], while rural schools have 50% less technological access [14]. The 2013 Curriculum, which adopts 4Cs, is constrained by unequal access, weak teacher training, and pedagogical disparities [9]. The Merdeka Curriculum seeks to address these gaps by emphasizing competency-based learning, flexibility, and character development through the Pancasila Student Profile [28]. Nonetheless, challenges persist in teacher

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Commented [A9]: Please give your opinion, at the end of the paragraph avoid quoting/cited readiness, project-based pedagogy, and digital infrastructure, particularly in rural schools [15].

Indonesia's literacy challenges are reflected in its low PISA score (369.3), resulting from poor teaching quality, limited technology, and urban–rural disparities. In contrast, Singapore (559.7) succeeds through digital platforms, problem-solving curricula, and continuous teacher training, while Malaysia (424.7) and Thailand (394.0) adopt STEM-based approaches [15]. Educational reform is needed to strengthen pedagogy via project-based learning, expand digital access, and enhance teacher training programs [13]. Scientific and numerical literacy are crucial for critical thinking, problem-solving, and innovation [12]. Yet, 56 of 81 countries, including Indonesia, remain below average due to rote learning and exam-focused systems [15]. Finland and Singapore demonstrate success through inquiry- and problem-based approaches [16], while limited exploratory learning and resources in Indonesia exacerbate the literacy gap [17].

Gender disparities persist, with males generally excelling in numeracy and females in reading comprehension, shaped by cultural norms and stereotypes [18]. Gender Schema Theory [19] and Expectancy-Value Theory [20], explain these differences. Cross-national studies reveal that gender gaps are often more pronounced in high-equality countries [21]. Effective pedagogy must consider gender-specific learning styles: discussion-based methods enhance girls' reading literacy, whereas problem-solving activities support boys' numeracy development [22]. Gender-inclusive reforms and mentorship programs have successfully reduced STEM gaps in Sweden and Finland [23].

Sundaland (Sumatra, Java, Kalimantan, Bali) illustrates how cultural and linguistic diversity shapes literacy [24]. Local languages, traditions, and socio-economic contexts influence learning practices. The Interdependence Hypothesis posits that strong mother-tongue skills support second-language literacy [25]. However, Indonesia's monolingual policies and the dominance of English threaten local languages [26]. Community-based bilingual education could help address these challenges, as demonstrated by the Basque Country model. Educational practices vary across regions: rote Islamic-based learning in Aceh and Minangkabau [27]; constructivist approaches in Java; Contextual Teaching and Learning (CTL) in Kalimantan [28]; and culturally responsive teaching in Bali [29]. Literacy disparities are compounded by socio-economic inequalities, with rural areas lacking facilities and qualified teachers [30]. Programs such as *Sekolah Garis Depan* have improved attendance but still face challenges in maintaining educational quality [28].

Ethnic groups further shape literacy: Javanese emphasize hierarchical learning [31], Sundanese favor interactive discussions [32], Batak prioritize logic and analysis [34], and the Minangkabau integrate religious education [34]. Linguistic diversity complicates the transition from mother tongue to Indonesian [35],[36]. While prior studies have addressed literacy, 4C skills, and gender disparities, few have examined scientific and numerical literacy in Indonesia's multicultural context using multi-level and bilingual approaches. Therefore, this study seeks to fill this gap by analyzing disparities in Sundaland based on region, gender, ethnicity, and socio-cultural factors.

This study investigates scientific literacy and numeracy among Sundaland's high school students, focusing on region, gender, ethnicity, school accreditation, socio-economic status, and mother tongue. It aims to identify regional, gender, and ethnic differences, as well as institutional and socio-cultural factors influencing outcomes, to inform inclusive and adaptive educational policies for multicultural settings. Despite growing interest in multilingual and culturally responsive education, empirical gaps remain. Few studies combine multi-level quantitative (HLM, ANCOVA) and qualitative evidence to model student-, school-, and community-level drivers. Bilingual, culturally

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adapted assessments are rare, despite their importance for STEM learning. Given Indonesia's persistently low PISA performance and disparities, timely evidence is crucial for targeted and scalable interventions. Accordingly, this study investigates disparities in scientific literacy and numeracy among Sundaland's high school students, focusing on region, gender, ethnicity, accreditation, socio-economic status, and mother tongue.

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2. METHOD

This study underscores the urgency of inclusive education policies to enhance scientific literacy and numeracy in Sundaland (Sumatra, Java, Kalimantan, Bali), a region marked by high cultural, ethnic, and linguistic diversity [37]. It analyzes literacy disparities linked to gender, culture, ethnicity, socioeconomic status, and linguistic diversity. Gender shapes learning approaches; culture and ethnicity influence educational values; socioeconomic status determines resource access; and linguistic diversity can facilitate or hinder literacy depending on mother-tongue instruction. Using a cross-sectional comparative design, the study maps these disparities empirically, offering a comprehensive view of factors driving literacy inequality (Figure 1).

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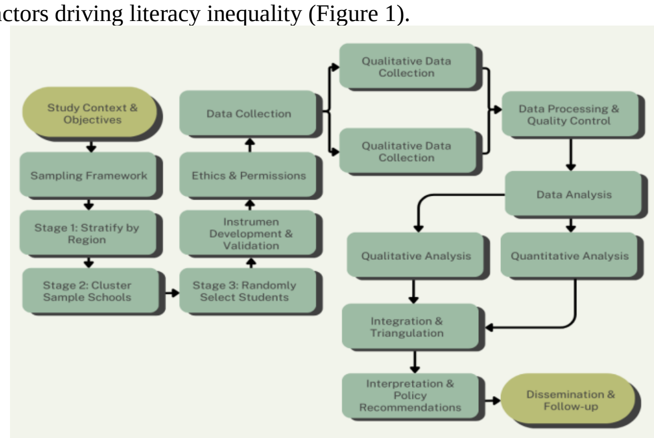

Figure 1. Research flowchart

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Population and Research Sample

According to the latest data from the Indonesian Ministry of Education's Pusdatin [14] and the Central Bureau of Statistics [38], Indonesia has 4.853.305 high school students. This study focuses on students from the Sundaland region, distributed as follows:

Table 1. High School Student Population by Geographic Region and Gender

Region	Regional Proportion	Total Population	Urban Population	Rural Population	Male	Female
Java	58.5%	2,840,721	2,045,319	795,402	1,422,161	1,418,560
Sumatra	23%	1,117,249	581,674	535,575	561,812	555,437
Kalimantan	10%	484,191	208,201	275,990	242,895	241,296
Bali	4.5%	211,144	141,467	69,677	105,789	105,355
Total Sundaland	100%	4,853,305	2,976,661	1,876,644	2,332,657	2,320,648

Table 2. Student Population by School Accreditation

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	58,5%	955.847	785.326	304.146	312.879	256.138	226.385
Sumatra	23%	287.423	195.952	98.299	205.612	182.415	147.548

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Kalimantan	10%	90.612	76.785	40.804	97.336	105.421	73.233
Bali	4,5%	75.248	45.398	20.821	30.489	25.366	13.822
Total Sundaland	100%	1.409.130	1.103.461	464.070	646.316	569.340	461.988

A total of 2.250 students were selected through Multistage Random Sampling to ensure proportional representation by region, gender, ethnicity, and language, with Stratified Random Sampling dividing regions [39], Cluster Random Sampling selecting schools [40], and Simple Random Sampling, choosing students within schools [41].

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Table 3. Sample Data of Students Based on Geographic Region and Gender

Region	Regional Proportion	High School Student Sample	Geographical Sample		Gender	
			Urban	Rural	M	F
Jawa	58.5%	1.317	948	369	659	658
Sumatra	23%	518	269	249	260	258
Kalimantan	10%	225	97	128	113	112
Bali	4.5%	101	68	33	51	50
Total Sundaland	100%	2.250	1.382	779	1.083	1.067

Table 4. Sample Data Based on School Accreditation

Region	High School Student Sample	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	1.317	464	382	156	154	125	36
Sumatra	518	184	135	68	93	78	50
Kalimantan	225	61	52	35	48	54	26
Bali	101	34	22	14	16	12	3
Total Sundaland	2.250	743	591	273	311	269	115

Ethnic samples were selected through a three-stage process: stratification by region and ethnicity using BPS data, clustering schools representing Batak, Minangkabau, Malay (Sumatra), and Dayak/Banjar (Kalimantan), and proportional random sampling of students by gender and ethnicity (e.g., Dayak 50%, Banjar 40%).

Table 5. 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%), Acehnese & Lampung (10%)	Batak: 207, Minangkabau: 181, Malay: 78, Acehnese & 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	

Test Instrument

This study developed a scientific and numerical literacy instrument for Indonesia based on PISA, TIMSS, and UNESCO frameworks (60% adapted, 40% newly developed), e.g., numeracy on regional energy use and science on climate impacts, presented bilingually. Items followed a PISA-based rubric (low, medium, high) with 40% multiple-choice, 35% short-answer, and 25% case studies. Content validity (UPI experts) was Aiken's V = 0.87; construct validity (CFA, AMOS) $\chi^2/df = 2.85$, CFI = 0.93, RMSEA = 0.047, SRMR = 0.035; reliability high: MC ($\alpha = 0.84$, $\omega = 0.86$), SA ($\alpha = 0.81$, $\omega = 0.83$), CS ($\alpha = 0.89$, $\omega = 0.91$), overall ($\alpha = 0.85$, $\omega = 0.87$); inter-rater: Cohen's Kappa = 0.78, ICC = 0.82. Participants were prospective teachers from La Tansa Mashiro University and Universitas Terbuka. Data included national reports, BPS, Kemendikbudristek, and questionnaires assessing six literacy aspects [9], and 14-question semi-structured interviews validating quantitative findings and socio-cultural literacy influences.

Data Analysis

This study examines gender and cultural disparities in scientific and numerical literacy across regions, ethnicities, socioeconomic status, and language. Normality (Kolmogorov-Smirnov/Shapiro-Wilk) and homogeneity (Levene) are tested. Analyses include ANOVA/Kruskal-Wallis, Two-Way ANOVA, ANCOVA, multiple regression (VIF), and Hierarchical Linear Modeling. Thematic analysis with triangulation validates patterns. Results are presented via SPSS, HLM, R, or Python.

3. RESULTS AND DISCUSSION

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A descriptive analysis of 2.520 students (2022–2024) from Sumatra, Java, Kalimantan, and Bali examined science and numeracy literacy disparities by region, ethnicity, and gender, reporting mean ± SD for each group.

Table 5. Descriptive Statistics of Science and Numeracy Literacy

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

Kolmogorov-Smirnov and Levene's tests were applied to validate science and numeracy literacy scores across regions, ethnicities, and genders. Most groups met normality assumptions ($p > 0.05$), Significant deviations were analyzed using Kruskal-Wallis as an alternative to Two-Way ANOVA. Levene's Test confirmed homogeneity of variance ($p = 0.391$ for science literacy; $p = 0.446$ for numeracy), permitting Two-Way ANOVA to analyze performance differences by region, ethnicity, and gender.

Science and Numeracy Literacy in Sundaland (Sumatra, Java, Kalimantan, Bali)

Science and numeracy literacy in Sundaland showed regional gaps, with the highest in Java and the lowest in Bali. Two-Way ANOVA tested regional × gender effects (sum of squares, df, mean squares, F, p), ANCOVA controlled for linguistic and socio-economic factors, and HLM assessed individual, school, and regional effects.

Table 6. Statistical Calculation Results

Variable	Sum of Squares	df	Mean Square	F-Value	p-Value

Science Literacy	3562.506	3	1187.502	86.083	0.000
Numeracy	3022.581	3	1007.527	63.051	0.000
Male	1750.147	3	583.382	38.415	0.000
Female	4872.81	3	1624.27	111.545	0.000

Table 6 shows that Two-Way ANOVA revealed significant regional differences in scientific literacy (F = 86.083, p = 0.000) and numeracy (F = 63.051, p = 0.000), with Java highest and Bali lowest, reflecting educational disparities in Sundaland schools. Gender differences were also significant, with females showing greater variability (F = 111.545, p = 0.000) than males (F = 38.415, p = 0.000), indicating sensitivity to regional influences. ANOVA interaction plots confirm these findings.

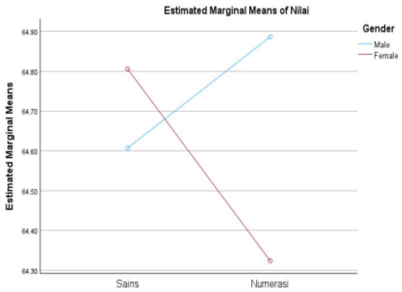

Figure 3. Science and Numeracy Proficiency by Gender Across Four Regions.

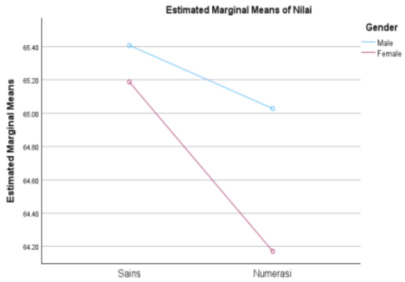

Figure 4. Science and Numeracy Proficiency by Gender in Sumatra.

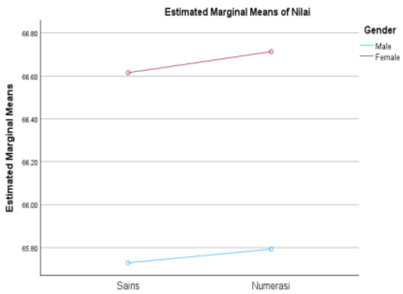

Figure 5. Science and Numeracy Proficiency by Gender in Java

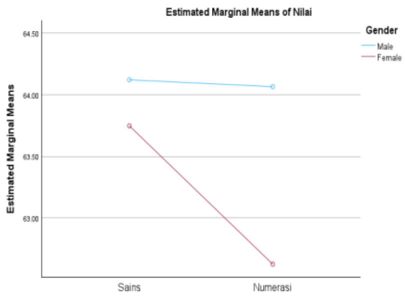

Figure 6. Science and Numeracy Proficiency by Gender in Kalimantan

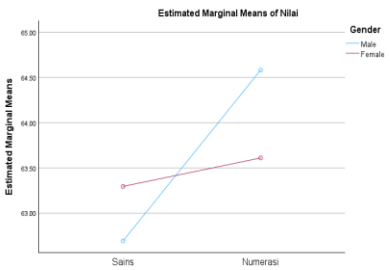

Figure 7. Science and Numeracy Proficiency by Gender in Bali

ANCOVA and Post-Hoc Tukey Test, controlling for SES, school accreditation, and access, revealed significant regional differences in science literacy and numeracy (Table 7). Java differed from Sumatra (p = 0.002), Kalimantan (p = 0.000), and Bali (p = 0.000); Sumatra from Kalimantan (p = 0.015) and Bali (p = 0.000); Kalimantan from Bali (p = 0.010), with all p < 0.05, indicating geography influences literacy.

Table 7. Post-Hoc Tukey Test (Identification of Sources of Differences)

Wilayah	Java	Sumatra	Kalimantan	Bali
Java	-	p = 0.002	p = 0.000	p = 0.000
Sumatra	p = 0.002	-	p = 0.015	p = 0.000
Kalimantan	p = 0.000	p = 0.015	-	p = 0.010
Bali	p = 0.000	p = 0.000	p = 0.010	-

Science literacy and numeracy in Sundaland vary significantly due to differences in educational resources, teaching quality, technology, SES, mother tongue use, school accreditation, and cultural factors, with Java excelling and Bali lagging despite controlling for SES and accreditation.

Table 8. ANCOVA for Controlling Confounding Variables

Region	School Accreditation	SES	Mother Tongue	Adjusted Mean		F-value	p-value
				Science	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*

ANCOVA (Table 8) indicates that school accreditation, SES, and mother tongue affect scientific literacy and numeracy in Sundaland, with Java highest (71.20 ± 2.50; 70.00 ± 2.85, F = 18.40; p = 0.000) due to superior accreditation, SES, and Javanese language, followed by Sumatra (Minangkabau, F = 15.70; p = 0.001), Kalimantan (Dayak, F = 14.50; p = 0.003), and Bali (Balinese, F = 13.10; p = 0.004), while HLM shows that individual factors (gender, cognition, mother tongue), institutional factors (accreditation, technology, teaching methods), and policy factors (bilingual programs, government support, equitable access) collectively shape literacy outcomes.

Table 9. HLM Results by Region

Level	Variabel	Sumatra	Jawa	Kalimantan	Bali	p-value
Level 1 (Individual)	Gender	1.50 ± 0.30	1.80 ± 0.25	1.20 ± 0.35	1.00 ± 0.40	0.001*
	Cognitive Ability	2.80 ± 0.25	3.10 ± 0.20	2.50 ± 0.30	2.30 ± 0.28	0.000*
	Mother Tongue	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002*
Level 2 (Institution)	Accreditation	3.40 ± 0.40	3.80 ± 0.35	2.90 ± 0.45	2.70 ± 0.50	0.000*
	Teaching Quality	2.60 ± 0.35	3.20 ± 0.30	2.50 ± 0.40	2.30 ± 0.38	0.001*
	Technology Integration	2.90 ± 0.30	3.50 ± 0.28	2.80 ± 0.35	2.50 ± 0.40	0.002*
Level 3 (Region)	Bilingual Program	2.80 ± 0.50	3.10 ± 0.45	3.40 ± 0.55	3.20 ± 0.50	0.000*
	Government Support	2.70 ± 0.48	3.00 ± 0.42	3.10 ± 0.50	2.90 ± 0.45	0.001*
	Access to Educational Resources	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002*

HLM analysis (Table 9) shows gender significantly affects numeracy (p = 0.001), with the highest in Java (1.80 ± 0.25) and the lowest in Bali (1.00 ± 0.40). Cognitive factors dominate in Java (3.10 ± 0.20; p = 0.000), mother tongue in Kalimantan (1.40 ± 0.25; p = 0.002). At the institutional level, school accreditation and teaching quality are key in Java (3.80 ± 0.35; p = 0.000), with technology use also significant (3.50 ± 0.28; p = 0.002). Regionally, bilingual programs in Kalimantan most influence numeracy (3.40 ± 0.55; p = 0.000*), followed by government support and educational resources (3.10 ± 0.50; p = 0.001*). Numeracy in Sundaland is shaped by individual, institutional, and regional factors.

Gender Differences in Science and Numeracy Literacy in the Sundaland Region.

Descriptive analysis reveals gender and regional disparities in Sundaland literacy: Java scored highest, Bali lowest. Two-Way ANOVA assessed gender and region effects, ANCOVA controlled linguistic and socioeconomic factors, and HLM examined individual, school, and policy influences. Independent t-tests (Table 9) show no significant gender difference in science literacy (t = -1.280; p = 0.201), but males outperformed females in numeracy (M = 64.89, SD = 3.99 vs. M = 64.32, SD = 4.27; t = 3.415; p = 0.001), confirming gender effects on numeracy in Sundaland.

Table 9. Results of the Independent t-test

Variable	Males	Females	t-value	p-value
Science Literacy	64,61 (SD = 3,97)	64,81 (SD = 3,83)	-1,280	0,201
Numeracy	64,89 (SD = 3,99)	64,32 (SD = 4,27)	3,415	0,001

Table 10 indicates that region strongly affects science literacy (F = 86.467; p = 0.000) and numeracy (F = 64.123; p = 0.000). Gender significantly impacts numeracy (F = 13.656; p = 0.000) and, to a lesser extent, science literacy (F = 2.268; p = 0.002). Significant region × gender interactions for science literacy (F = 4.476; p = 0.004) and numeracy (F = 11.356; p = 0.000) reveal that gender effects vary across regions.

Table 10. Two-Way ANOVA Results

Source of Variation	Science Literacy	Numeracy
Region	F = 86,467; p = 0,000	F = 64,123; p = 0,000
Gender	F = 2,268; p = 0,002	F = 13,656; p = 0,000
Region * Gender	F = 4,476; p = 0,004	F = 11,356; p = 0,000

To examine gender and regional effects on scientific literacy and numeracy, interaction graphs visualize score differences between males and females across regions.

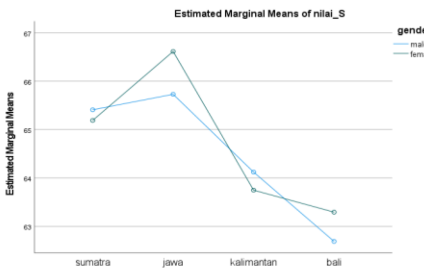

Figure 8. Science Proficiency by Gender

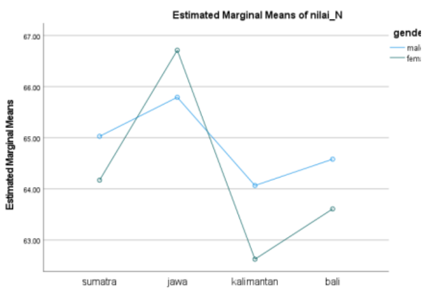

Figure 9. Numeracy Proficiency by Gender

The Tukey HSD Post-Hoc test (Table 11) shows gender and regional disparities in Sundaland, with females excelling in scientific literacy and males in numeracy, influenced by social norms, economic factors, and educational infrastructure, highlighting the need for inclusive, context-specific policies.

Table 11. Tukey HSD Post-Hoc Test (Identifying Sources of Gender Differences)

Group Comparison	Gender	Sumatra M	Sumatra F	Jawa M	Jawa F	Kalimantan M	Kalimantan F	Bali M	Bali F
Sumatra	M	-	p = 0.458	p = 0.279	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
	F	p = 0.458	-	p = 0.051	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Jawa	M	p = 0.279	p = 0.051	-	p = 0.000	p = 0.000	p = 0.000	p = 0.008	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	-	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Kalimantan	M	p = 0.000	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010	p = 0.000	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-	p = 0.000	p = 0.000
Bali	M	p = 0.000	p = 0.000	p = 0.008	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-

Tukey HSD (Table 12) showed gender differences in Sundaland females in Java and Bali outperformed Sumatra males in scientific literacy (p = 0.000), Kalimantan males led in numeracy (p = 0.000), and Kalimantan females differed from others (p = 0.010) highlighting gender and cultural effects on performance, with ANCOVA controlling for school accreditation detailed in Table 13 (Adjusted Means, F-values, p-values).

Table 12. ANCOVA for Controlling Confounding Variables Based on School Accreditation

Group Comparison	School Accreditation	Gender	SES	Adjusted Mean: Science Literacy	Adjusted Mean: Numeracy	F-value	p-value
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*
Jawa	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*

Group Comparison	School Accreditation	Gender	SES	Adjusted Mean: Science Literacy	Adjusted Mean: Numeracy	F-value	p-value
	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*

ANCOVA shows females lead in scientific literacy at high-SES, top-accredited Java schools (71.40 ± 3.00; $p = 0.000$) and males in numeracy in Sumatra (67.80 ± 3.60; $p = 0.001$), with the gender gap narrowing in medium-SES, "Very Good" schools but persisting in low-SES, "Good" schools in Kalimantan and Bali, while HLM across Sundaland examines gender differences at individual (cognitive ability, mother tongue, regional factors), institutional (accreditation, teaching quality, technology), and regional (bilingual programs, government support, resource access) levels (Table 13).

Table 13. HLM Results by Gender

Level	Variable	Male	Female	p-value
Level 1 (Individual)	Sundaland Region	2.50 ± 0.30	2.80 ± 0.28	0.002*
	Cognitive Ability	3.50 ± 0.28	3.80 ± 0.25	0.000*
	Mother Tongue Background	1.80 ± 0.30	2.10 ± 0.28	0.002*
Level 2 (Institutional)	School Accreditation	4.20 ± 0.40	4.50 ± 0.38	0.000*
	Teaching Quality	3.70 ± 0.35	4.00 ± 0.32	0.001*
	Technology Integration	3.80 ± 0.33	4.20 ± 0.30	0.002*
Level 3 (Regional)	Bilingual Program	3.90 ± 0.50	4.30 ± 0.45	0.000*
	Regional Government Support	3.60 ± 0.48	4.00 ± 0.42	0.001*
	Access to Educational Resources	3.40 ± 0.45	3.80 ± 0.43	0.002*

Table 13 HLM results indicate that females significantly outperform males in Sundaland science literacy and numeracy ($p < 0.05$), with advantages shaped by mother tongue (Level 1), school accreditation, teaching quality, and technology integration (Level 2), as well as bilingual programs, government support, and resource access (Level 3), reinforced by adaptive learning, discipline, and supportive social and educational policies.

Differences in Science Literacy and Numeracy Based on Ethnicity in Sundaland

Table 14 reveals significant ethnic disparities in Sundaland students' science literacy and numeracy. Batak and Javanese lead in science literacy, Acehnese and Betawi in numeracy, while Malay and Sasak rank lowest in both. ANOVA confirms ethnicity's significant effect on science literacy ($F = 38.377$; $p = 0.000$) and numeracy ($F = 32.407$; $p = 0.000$). Results are robust under independent t-tests, ANCOVA, and HLM, controlling for individual, school, and policy factors, highlighting ethnicity as a principal determinant of students' performance.

Table 14. ANOVA Results

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups (Science Literacy)	6758.749	14	482.768	38.377	0.000
Within Groups	31511.714	2505	12.58		
Between Groups (Numeracy)	6628.616	14	473.473	32.407	0.000
Within Groups	36598.464	2505	14.61		

The interaction visualization elucidates ethnic disparities in science and numeracy literacy in Sundaland, revealing groups with extreme performance, regional variations, and the consistency of ethnicity's influence across populations.

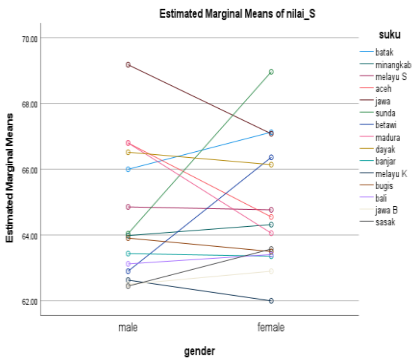

Figure 10. Science Proficiency by Gender and Ethnicity Across Four Regions.

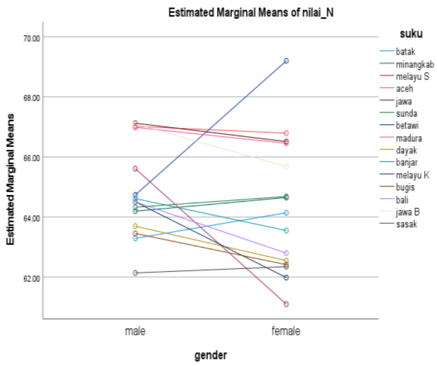

Figure 11. Numeracy Proficiency by Gender and Ethnicity Across Four Regions

Table 15: Batak, Sundanese, Betawi females > males in science literacy; Acehnese, Javanese males > females ($p < 0.05$). In numeracy, only Betawi females > males; others ns ($p > 0.05$).

Table 15. Independent t-test Based on Gender Across Various Ethnic Groups in Sundaland

Etnis	Gender	Science Literacy	t-value	p-value	Numeracy	t-value	p-value
Batak	M	66.00 (2.70)	-2.608	0.010	63.29 (4.19)	-1.407	0.161
	F	67.13 (2.89)			64.14 (3.63)		
Aceh	M	66.80 (2.90)	4.527	0.000	67.02 (3.75)	0.411	0.681
	F	64.55 (3.51)			66.79 (3.40)		
Javanese	M	67.02 (3.75)	4.011	0.000	67.13 (2.90)	1.215	0.226
	F	66.79 (3.40)			66.51 (3.61)		
Sunda	M	64.04 (3.20)	-10.299	0.000	64.33 (4.16)	-0.596	0.552
	F	68.96 (2.99)			64.68 (3.62)		
Betawi	M	62.90 (3.20)	-7.728	0.000	64.74 (3.10)	-9.505	0.000
	F	66.36 (2.57)			69.20 (2.99)		

Tukey HSD (Tabel 15) mengungkap disparitas etnis dan gender di literasi sains dan numerasi Sundaland: Javanese dan Batak unggul di sains (Batak vs. Minangkabau, MD = 2,41, p = 0,000; Javanese vs. Malay S., MD = 3,32, p = 0,000), Dayak dan Javanese di numerasi (Dayak vs. Banjar, MD = 2,93, p = 0,000; Javanese vs. Betawi, MD = 3,50, p = 0,000); gender memengaruhi: perempuan Batak/Javanese di sains, laki-laki Dayak/Javanese di numerasi (Batak F vs. Malay S., MD = 2,70, p = 0,000; Javanese M vs. Sundanese, MD = 1,63, p = 0,003); Malay K. dan Sasak terendah (Dayak vs. Malay K., MD = 4,01, p = 0,000; Javanese vs. Sasak, MD = 5,12, p = 0,000), mencerminkan ketimpangan sosial-ekonomi, pendidikan, dan infrastruktur.

Table 16. Tukey HSD Test for Science and Numeracy Literacy by Ethnicity

Etnis	Gender	Sumatra	Jawa	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)*

Etnis	Gender	Sumatra	Jawa	Kalimantan	Bali
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)

Table 17 (Tukey HSD) shows significant differences in scientific literacy and numeracy among Sundaland ethnic groups ($p < 0.001$), with Javanese and Batak highest, Dayak excelling in numeracy, some groups lagging due to limited education, gender differences present, and Javanese-Balinese outperforming native Balinese in Bali ($p < 0.000$), highlighting the influence of ethnicity, gender, and socio-cultural context and the need for culturally responsive curricula, teacher development, and targeted support.

Table 17. ANCOVA for Scientific Literacy and Numeracy Based on Ethnicity.

Wilayah	Etnis	SES	Bahasa Ibu	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

Wilayah	Etnis	SES	Bahasa Ibu	Science Literacy	Numeracy	F-value	p-value
		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

ANCOVA analysis (Table 18) indicates that scientific literacy and numeracy in Sundaland vary significantly by ethnic group, mediated by mother tongue and socioeconomic status (SES), with high-SES groups Batak in Sumatra (68.50 ± 2.60; 67.40 ± 3.00), Javanese in Java (71.20 ± 2.50; 70.00 ± 2.85), Dayak in Kalimantan (66.90 ± 2.85; 65.80 ± 3.40), and Balinese in Bali (65.40 ± 3.20; 64.50 ± 3.80) scoring highest, while low-SES groups in remote areas (Dayak, Sasak) score lower due to limited educational access, highlighting the need for culturally inclusive policies.

Table 19. HLM for Differences in Scientific Literacy and Numeracy by Ethnicity

Level	Variable	Batak	Minang kabau	Javanese	Dayak	Balinese	p-value
Level 1 (Individual)	Gender	1.60 ± 0.28	1.50 ± 0.30	1.80 ± 0.25	1.40 ± 0.35	1.20 ± 0.40	0.001
	Cognitive Ability	2.90 ± 0.24	2.80 ± 0.26	3.20 ± 0.20	2.70 ± 0.30	2.50 ± 0.28	0.000
	Mother Tongue Background	1.20 ± 0.18	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002
Level 2 (Institutional)	School Accreditation	3.50 ± 0.38	3.40 ± 0.40	3.80 ± 0.35	3.00 ± 0.45	2.80 ± 0.50	0.000
	Teaching Quality	2.70 ± 0.30	2.60 ± 0.35	3.30 ± 0.30	2.60 ± 0.40	2.40 ± 0.38	0.001
	Technology Integration	3.00 ± 0.28	2.90 ± 0.30	3.60 ± 0.28	2.90 ± 0.35	2.60 ± 0.40	0.002
Level 3 (Regional)	Bilingual Program	2.90 ± 0.45	2.80 ± 0.50	3.20 ± 0.45	3.40 ± 0.55	3.10 ± 0.50	0.000
	Regional Government Support	2.80 ± 0.42	2.70 ± 0.48	3.00 ± 0.42	3.20 ± 0.50	2.90 ± 0.45	0.001
	Access to Educational Resources	2.60 ± 0.40	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002

HLM analysis shows Sundaland's scientific literacy and numeracy vary by individual, institutional, and ethnic factors. Javanese scored highest in cognition, language, accreditation, teaching, and technology; Batak and Minangkabau followed, Dayak and Balinese lagged. Dayak excelled in bilingual programs, Javanese in government support. Results stress culture, policy, and institutional roles, highlighting teaching quality, technology, and local language use as keys to bridging ethnic literacy gaps.

Discussion

Science and numeracy literacy in Sundaland (Sumatra, Java, Kalimantan, Bali) is shaped by socioeconomic factors, educational infrastructure, culture, and linguistic diversity. Java, as the educational hub, performs best due to technology, modern labs, and teacher training [14], [42], [43], though urban–rural gaps persist. In Sumatra, Batak and Minangkabau communities benefit from strong learning cultures and community support [44], but remote areas face resource limitations, mitigated by ethnomathematics and local language use [17]. Kalimantan suffers from digital inequality, poor infrastructure, and language barriers [45]. These findings align with prior research on the role of ethnomathematics and project-based learning in improving numeracy and higher-order thinking skills [1],[17], suggesting that locally rooted pedagogical models can be effective in reducing urban-rural disparities.

Gender gaps in literacy reflect cultural and linguistic influences. Urban women excel due to technology and STEM access [46], [43], while rural women face stereotypes and underrepresentation [21], [22]. In Java, women outperform in numeracy but men dominate technical skills [14]. In Sumatra, Batak and Minangkabau women excel in science literacy [44]. Kalimantan women lag due to limited labs and instruction-language mismatch [45]. In Bali, patriarchal norms hinder numeracy, yet women excel in environmental science aligned with Tri Hita Karana [29]. This pattern is consistent with global evidence showing female advantage in literacy and contextual variations in STEM participation [46], [21], while the persistence of patriarchal constraints in Bali highlights a divergence from intervention-based findings in other contexts [22], underscoring the salience of cultural norms in shaping gendered educational outcomes.

Language significantly affects STEM comprehension. In Sumatra, rural students struggle with Bahasa Indonesia despite Batak and Minangkabau literacy cultures [44], [47]. Javanese and Sundanese hierarchies complicate abstract STEM concepts [48]. In Kalimantan, Dayak and Banjar grammatical differences hinder comprehension [28], while Bali's Balinese language aids ecological understanding but clashes with scientific terminology [29]. Solutions include local-language integration, bilingual materials, and teacher training [17], [49]. These findings corroborate previous studies showing that the language of instruction substantially shapes mathematical and scientific reasoning [36], and extend this evidence by illustrating how linguistic hierarchies in Javanese and Sundanese further complicate comprehension of abstract STEM concepts.

Inclusive, context-based policies improve literacy. Bali integrates Hindu values into environmental education [29], Sumatra applies project-based Minangkabau approaches [17], Java uses Sundanese ethnomathematics [1], and Kalimantan collaborates with Dayak communities [28]. The effectiveness of integrating cultural values into STEM pedagogy is in line with theoretical frameworks emphasizing 21st-century competencies and education for sustainable development [6], [16], thereby confirming that culturally responsive approaches can serve as scalable models for inclusive education in diverse societies.

Implications

Findings highlight that literacy disparities are shaped by gender, cognition, school quality, accreditation, technology, bilingual programs, local policies, and resources. Recommendations include culturally responsive, gender-sensitive policies, PBL curricula, digital learning expansion, multilingual education, and ethnomathematics to bridge interethnic gaps and strengthen local identity.

Limitations

Limitations include geographic restriction to Sundaland, cross-sectional design excluding long-term impact, limited qualitative depth on minority students, and unexamined variables like learning styles, community support, and teacher quality.

Suggestions

Future research should: (1) adopt longitudinal designs to track literacy over time; (2) expand to Eastern Indonesia and indigenous communities; (3) integrate mixed-methods for deeper insights; (4) provide teacher training in inclusive pedagogy and local languages; (5) pursue international collaboration with multicultural countries for benchmarking sustainable multilingual education.

4. CONCLUSION

This study finds that scientific literacy and numeracy in Sundaland are shaped by gender, culture, and linguistics. Java performs best due to educational access, Bali lowest due to infrastructure limits. Males excel in numeracy, females in scientific literacy, reflecting social norms. Mother tongue use enhances conceptual understanding, highlighting the need for linguistically inclusive policies. Literacy outcomes depend on individual (gender, cognitive abilities), institutional (school accreditation, teaching quality), and regional (bilingual programs, government support) factors. Batak and Minangkabau excel in strong learning cultures, while Dayak and Banjar face linguistic and social barriers. Addressing these disparities requires policies integrating ethnomathematics, culturally responsive teaching, and school-community-research collaboration. Further studies should evaluate multilingual education and inclusive policy impacts on literacy gaps in Indonesia.

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AUTHOR CONTRIBUTION STATEMENT

DY conceived the research design, led the writing process, and supervised the data analysis. YJ coordinated data collection in the Sundaland region and contributed to the statistical analysis. EAJ was responsible for the development and validation of research instruments and contributed to the literature review. SA conducted fieldwork, managed interviews, and participated in qualitative data interpretation. MRU assisted with model design, data visualization, and technical editing of the manuscript. JM contributed to the ethnographic context analysis and the discussion of regional educational disparities. All authors reviewed and approved the final version of the manuscript.

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Analyzing Cultural Disparities and Gender in Science Literacy and Numeracy Among Senior High School Students in Sundaland, Indonesia

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Science Literacy.

ABSTRACT

Gender and cultural disparities remain pressing challenges in STEM education across Indonesia's multi-ethnic regions, particularly in Sundaland, where variations in school accreditation, infrastructure readiness, and mother-tongue use stratify learning opportunities.. This study examines differences in scientific literacy and numeracy, focusing on the roles of ethnicity, socioeconomic status (SES), and mother-tongue use, while also exploring their interactions with gender and school-level conditions.. A quantitative survey design using Hierarchical Linear Modeling (HLM) was applied to capture both student- and school-level variations. Data were collected through literacy tests, questionnaires, and interviews from a stratified sample categorized by accreditation, gender, and SES. The results show that Javanese students achieved the highest scores, while Balinese students obtained the lowest in both competencies, largely reflecting differences in infrastructure and technological support. Male students outperformed in numeracy, whereas females excelled in scientific literacy. Mother-tongue use enhanced conceptual understanding, particularly among Batak and Minangkabau students with strong learning traditions. These results underscore the need for inclusive, culturally responsive policies to address literacy gaps in multi-ethnic contexts. Ethnomathematics initiatives and multilingual education are recommended to promote equity in learning. Future research should explore the long-term impacts of inclusive policies and community-based programs on student motivation and STEM achievement.

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Analisis Disparitas Kultural dan Gender dalam Literasi Sains dan Numerasi pada Siswa Sekolah Menengah Atas di Sundaland, Indonesia

Kata Kunci:

Kesenjangan Kultural,
Kesenjangan Gender,
Literasi Numerasi,
Literasi Sains
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ABSTRAK

Kesenjangan gender dan budaya tetap menjadi tantangan mendesak dalam pendidikan STEM di berbagai wilayah multi-etnis Indonesia, khususnya di Sundaland, di mana perbedaan akreditasi sekolah, kesiapan infrastruktur, dan penggunaan bahasa ibu membentuk peluang belajar yang terstratifikasi. Penelitian ini menelaah variasi literasi sains dan numerasi dengan menyoroti pengaruh etnisitas, status sosial ekonomi (SES), dan penggunaan bahasa ibu, serta interaksinya dengan gender dan faktor tingkat sekolah. Desain survei kuantitatif dengan pendekatan Hierarchical

Linear Modeling (HLM) digunakan untuk menangkap variasi pada tingkat siswa maupun sekolah. Data dikumpulkan melalui tes literasi, kuesioner, dan wawancara dari sampel terstratifikasi berdasarkan akreditasi, gender, dan SES. Hasil penelitian menunjukkan bahwa siswa Jawa memperoleh skor tertinggi, sedangkan siswa Bali memperoleh skor terendah pada kedua kompetensi, mencerminkan kesenjangan dalam infrastruktur dan dukungan teknologi. Siswa laki-laki lebih unggul dalam numerasi, sementara siswa perempuan lebih unggul dalam literasi sains. Penggunaan bahasa ibu meningkatkan pemahaman konseptual, khususnya pada siswa Batak dan Minangkabau dengan tradisi belajar yang kuat. Temuan ini menegaskan urgensi kebijakan yang inklusif dan responsif secara budaya untuk mengatasi kesenjangan literasi di konteks multi-etnis. Inisiatif etnomatematika dan pendidikan multibahasa direkomendasikan untuk mendorong kesetaraan, sementara penelitian selanjutnya perlu menelaah dampak jangka panjang kebijakan tersebut dan program berbasis komunitas terhadap motivasi belajar serta capaian STEM siswa.

Contribution to the literature

- Intersectional focus: Analyzes how gender, ethnicity, and language shape disparities in science and numeracy literacy among high school students in Sundaland, Indonesia.
- Methodological contribution: Applies a multi-level quantitative framework (HLM, ANCOVA) combined with qualitative insights to examine educational inequalities.
- Assessment design: Uses bilingual instruments adapted from PISA, TIMSS, and UNESCO, highlighting the role of mother-tongue instruction in strengthening conceptual understanding.
- Policy relevance: Provides context-specific recommendations for inclusive education, grounded in sociocultural theory, equity principles, and multilingual pedagogy.

1. INTRODUCTION

The progress of a nation is strongly determined by the quality of its human resources, which must be educated, competitive, and adaptive to global change. These attributes are reflected in the ability to foster critical thinking, collaboration, and innovation through education. International organizations consistently emphasize this link. UNESCO (2021) and the OECD (2019) highlight that nations investing in education and 21st-century skills achieve higher levels of social resilience and economic growth. The World Bank's Human Capital Index (2020) shows that educational quality directly predicts long-term national competitiveness. Literacy underpins critical thinking, problem-solving, and creativity in the digital era (Iswara et al., 2022). In the context of the Fourth Industrial Revolution and Society 5.0, education must equip learners with adaptive skills (Anwar, 2021). Twenty-first-century literacy encompasses six dimensions: reading and writing, numeracy, science, finance, digital, and cultural–civic (Konopko, 2015), fostering information processing, problem-solving, technology use, and social engagement. Complementing these, the 4C skills Critical Thinking, Communication, Collaboration, and Creativity are widely recognized as central to addressing global challenges (Yulianto et al., 2024), enhancing both academic achievement and workforce readiness. However, in the Indonesian context, the integration of scientific and numerical literacy within this 21st-century and 4C framework remains limited (Kain et al., 2024), as global benchmarks often remain

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aspirational rather than operational. The critical challenge lies in translating these competencies into equitable classroom practices, particularly in regions marked by socio-economic and cultural disparities. Thus, rather than adopting global frameworks wholesale, Indonesia must localize these competencies by aligning them with linguistic diversity, resource availability, and community-based values to ensure relevance and sustainability.

Previous research has highlighted the role of experiment-based learning in strengthening evidence-based analysis (Oliveira & Bonito, 2023; Wörner et al., 2022) and fostering collaboration in data-driven problem-solving (Mende et al., 2020; Peffer & Renken, 2017). In this regard, scientific literacy is associated with hypothesis evaluation and evidence-based decision-making (Dawson et al., 2024; Osborne & Allchin, 2024), while numerical literacy contributes to data-driven teamwork and statistical interpretation (Schreiter et al., 2024; Sutherland et al., 2022). Together, these literacies enhance critical thinking, creativity, and problem-solving in education (Yulianto et al., 2024). In the Indonesian context, however, the integration of these two domains is still fragmented, often limited by traditional teaching practices and unequal access to inquiry-based learning. Addressing this gap is central to our study, which situates scientific and numerical literacy within the multicultural and gender-diverse settings of Sundaland to evaluate how these skills can be fostered more inclusively. Specifically, we investigate how science and numeracy literacy are associated with students' 4C skills (critical thinking, collaboration, communication, creativity) and the role of bilingual and culturally adapted instruction in mediating these outcomes across different ethnic and regional contexts.

Countries excelling in PISA, such as Singapore and Finland, integrate scientific literacy and numeracy with 4Cs through inquiry- and project-based learning (Yulianto et al., 2024). Indonesia, by contrast, struggles due to rote teaching methods, limited exploration, and insufficient discussion (Ismawati et al., 2023). This highlights the discrepancy between the ideal integration of literacy and 4C competencies and the current fragmented implementation, which is influenced by disparities in teacher preparedness, gender norms, regional resources, and ethnic-linguistic diversity. Seventy percent of teachers face challenges implementing higher-order thinking skills (HOTS) (Yulianto et al., 2024), while rural schools have 50% less technological access (Kemendikbudristek, 2023). The 2013 Curriculum, which adopts 4Cs, is constrained by unequal access, weak teacher training, and pedagogical disparities (Yulianto et al., 2024). The Merdeka Curriculum seeks to address these gaps by emphasizing competency-based learning, flexibility, and character development through the Pancasila Student Profile (Hamudy & Rifki, 2024). Nonetheless, challenges persist in teacher readiness, project-based pedagogy, and digital infrastructure, particularly in rural schools. This indicates that systemic reforms have not yet translated into equitable classroom practices, highlighting the urgency of examining how cultural and gender disparities interact with curricular implementation to shape science literacy and numeracy outcomes.

Indonesia's literacy challenges are underscored by its PISA 2022 average mathematics score of approximately 372 and science score of 396, reflecting modest gains but still substantially below top-performing nations. In contrast, Singapore's PISA 2022 scores (~587 in mathematics, ~576 in science, ~565 in reading) illustrate the results of integrating digital platforms, problem-solving curricula, and sustained teacher professional development. Malaysia and Thailand also show incremental improvements in PISA 2022, but their scores remain significantly lower than those of leading education systems, pointing to ongoing disparities in access, pedagogy, and infrastructure (OECD, 2023). Educational reform is needed to strengthen pedagogy via project-based learning, expand

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digital access, and enhance teacher training programs (Ismawati et al., 2023). Finland and Singapore demonstrate success through inquiry- and problem-based approaches (Stehle & Peters-Burton, 2019), while limited exploratory learning and resources in Indonesia exacerbate the literacy gap (Lidinillah et al., 2022). These contrasts underscore that Indonesia's current strategies, while reform-oriented, remain insufficiently transformative; without addressing structural inequities and fostering inquiry-driven pedagogy, the literacy gap will persist and continue to hinder students' competitiveness in the global knowledge economy.

Gender disparities persist, with males generally excelling in numeracy and females in reading comprehension, shaped by cultural norms and stereotypes (Borgonovi & Greiff, 2020). Gender Schema Theory (Barone & Assirelli, 2020) illustrates how socio-cultural expectations form cognitive filters that steer students toward or away from particular domains, while Expectancy-Value Theory (Verdugo-Castro et al., 2022) explains how motivation and self-perception of competence drive their academic engagement. Together, these perspectives reveal that gender differences are not biologically inevitable but socially and psychologically constructed, meaning they can be mitigated through well-designed pedagogy. Cross-national evidence shows that these gaps may paradoxically appear larger in high-equality societies (Balducci, 2023), suggesting that cultural framing and personal choice interact in complex ways. While prior studies point to the effectiveness of gender-responsive strategies such as discussion-based methods for enhancing girls' reading literacy and problem-solving approaches for strengthening boys' numeracy (Driscoll et al., 2024), international experiences from Sweden and Finland show the importance of sustained mentorship and inclusive reform (Prieto-Rodriguez et al., 2020). In the Indonesian context, this implies that reducing gender gaps in science literacy and numeracy requires more than curriculum change: it calls for teacher capacity-building, culturally sensitive pedagogy, and structured mentorship to challenge stereotypes and support both boys and girls equitably. Beyond gender, literacy and numeracy outcomes in Indonesia are further shaped by the nation's rich cultural and linguistic diversity, which introduces additional layers of complexity in educational equity.

Sundaland (Sumatra, Java, Kalimantan, Bali) illustrates how cultural and linguistic diversity shapes literacy (Hanebuth & Stattegger, 2003). Local languages, traditions, and socio-economic contexts influence learning practices. While the Interdependence Hypothesis emphasizes that strong mother-tongue skills foster second-language literacy (Lachmann & Bergström, 2023), Indonesia's monolingual policies and the growing dominance of English undermine local languages (Walker et al., 2019). Community-based bilingual education could help address these challenges, as demonstrated by the Basque Country model. Educational practices vary across regions, ranging from rote Islamic-based learning in Aceh and Minangkabau (Basri, 2015), constructivist approaches in Java, Contextual Teaching and Learning (CTL) in Kalimantan (Hamudy & Rifki, 2024), to culturally responsive teaching in Bali (Suardana et al., 2023). Literacy disparities are further compounded by socio-economic inequalities, as rural areas often lack facilities and qualified teachers (Sartono et al., 2024). Programs such as *Sekolah Garis Depan* have improved attendance but still face challenges in maintaining educational quality (Hamudy & Rifki, 2024). Taken together, these conditions suggest that Sundaland's educational landscape is not only fragmented but also shaped by an intersection of cultural traditions, linguistic backgrounds, and socio-economic resources. Thus, analyzing science literacy and numeracy in this region requires attention to how cultural values and resource distribution reinforce or constrain learning opportunities.

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Ethnic groups further shape literacy: Javanese emphasize hierarchical learning (Al Ghiffari et al., 2023), Sundanese favor interactive discussions (Asmahasanah et al., 2022), and Batak prioritize logic and analysis (Alfurqan, 2020), and the Minangkabau integrate religious education (Alfurqan, 2020). Linguistic diversity complicates the transition from mother tongue to Indonesian (Daly et al., 2023; Bermejo et al., 2021). While previous studies in Indonesia have investigated general literacy and 4C skills (Lesperance, R., & Kuhn, 2023), gender disparities in reading and numeracy (He, 2019), and the impact of curricular reforms such as the 2013 Curriculum and Merdeka Curriculum on student competencies (Lesperance, R., & Kuhn, 2023), research on scientific and numerical literacy within multicultural contexts remains scarce. Most existing works adopt single-level analyses or focus narrowly on cognitive outcomes, neglecting how socio-cultural factors such as ethnicity, language, and school accreditation intersect with student achievement (He, 2019). Moreover, while a few international comparative studies highlight the influence of bilingual education and translanguaging on STEM learning (Grapin et al., 2025), Indonesian evidence remains limited and largely descriptive (Lesperance & Kuhn, 2023). To date, no studies have systematically combined multi-level quantitative approaches (e.g., HLM, ANCOVA) with bilingual and culturally adapted assessments to model disparities in scientific and numerical literacy across regions, genders, and ethnic groups in Sundaland (Lesperance & Kuhn, 2023; Beaton et al., 2000). Thus, there remains a critical need to examine how socio-cultural and institutional factors intersect with region, ethnicity, and gender to shape both scientific and numeracy literacy, alongside the development of 4C competencies, within a localized Indonesian context. This research seeks to fill that gap by explicitly situating literacy outcomes within Indonesia's socio-cultural diversity, thereby extending both national and global discussions on equity in STEM education. Therefore, this study seeks to fill this gap by analyzing disparities in Sundaland based on region, gender, ethnicity, and socio-cultural factors.

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Despite growing interest in multilingual and culturally responsive education, significant empirical gaps remain. Most Indonesian studies on literacy and numeracy remain descriptive, relying on single-level analyses without integrating student-, school-, and community-level factors (He, 2019; Sartono et al., 2024). International research demonstrates the importance of multi-level approaches such as HLM or ANCOVA (Blömeke et al., 2022; Kyriakides & Creemers, 2013), yet their application in Indonesia is still rare. Globally, multi-level analyses have provided nuanced insights into how student outcomes are shaped not only by individual characteristics but also by school and community contexts, emphasizing the importance of context-sensitive educational interventions. Similarly, bilingual and culturally adapted assessments critical for STEM learning in linguistically diverse settings are underdeveloped (Grapin et al., 2025; Lesperance & Kuhn, 2023). Moreover, studies in Indonesia often overlook the interplay between mother tongue, ethnicity, and school accreditation in shaping science literacy and numeracy (Ismawati et al., 2023; Suardana et al., 2023). This lack limits educators' ability to accurately assess students' competencies and hinders the development of inclusive and effective STEM teaching strategies in multilingual Indonesian classrooms. Therefore, this study is novel in systematically combining multi-level quantitative methods (HLM, ANCOVA) with qualitative approaches and bilingual, culturally adapted assessments, an approach not previously applied in Indonesia. The purpose of this research is to model disparities across regions, genders, and ethnic groups in Sundaland's high school students, and to identify institutional and socio-cultural factors influencing scientific literacy and numeracy outcomes. By integrating multi-level quantitative and qualitative methods with culturally responsive assessments, this study provides both theoretical insights into the interaction of socio-cultural and institutional factors on literacy and numeracy, and practical guidance for designing inclusive educational policies and interventions in linguistically diverse settings.

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2. METHOD

Research Design

This study employs a cross-sectional comparative survey design, which systematically examines disparities in scientific literacy and numeracy across gender, cultural, ethnic, socioeconomic, and linguistic groups. This design allows for simultaneous comparison across multiple demographic and socio-cultural groups, providing a snapshot of existing disparities while accounting for nested influences such as school, community, and regional characteristics. It is particularly suitable for capturing complex interactions among gender, culture, ethnicity, socioeconomic status, and linguistic diversity, which are central to understanding literacy inequalities in Sundaland. By adopting this quantitative approach, the research underscores the urgency of formulating inclusive education policies to address the structural inequities observed in Sundaland (Sumatra, Java, Kalimantan, Bali), a region characterized by high cultural, ethnic, and linguistic diversity. It analyzes literacy disparities linked to gender, culture, ethnicity, socioeconomic status, and linguistic diversity. Gender shapes learning approaches; culture and ethnicity influence educational values; socioeconomic status determines resource access; and linguistic diversity can facilitate or hinder literacy depending on mother-tongue instruction. Using a cross-sectional comparative design, the study maps these disparities empirically, offering a comprehensive view of factors driving literacy inequality (Figure 1).

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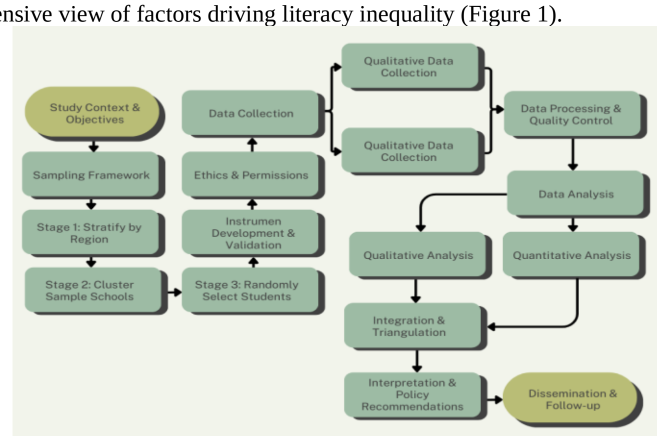

Figure 1. Research flowchart

As illustrated in Figure 1, the research flowchart demonstrates the sequential and interconnected nature of the methodological stages. The process begins with defining the study context and objectives, which informs the sampling framework. Interference occurs as the stratification by region (Stage 1) directly guides the clustering of schools (Stage 2), which in turn determines the pool for the random selection of student participants (Stage 3). Following sampling, the instrument development and validation phase ensures measurement reliability before data collection. Ethical clearance and permissions provide legitimacy and adherence to research ethics, creating a necessary precondition that interferes with and supports the integrity of subsequent steps. The flowchart further distinguishes qualitative and quantitative data collection, which interact during the integration and triangulation stage, ensuring that both strands inform one another. Finally, data analysis, both qualitative and quantitative, feeds into interpretation and policy recommendations, while the dissemination and follow-up stage closes the loop by linking findings back to the educational and policy context. Thus, the flowchart does not merely serve as a schematic but explicitly demonstrates how each step interferes with and conditions the next, ensuring methodological coherence and transparency.

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Population and Research Sample

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According to the most recent data from the Ministry of Education's Pusdatin [14] and the Central Bureau of Statistics [38], Indonesia has 4.853.305 senior high school students, of which nearly three-fifths are concentrated in Java (58.5%), followed by Sumatra (23%), Kalimantan (10%), and Bali (4.5%). Urban students (2,976,661) outnumber rural students (1.876.644), yet the rural proportion remains substantial, particularly in Sumatra and Kalimantan. Gender distribution across regions is remarkably balanced (2.332.657 males vs. 2.320.648 females), showing that disparities in literacy and numeracy are not rooted in demographic imbalance but rather contextual differences in geography and schooling. These distributions are summarized in Table 1.

Table 1. High School Student Population by Geographic Region and Gender

Region	Regional Proportion	Total Population	Urban Population	Rural Population	Male	Female
Java	58.5%	2,840,721	2,045,319	795,402	1,422,161	1,418,560
Sumatra	23%	1,117,249	581,674	535,575	561,812	555,437
Kalimantan	10%	484,191	208,201	275,990	242,895	241,296
Bali	4.5%	211,144	141,467	69,677	105,789	105,355
Total Sundaland	100%	4,853,305	2,976,661	1,876,644	2,332,657	2,320,648

When disaggregated by school accreditation, a sharp contrast emerges between urban and rural contexts. Urban schools dominate the "Excellent" and "Very Good" categories, especially in Java (over 1.7 million students combined), while rural areas show a higher concentration in the "Good" category. This imbalance suggests that institutional quality and geography intersect strongly, creating layered disparities in learning opportunities. Details are presented in Table 2.

Table 2. Student Population by School Accreditation

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	58,5%	955.847	785.326	304.146	312.879	256.138	226.385
Sumatra	23%	287.423	195.952	98.299	205.612	182.415	147.548
Kalimantan	10%	90.612	76.785	40.804	97.336	105.421	73.233
Bali	4,5%	75.248	45.398	20.821	30.489	25.366	13.822
Total Sundaland	100%	1.409.130	1.103.461	464.070	646.316	569.340	461.988

Based on this population frame, a multistage random sampling strategy was implemented. First, regions were stratified to maintain proportional representation. Second, schools were selected via cluster random sampling. Finally, within each school, students were chosen by simple random sampling. A total of 2.250 students were sampled, mirroring the population's proportionality by region, gender, and urban–rural context. Table 3 provides this distribution.

Table 3. Sample Data of Students Based on Geographic Region and Gender

Region	Regional Proportion	High School Student Sample	Geographical Sample Urban	Geographical Sample Rural	Gender M	Gender F
Jawa	58.5%	1.317	948	369	659	658
Sumatra	23%	518	269	249	260	258
Kalimantan	10%	225	97	128	113	112
Bali	4.5%	101	68	33	51	50
Total Sundaland	100%	2.250	1.382	779	1.083	1.067

Further disaggregation by school accreditation within the sample reveals the same structural disparities noted at the population level. Students in urban Java schools are overrepresented in "Excellent" accreditation, while rural students, particularly in Sumatra and Kalimantan, are more likely to come from "Good" schools. Table 4 outlines this breakdown.

Table 4. Sample Data Based on School Accreditation

Region	High School Student Sample	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	1.317	464	382	156	154	125	36
Sumatra	518	184	135	68	93	78	50
Kalimantan	225	61	52	35	48	54	26
Bali	101	34	22	14	16	12	3
Total Sundaland	2.250	743	591	273	311	269	115

To ensure cultural representativeness, ethnic groups were sampled proportionally within regions. For instance, the Javanese (70%) and Sundanese (20%) dominate the Java sample, while Batak and Minangkabau are predominant in Sumatra, and Dayak and Banjar in Kalimantan. Bali shows a high concentration of Balinese (85%), reflecting its relatively homogenous demographic profile. This ensures that both major and minority ethnic groups are adequately represented in the study (see Table 5).

Table 5. 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%), Acehnese & Lampung (10%)	Batak: 207, Minangkabau: 181, Malay: 78, Acehnese & 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	

Test Instrument

This study developed a scientific and numerical literacy instrument for Indonesia based on PISA, TIMSS, and UNESCO frameworks (60% adapted, 40% newly developed), e.g., numeracy on regional energy use and science on climate impacts, presented bilingually. Items followed a PISA-based rubric (low, medium, high) with 40% multiple-choice, 35% short-answer, and 25% case studies. Content validity (UPI experts) was Aiken's V = 0.87; construct validity (CFA, AMOS) $\chi^2/df = 2.85$, CFI = 0.93, RMSEA = 0.047, SRMR = 0.035; reliability high: MC ($\alpha = 0.84$, $\omega = 0.86$), SA ($\alpha = 0.81$, $\omega = 0.83$), CS ($\alpha = 0.89$, $\omega = 0.91$), overall ($\alpha = 0.85$, $\omega = 0.87$); inter-rater: Cohen's Kappa = 0.78, ICC = 0.82. Participants were prospective teachers from La Tansa Mashiro University and Universitas Terbuka. Data included national reports, BPS, Kemendikbudristek, and questionnaires assessing six literacy aspects [9], and 14-question semi-structured interviews validating quantitative findings and socio-cultural literacy influences.

Data Analysis

This study examines gender and cultural disparities in scientific and numerical literacy across regions, ethnicities, socioeconomic status, and language. Normality (Kolmogorov-Smirnov/Shapiro-Wilk) and homogeneity (Levene) are tested. Analyses include ANOVA/Kruskal-Wallis, Two-Way ANOVA, ANCOVA, multiple regression (VIF), and Hierarchical Linear Modeling. Thematic analysis with triangulation validates patterns. Results are presented via SPSS, HLM, R, or Python.

3. RESULTS AND DISCUSSION

Table 5 presents the descriptive statistics of science and numeracy literacy across regions, ethnicities, and genders among 2,520 students from Sumatra, Java, Kalimantan, and Bali. The values are reported as mean ± standard deviation ($\bar{X}$ ± SD), allowing for comparison between male and female students within and across cultural groups.

Table 5. Descriptive Statistics of Science and Numeracy Literacy

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

The results of Table 5 show that disparities in science and numeracy literacy are evident across both cultural and gender lines. For instance, Javanese students in Java scored highest in science literacy (69.18 ± 2.98 for males and 67.08 ± 3.76 for females), whereas Sasak students in Bali obtained comparatively lower scores (62.45 ± 3.16 for males and 63.57 ± 3.55 for females). Gender gaps also varied by ethnicity: Betawi females (66.36 ± 2.57) outperformed their male peers (62.90 ± 3.20) in science literacy, while Acehnese males (66.80 ± 2.90) exceeded females (64.55 ± 3.51). In numeracy, Betawi females (69.20 ± 2.99) notably surpassed males (64.74 ± 3.10), while Malay females in Sumatra lagged behind males. These variations suggest that both cultural background and gender intersect to shape students' performance, justifying the use of Two-Way ANOVA to statistically confirm these disparities.

Kolmogorov–Smirnov and Levene's tests were applied to validate the assumptions of normality and homogeneity across regions, ethnicities, and genders. Most groups met normality assumptions ($p > 0.05$). For groups with significant deviations, the Kruskal–Wallis test was used as an alternative to Two-Way ANOVA. Levene's Test confirmed

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homogeneity of variance (p = 0.391 for science literacy; p = 0.446 for numeracy), permitting the use of Two-Way ANOVA to examine performance differences by region, ethnicity, and gender.

Science and Numeracy Literacy in Sundaland (Sumatra, Java, Kalimantan, Bali)

Science and numeracy literacy in Sundaland (Sumatra, Java, Kalimantan, and Bali) showed clear regional disparities, with the highest proficiency observed in Java and the lowest in Bali. Two-Way ANOVA was used to examine the effects of region and gender, while ANCOVA controlled for linguistic and socio-economic factors, and HLM assessed individual, school, and regional effects. Table 6 shows the statistical calculation results for science literacy, numeracy, and gender differences across the four Sundaland regions. The table reports the sum of squares, degrees of freedom (df), mean square, F-values, and p-values derived from the Two-Way ANOVA.

Table 6. Statistical Calculation Results

Variable	Sum of Squares	df	Mean Square	F-Value	p-Value
Science Literacy	3562.51	3	1187.50	86.08	0.000
Numeracy	3022.58	3	1007.53	63.05	0.000
Male	1750.15	3	583.38	38.42	0.000
Female	4872.81	3	1624.27	111.55	0.000

The results of Table 6 indicate significant regional and gender disparities in science and numeracy literacy. Regional differences in scientific literacy (F = 86.083, p = 0.000) and numeracy (F = 63.051, p = 0.000) were pronounced, with Java achieving the highest mean scores and Bali the lowest. Gender effects were also statistically significant, as female students demonstrated greater variability (F = 111.545, p = 0.000) compared to male students (F = 38.415, p = 0.000). These results suggest that female students' performance is more sensitive to regional influences than their male counterparts, a trend confirmed by the ANOVA interaction plots. Figures 3–7 further illustrate these disparities across gender and region, highlighting the consistency of the statistical results with visual patterns of performance differences.

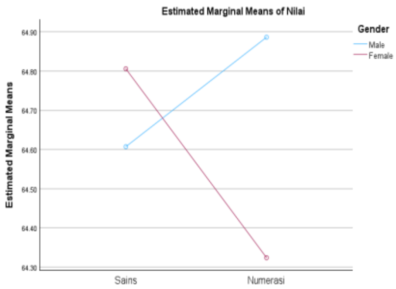

Figure 3. Science and Numeracy Proficiency by Gender Across Four Regions.

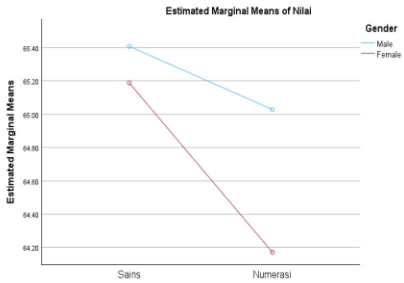

Figure 4. Science and Numeracy Proficiency by Gender in Sumatra.

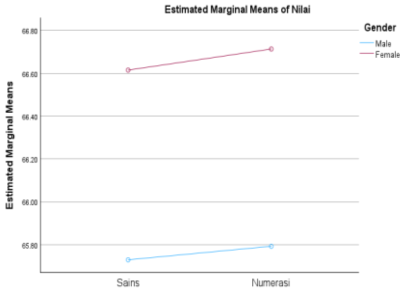

Figure 5. Science and Numeracy Proficiency by Gender in Java

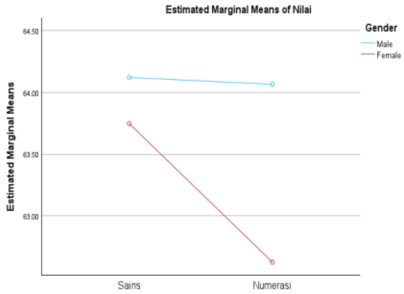

Figure 6. Science and Numeracy Proficiency by Gender in Kalimantan

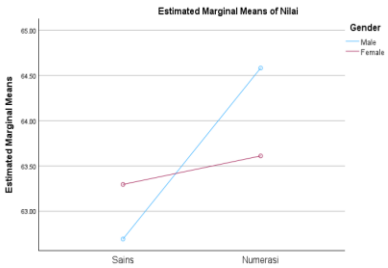

Figure 7. Science and Numeracy Proficiency by Gender in Bali

Table 7 shows the Post-Hoc Tukey Test results after controlling for SES, school accreditation, and access. The table demonstrates significant regional differences in science literacy and numeracy among Sundaland students.

Table 7. Post-Hoc Tukey Test (Identification of Sources of Differences)

Wilayah	Java	Sumatra	Kalimantan	Bali
Java	-	p = 0.002	p = 0.000	p = 0.000
Sumatra	p = 0.002	-	p = 0.015	p = 0.000
Kalimantan	p = 0.000	p = 0.015	-	p = 0.010
Bali	p = 0.000	p = 0.000	p = 0.010	-

The results of Table 7 show that Java significantly outperformed Sumatra (p = 0.002), Kalimantan (p = 0.000), and Bali (p = 0.000). Sumatra also differed significantly from Kalimantan (p = 0.015) and Bali (p = 0.000), while Kalimantan differed from Bali (p = 0.010). These findings indicate that geography plays a decisive role in shaping students' literacy outcomes. Table 8 shows the adjusted means of science literacy and numeracy scores by region after controlling for school accreditation, SES, and mother tongue.

Table 8. ANCOVA for Controlling Confounding Variables

Region	School Accreditation	SES	Mother Tongue	Adjusted Mean		F-value	p-value
				Science	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*

Region	School Accreditation	SES	Mother Tongue	Adjusted Mean		F-value	p-value
				Science	Numeracy		
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*

The results of Table 8 show that Java consistently scored the highest (71.20 ± 2.50 for science literacy; 70.00 ± 2.85 for numeracy), followed by Sumatra, Kalimantan, and Bali. These findings suggest that higher school accreditation, socioeconomic status, and the use of Javanese as a mother tongue strongly support student performance, whereas Balinese students scored the lowest despite similar accreditation levels. Table 9 shows the results of the HLM analysis, examining the influence of individual, institutional, and regional factors on science literacy and numeracy across Sundaland.

Table 9. HLM Results by Region

Level	Variabel	Sumatra	Java	Kalimantan	Bali	p-value
Level 1 (Individual)	Gender	1.50 ± 0.30	1.80 ± 0.25	1.20 ± 0.35	1.00 ± 0.40	0.001*
	Cognitive Ability	2.80 ± 0.25	3.10 ± 0.20	2.50 ± 0.30	2.30 ± 0.28	0.000*
	Mother Tongue	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002*
Level 2 (Institution)	Accreditation	3.40 ± 0.40	3.80 ± 0.35	2.90 ± 0.45	2.70 ± 0.50	0.000*
	Teaching Quality	2.60 ± 0.35	3.20 ± 0.30	2.50 ± 0.40	2.30 ± 0.38	0.001*
	Technology Integration	2.90 ± 0.30	3.50 ± 0.28	2.80 ± 0.35	2.50 ± 0.40	0.002*
Level 3 (Region)	Bilingual Program	2.80 ± 0.50	3.10 ± 0.45	3.40 ± 0.55	3.20 ± 0.50	0.000*
	Government Support	2.70 ± 0.48	3.00 ± 0.42	3.10 ± 0.50	2.90 ± 0.45	0.001*
	Access to Educational Resources	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002*

The results of Table 9 show that at the individual level, gender significantly influenced numeracy (p = 0.001), with the highest performance in Java (1.80 ± 0.25) and the lowest in Bali (1.00 ± 0.40). At the institutional level, school accreditation and teaching quality were the most decisive factors in Java, while technology integration also contributed significantly. At the regional level, bilingual programs in Kalimantan (3.40 ± 0.55; p = 0.000) had the strongest effect, supported by government policies and access to resources. Collectively, these results confirm that literacy outcomes are shaped by multi-level factors rather than a single determinant.

Gender Differences in Science and Numeracy Literacy in the Sundaland Region.

Table 9 presents the independent t-test results comparing male and female students' performance in science literacy and numeracy across Sundaland.

Table 9. Results of the Independent t-test

Variable	Males	Females	t-value	p-value
Science Literacy	64.61 (SD = 3.97)	64.81 (SD = 3.83)	-1.28	0.201
Numeracy	64.89 (SD = 3.99)	64.32 (SD = 4.27)	3.42	0.001

The results of Table 9 indicate no significant gender differences in science literacy (M = 64.61, SD = 3.97 for males; M = 64.81, SD = 3.83 for females; t = -1.28, p = 0.201). However, significant differences were found in numeracy, where males outperformed females (M = 64.89, SD = 3.99 vs. M = 64.32, SD = 4.27; t = 3.42, p = 0.001). Table 10 reports the Two-Way ANOVA results, examining the effects of region, gender, and their interactions on science literacy and numeracy.

Table 10. Two-Way ANOVA Results

Source of Variation	Science Literacy	Numeracy

Region	F = 86.47; p = 0,000	F = 64.12; p = 0,000
Gender	F = 2.27; p = 0,002	F = 13.66; p = 0,000
Region * Gender	F = 4.48; p = 0,004	F = 11.36; p = 0,000

The results of Table 10 reveal that region significantly influences both science literacy ($F = 86.47$, $p < 0.001$) and numeracy ($F = 64.12$, $p < 0.001$). Gender shows a stronger effect on numeracy ($F = 13.66$, $p < 0.001$) than on science literacy ($F = 2.27$, $p = 0.002$). Significant region × gender interactions further indicate that gender effects vary across regions for both domains. To examine gender and regional effects on scientific literacy and numeracy, interaction graphs visualize score differences between males and females across regions (see Tables 8 – 9).

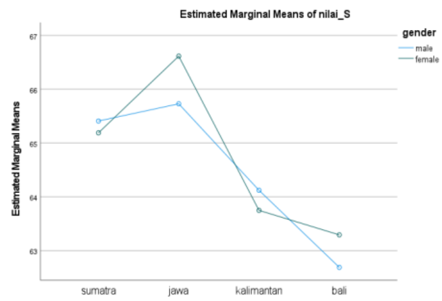

Figure 8. Science Proficiency by Gender

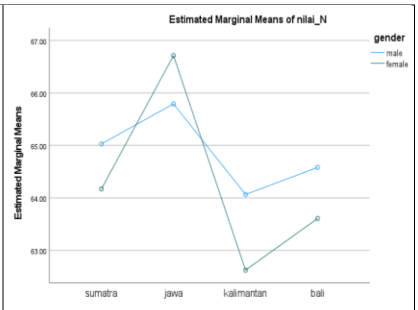

Figure 9. Numeracy Proficiency by Gender

Table 11 provides the Tukey HSD Post-Hoc results identifying the sources of gender and regional disparities.

Table 11. Tukey HSD Post-Hoc Test (Identifying Sources of Gender Differences)

Group Comparison	Gender	Sumatra		Jawa		Kalimantan		Bali	
		M	F	M	F	M	F	M	F
Sumatra	M	-	p = 0.458	p = 0.279	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
	F	p = 0.458	-	p = 0.051	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Jawa	M	p = 0.279	p = 0.051	-	p = 0.000	p = 0.000	p = 0.000	p = 0.008	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	-	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Kalimantan	M	p = 0.000	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010	p = 0.000	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-	p = 0.000	p = 0.000
Bali	M	p = 0.000	p = 0.000	p = 0.008	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-

The results of Table 11 demonstrate that females outperform males in science literacy in Java and Bali ($p < 0.001$), whereas males show higher numeracy in Kalimantan ($p < 0.001$). These disparities highlight the interplay of cultural and regional contexts in shaping performance outcomes. Table 12 summarizes the ANCOVA results controlling for school accreditation and socioeconomic status across Sundaland regions.

Table 12. ANCOVA for Controlling Confounding Variables Based on School Accreditation

Group Comparison	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*
Jawa	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*

The results of Table 12 reveal that females in high-SES, top-accredited schools in Java significantly outperform their male peers in science literacy (Adjusted Mean = 71.40, $p < 0.001$), while males in Sumatra dominate numeracy scores (Adjusted Mean = 67.80, $p = 0.001$). The gender gap narrows in medium-SES, "Very Good" schools, but persists in low-SES, "Good" schools in Kalimantan and Bali. Table 13 displays the multilevel model (HLM) results, examining gender disparities across individual, institutional, and regional levels.

Table 13. HLM Results by Gender

Level	Variable	Male	Female	p-value
Level 1 (Individual)	Sundaland Region	2.50 ± 0.30	2.80 ± 0.28	0.002*
	Cognitive Ability	3.50 ± 0.28	3.80 ± 0.25	0.000*
	Mother Tongue Background	1.80 ± 0.30	2.10 ± 0.28	0.002*
Level 2 (Institutional)	School Accreditation	4.20 ± 0.40	4.50 ± 0.38	0.000*
	Teaching Quality	3.70 ± 0.35	4.00 ± 0.32	0.001*
	Technology Integration	3.80 ± 0.33	4.20 ± 0.30	0.002*
Level 3 (Regional)	Bilingual Program	3.90 ± 0.50	4.30 ± 0.45	0.000*
	Regional Government Support	3.60 ± 0.48	4.00 ± 0.42	0.001*
	Access to Educational Resources	3.40 ± 0.45	3.80 ± 0.43	0.002*

The results of Table 13 show that females significantly outperform males in science literacy and numeracy ($p < 0.05$) with advantages shaped by mother tongue (Level 1), school accreditation, teaching quality, and technology integration (Level 2), as well as bilingual programs, government support, and resource access (Level 3), reinforced by adaptive learning, discipline, and supportive social and educational policies. These advantages are shaped by individual factors such as cognitive ability and mother tongue, institutional factors such as school accreditation, teaching quality, and technology integration, as well as regional factors including bilingual programs, government support, and access to resources.

Differences in Science Literacy and Numeracy Based on Ethnicity in Sundaland

Differences in Science Literacy and Numeracy Based on Ethnicity in Sundaland. Table 14 shows the ANOVA results comparing science literacy and numeracy scores across ethnic groups in Sundaland. The findings indicate significant ethnic disparities, with Batak and Javanese students leading in science literacy, Acehnese and Betawi students excelling in numeracy, while Malay and Sasak students rank lowest in both domains.

Table 14. ANOVA Results

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups (Science Literacy)	6758.75	14	482.77	38.38	0.000
Within Groups	31511.71	2505	12.58		
Between Groups (Numeracy)	6628.62	14	473.47	32.41	0.000
Within Groups	36598.46	2505	14.61		

The results of Table 14 confirm that ethnicity has a statistically significant effect on both science literacy (F = 38.38, p = 0.000) and numeracy (F = 32.41, p = 0.000). These effects remain robust under independent t-tests, ANCOVA, and HLM models, even after controlling for individual, school, and policy factors, underscoring ethnicity as a principal determinant of students' performance. The interaction visualization elucidates ethnic disparities in science and numeracy literacy in Sundaland, revealing groups with extreme performance, regional variations, and the consistency of ethnicity's influence across populations (see Tables 10 – 11).

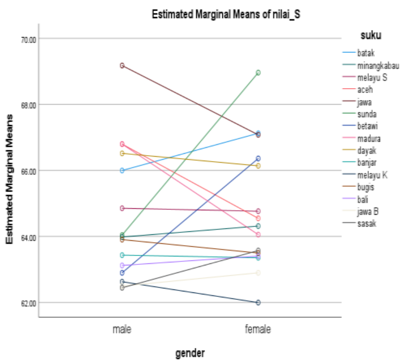

Figure 10. Science Proficiency by Gender and Ethnicity Across Four Regions.

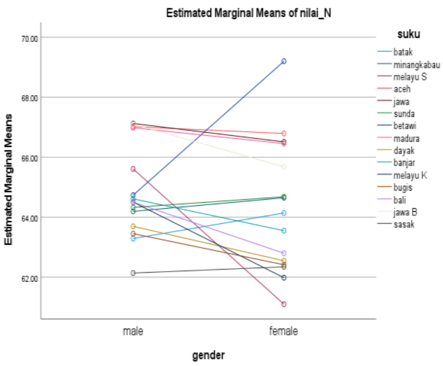

Figure 11. Numeracy Proficiency by Gender and Ethnicity Across Four Regions

Table 15 presents the independent t-test results by gender across various ethnic groups in Sundaland. The data reveal gendered patterns: Batak, Sundanese, and Betawi females outperform males in science literacy, while Acehnese and Javanese males exceed females. In numeracy, only Betawi females significantly outperform males, with no significant differences in other ethnic groups.

Table 15. Independent t-test Based on Gender Across Various Ethnic Groups in Sundaland

Etnis	Gender	Science Literacy	t-value	p-value	Numeracy	t-value	p-value
Batak	M	66.00 (2.70)	-2.608	0.010	63.29 (4.19)	-1.407	0.161
	F	67.13 (2.89)			64.14 (3.63)		
Aceh	M	66.80 (2.90)	4.527	0.000	67.02 (3.75)	0.411	0.681
	F	64.55 (3.51)			66.79 (3.40)		
Javanese	M	67.02 (3.75)	4.011	0.000	67.13 (2.90)	1.215	0.226
	F	66.79 (3.40)			66.51 (3.61)		
Sunda	M	64.04 (3.20)	-10.299	0.000	64.33 (4.16)	-0.596	0.552
	F	68.96 (2.99)			64.68 (3.62)		
Betawi	M	62.90 (3.20)	-7.728	0.000	64.74 (3.10)	-9.505	0.000
	F	66.36 (2.57)			69.20 (2.99)		

The independent t-test results show clear gender-based differences across ethnic groups. Batak females outperform males in science literacy, though numeracy differences are not significant. In Aceh and Javanese groups, males score significantly higher in science, but gender differences in numeracy are negligible. Sundanese females outperform males in science, while numeracy is similar. Among Betawi students, females significantly outperform males in both science and numeracy. Overall, gender effects are ethnicity-specific, with females excelling in some contexts (Sunda, Betawi) and males in others (Aceh, Javanese). Table 16 shows the post-hoc Tukey HSD comparisons, which further clarify disparities in science literacy and numeracy across ethnic and gender groups.

Table 16. Independent t-test Based on Gender Across Various Ethnic Groups in Sundaland

Etnis	Gender	Science Literacy	t-value	p-value	Numeracy	t-value	p-value
Batak	M	66.00 (2.70)	-2.61	0.010	63.29 (4.19)	-1.41	0.161
	F	67.13 (2.89)			64.14 (3.63)		
Aceh	M	66.80 (2.90)	4.53	0.000	67.02 (3.75)	0.41	0.681
	F	64.55 (3.51)			66.79 (3.40)		
Javanese	M	67.02 (3.75)	4.01	0.000	67.13 (2.90)	1.22	0.226
	F	66.79 (3.40)			66.51 (3.61)		
Sunda	M	64.04 (3.20)	-10.30	0.000	64.33 (4.16)	-0.60	0.552
	F	68.96 (2.99)			64.68 (3.62)		
Betawi	M	62.90 (3.20)	-7.74	0.000	64.74 (3.10)	-9.51	0.000
	F	66.36 (2.57)			69.20 (2.99)		

The results of Table 16 indicate that gender disparities in Sundaland vary across ethnic groups. Female students outperformed males in science literacy among Batak, Sundanese, and Betawi, with particularly strong advantages for Sundanese and Betawi girls. Conversely, Acehnese and Javanese boys scored higher in science literacy than their female peers. For numeracy, significant gender differences appeared only among Betawi students, where females substantially outperformed males, while in other ethnic groups the gaps were statistically insignificant. These findings suggest that gender effects on literacy are context-dependent, with science literacy showing clearer disparities than numeracy. Table 17 shows the post-hoc Tukey HSD comparisons, which further clarify disparities in science literacy and numeracy across ethnic and gender groups..

Table 17. Tukey HSD Test for Science and Numeracy Literacy by Ethnicity

Etnis	Gender	Sumatra	Jawa	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)*

Etnis	Gender	Sumatra	Jawa	Kalimantan	Bali
	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)

Table 17 Tukey HSD analyses revealed significant ethnic and gender disparities in Sundaland’s science and numeracy literacy. Javanese and Batak students scored highest in science (e.g., Batak vs. Minangkabau, MD = 2.41, $p < 0.001$), while Dayak and Javanese males led in numeracy (e.g., Javanese M vs. Betawi, MD = 3.50, $p < 0.001$). Malay K. and Sasak students scored lowest across domains. Females excelled in science, whereas males outperformed in numeracy, reflecting persistent socio-economic and educational inequalities. Table 18 presents the ANCOVA analysis, controlling for socioeconomic status (SES) and mother tongue.

Table 18. ANCOVA for Scientific Literacy and Numeracy Based on Ethnicity.

Wilayah	Etnis	SES	Bahasa Ibu	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

Wilayah	Etnis	SES	Bahasa Ibu	Science Literacy	Numeracy	F-value	p-value
		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

ANCOVA analysis (Table 18) indicates that scientific literacy and numeracy in Sundaland vary significantly by ethnic group, mediated by mother tongue and socioeconomic status (SES), with high-SES groups Batak in Sumatra (68.50 ± 2.60; 67.40 ± 3.00), Javanese in Java (71.20 ± 2.50; 70.00 ± 2.85), Dayak in Kalimantan (66.90 ± 2.85; 65.80 ± 3.40), and Balinese in Bali (65.40 ± 3.20; 64.50 ± 3.80) scoring highest, while low-SES groups in remote areas (Dayak, Sasak) score lower due to limited educational access, highlighting the need for culturally inclusive policies. Table 19 shows the multilevel HLM results, accounting for individual, institutional, and regional factors.

Table 19. HLM for Differences in Scientific Literacy and Numeracy by Ethnicity

Level	Variable	Batak	Minang kabau	Javanese	Dayak	Balinese	p-value
Level 1 (Individual)	Gender	1.60 ± 0.28	1.50 ± 0.30	1.80 ± 0.25	1.40 ± 0.35	1.20 ± 0.40	0.001
	Cognitive Ability	2.90 ± 0.24	2.80 ± 0.26	3.20 ± 0.20	2.70 ± 0.30	2.50 ± 0.28	0.000
	Mother Tongue Background	1.20 ± 0.18	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002
Level 2 (Institutional)	School Accreditation	3.50 ± 0.38	3.40 ± 0.40	3.80 ± 0.35	3.00 ± 0.45	2.80 ± 0.50	0.000
	Teaching Quality	2.70 ± 0.30	2.60 ± 0.35	3.30 ± 0.30	2.60 ± 0.40	2.40 ± 0.38	0.001
	Technology Integration	3.00 ± 0.28	2.90 ± 0.30	3.60 ± 0.28	2.90 ± 0.35	2.60 ± 0.40	0.002
Level 3 (Regional)	Bilingual Program	2.90 ± 0.45	2.80 ± 0.50	3.20 ± 0.45	3.40 ± 0.55	3.10 ± 0.50	0.000
	Regional Government Support	2.80 ± 0.42	2.70 ± 0.48	3.00 ± 0.42	3.20 ± 0.50	2.90 ± 0.45	0.001
	Access to Educational Resources	2.60 ± 0.40	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002

HLM analysis shows Sundaland's scientific literacy and numeracy vary by individual, institutional, and ethnic factors. Javanese scored highest in cognition, language, accreditation, teaching, and technology; Batak and Minangkabau followed, Dayak and Balinese lagged. Dayak excelled in bilingual programs, with Javanese in government support. Results stress culture, policy, and institutional roles, highlighting teaching quality, technology, and local language use as keys to bridging ethnic literacy gaps.

Discussion

Science and numeracy literacy in Sundaland, covering Sumatra, Java, Kalimantan, and Bali, is shaped by socioeconomic conditions, educational infrastructure, culture, and language. Java performs best due to access to technology, modern laboratories, and well-trained teachers (Blömeke et al., 2022; Yulianto et al., 2024; Schreiter et al., 2024), though urban–rural gaps persist. In Sumatra, Batak and Minangkabau communities benefit from strong learning cultures and community support (Alfurqan, 2020), but remote areas face resource constraints, which can be mitigated through ethnomathematics and local-language integration (Iswara et al., 2022). Kalimantan struggles with digital inequality, poor infrastructure, and language barriers (Hamudy & Rifki, 2024). These patterns indicate that locally rooted pedagogical models, such as project-based learning and ethnomathematics, are effective in reducing disparities and enhancing higher-order thinking skills (Iswara et al., 2022; Yulianto et al., 2024). Overall, bridging literacy gaps in Sundaland requires combining technological and infrastructural investments with culturally and linguistically responsive teaching strategies that leverage community strengths to promote equitable and inclusive learning.

Gender gaps in literacy across Sundaland are shaped by cultural, linguistic, and infrastructural factors. Urban women outperform men due to greater access to technology and STEM resources (Balducci, 2023; Blömeke et al., 2022), whereas rural women face stereotypes and limited representation, constraining their STEM engagement (Verdugo-Castro et al., 2022; Driscoll et al., 2024). Regionally, women in Java excel in numeracy, though men dominate technical skills (Yulianto et al., 2024); Batak and Minangkabau women in Sumatra achieve higher science literacy (Alfurqan, 2020); Kalimantan women lag behind due to limited lab access and language mismatches in instruction (Hamudy & Rifki, 2024); in Bali, patriarchal norms hinder numeracy, yet women succeed in environmental science through alignment with Tri Hita Karana principles (Suardana et al., 2023). These patterns reveal that gender disparities are context-dependent, emerging from the interaction of socio-cultural norms, language, and resource availability. While global evidence shows female advantages in literacy and variable STEM participation (Balducci, 2023; Verdugo-Castro et al., 2022), local traditions, such as Bali's patriarchal structures, can override these trends. Therefore, policies to reduce gender gaps must integrate culturally responsive and context-sensitive strategies that leverage local strengths while addressing structural and societal barriers.

Language significantly shapes STEM comprehension in Sundaland. In Sumatra, rural students struggle with Bahasa Indonesia despite Batak and Minangkabau literacy traditions (Alfurqan, 2020; Daly et al., 2023). Javanese and Sundanese linguistic hierarchies complicate the understanding of abstract STEM concepts (Al Ghiffari et al., 2023; Asmahasanah et al., 2022), while in Kalimantan, Dayak and Banjar grammatical differences hinder engagement with STEM content (Hamudy & Rifki, 2024). In Bali, Balinese facilitates ecological understanding but conflicts with scientific terminology (Suardana et al., 2023). Integrating local languages, providing bilingual materials, and teacher training can improve comprehension and learning outcomes (Iswara et al., 2022; Grapin et al., 2025). Overall, these findings highlight that STEM achievement is shaped by the intersection of language, culture, and pedagogy. Culturally and linguistically responsive approaches are essential to reducing comprehension gaps and promoting equity in STEM education across diverse communities.

Inclusive, context-based educational policies significantly enhance literacy outcomes across Sundaland. In Bali, environmental education is strengthened by integrating Hindu values, which fosters both cultural awareness and scientific understanding (Suardana et al., 2023). In Sumatra, project-based learning approaches rooted in Minangkabau traditions provide students with experiential engagement, enhancing problem-solving and numeracy skills (Iswara et al., 2022). Java implements Sundanese ethnomathematics, bridging local knowledge with formal STEM concepts and supporting students' conceptual understanding (Lidinillah et al., 2022). Meanwhile, in Kalimantan, collaboration with Dayak communities allows curricula to reflect local socio-cultural realities, promoting both relevance and student motivation (Hamudy & Rifki, 2024). These region-specific strategies exemplify how embedding cultural values within STEM pedagogy not only aligns with frameworks for 21st-century competencies and education for sustainable development (Kain et al., 2024; Yulianto et al., 2024) but also demonstrates that culturally responsive approaches can be systematically scaled across diverse contexts, potentially reducing educational disparities while simultaneously preserving local heritage. By synthesizing these examples, it becomes evident that inclusive policies grounded in local culture do more than improve literacy; they create a sustainable model for equitable STEM education that respects and leverages sociocultural diversity.

Findings highlight that literacy disparities are shaped by gender, cognition, school quality, accreditation, technology, bilingual programs, local policies, and resources. Recommendations include culturally responsive, gender-sensitive policies, PBL curricula, digital learning expansion, multilingual education, and ethnomathematics to bridge interethnic gaps and strengthen local identity. Limitations include geographic restriction to Sundaland, cross-sectional design excluding long-term impact, limited qualitative depth on minority students, and unexamined variables like learning styles, community support, and teacher quality. Future research should: (1) adopt longitudinal designs to track literacy over time; (2) expand to Eastern Indonesia and indigenous communities; (3) integrate mixed-methods for deeper insights; (4) provide teacher training in inclusive pedagogy and local languages; (5) pursue international collaboration with multicultural countries for benchmarking sustainable multilingual education.

4. CONCLUSION

This study finds that scientific literacy and numeracy in Sundaland are shaped by gender, culture, and linguistics. Java performs best due to educational access, and Bali performs lowest due to infrastructure limits. Males excel in numeracy, females in scientific literacy, reflecting social norms. Mother tongue use enhances conceptual understanding, highlighting the need for linguistically inclusive policies. Literacy outcomes depend on individual (gender, cognitive abilities), institutional (school accreditation, teaching quality), and regional (bilingual programs, government support) factors. Batak and Minangkabau excel in strong learning cultures, while Dayak and Banjar face linguistic and social barriers. Addressing these disparities requires policies integrating ethnomathematics, culturally responsive teaching, and school-community-research collaboration. Further studies should evaluate multilingual education and inclusive policy impacts on literacy gaps in Indonesia.

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AUTHOR CONTRIBUTION STATEMENT

DY conceived the research design, led the writing, and supervised data analysis. YJ coordinated data collection in Sundaland and contributed to statistical analyses. EAJ developed and validated research instruments and assisted with the literature review. SA managed fieldwork, interviews, and qualitative data interpretation. MRU supported model design, data visualization, and manuscript editing. JM analyzed the ethnographic context and regional educational disparities. MSS contributed to methodological design, assisted in data collection and analysis, and provided critical manuscript revisions. All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Analyzing Gender and Cultural Disparities in Science Literacy and Numeracy: Socioeconomic, Linguistic, and Educational Perspectives Among Senior High School Students in Sundaland, Indonesia

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ABSTRACT

This study analyzes gender and cultural disparities in scientific literacy and numeracy among high school students in the multi-ethnic region of Sundaland, Indonesia. The primary focus is on the influence of ethnicity, socioeconomic status, and the use of the mother tongue on literacy achievement. Employing a quantitative design based on Hierarchical Linear Modeling (HLM), data were collected through literacy tests, questionnaires, and in-depth interviews from a stratified sample selected based on school accreditation, gender, and socioeconomic status. The findings reveal that Javanese students scored the highest, while Balinese students scored the lowest, influenced by differences in educational infrastructure and technological support. Males excelled in numeracy, whereas females outperformed in scientific literacy. The use of the mother tongue was found to enhance conceptual understanding in science and numeracy, particularly among the Batak and Minangkabau ethnic groups, who are known for their strong learning culture. This study underscores the importance of inclusive and culturally responsive educational policies to bridge literacy gaps in multi-ethnic communities. Moreover, ethnomathematics programs and multilingual education are recommended to improve literacy quality. The study's limitations include restricted geographical coverage and the absence of longitudinal data. Future research is expected to evaluate the long-term impact of inclusive education policies and the development of community-based programs to enhance student learning motivation.

Analisis Kesenjangan Gender dan Budaya dalam Literasi Sains dan Numerasi: Tinjauan Sosial Ekonomi, Bahasa, dan Pendidikan pada Siswa SMA di Sundaland, Indonesia.

Kata Kunci:

Kesenjangan Gender, Kesenjangan Budaya, Literasi Sains, Literasi Numerasi,

ABSTRAK

Studi ini menganalisis kesenjangan gender dan budaya dalam literasi sains dan numerasi di kalangan siswa sekolah menengah atas di wilayah multi-etnis Sundaland, Indonesia. Fokus utama penelitian ini adalah pada pengaruh etnisitas, status sosial ekonomi, dan penggunaan bahasa ibu terhadap pencapaian

Perspektif Sosioekonomi, Keberagaman Linguistik

literasi. Dengan menggunakan desain kuantitatif berbasis Hierarchical Linear Modeling (HLM), data dikumpulkan melalui tes literasi, kuesioner, dan wawancara mendalam dari sampel berstrata yang dipilih berdasarkan akreditasi sekolah, jenis kelamin, dan status sosial ekonomi. Hasil penelitian menunjukkan bahwa siswa etnis Jawa memperoleh skor tertinggi, sementara siswa etnis Bali memperoleh skor terendah, yang dipengaruhi oleh perbedaan infrastruktur pendidikan dan dukungan teknologi. Siswa laki-laki unggul dalam numerasi, sedangkan siswa perempuan menunjukkan kinerja lebih baik dalam literasi sains. Penggunaan bahasa ibu terbukti meningkatkan pemahaman konseptual dalam sains dan numerasi, terutama di kalangan etnis Batak dan Minangkabau yang dikenal memiliki budaya belajar yang kuat. Studi ini menekankan pentingnya kebijakan pendidikan yang inklusif dan responsif terhadap keragaman budaya guna menjembatani kesenjangan literasi di komunitas multi-etnis. Selain itu, program etnomatematika dan pendidikan multibahasa direkomendasikan untuk meningkatkan kualitas literasi. Adapun keterbatasan penelitian ini meliputi cakupan geografis yang terbatas dan tidak tersedianya data longitudinal. Penelitian selanjutnya diharapkan dapat mengevaluasi dampak jangka panjang dari kebijakan pendidikan inklusif serta mengembangkan program berbasis komunitas untuk meningkatkan motivasi belajar siswa.

Contribution to the literature

This study makes a significant contribution to the existing body of literature by providing a comprehensive analysis of how gender, ethnicity, and linguistic diversity intersect to influence science and numeracy literacy among high school students in Sundaland one of the most culturally diverse regions in Indonesia. It stands as one of the few empirical investigations in Southeast Asia that employs a robust, multi-level quantitative framework specifically Hierarchical Linear Modeling (HLM) and Analysis of Covariance (ANCOVA) in conjunction with qualitative insights to examine disparities in educational outcomes. The use of bilingual assessment instruments, carefully adapted from internationally recognized frameworks such as PISA, TIMSS, and UNESCO, underscores the critical role of mother tongue instruction in facilitating deeper conceptual understanding across various ethnic groups. Moreover, this study advances the discourse on inclusive education policy by offering contextually grounded recommendations informed by sociocultural theory, principles of educational equity, and multilingual pedagogical approaches.

1. INTRODUCTION

The advancement of a nation heavily relies on the quality of its human resources: individuals who are educated, competitive, and capable of adapting to the dynamics of global change. This can be measured through formal education levels, critical thinking abilities, technical skills, as well as collaborative and innovative capacities in addressing global challenges. Literacy has now evolved into the foundation for critical thinking, problem-solving, and innovation in the digital era [1], [2], [3]. A strong literacy culture enhances analytical skills, communication, collaboration, and creativity, all of which are essential elements in knowledge-based socio-economic development [4]. For instance, Finland's digital literacy program, which emphasizes the development of critical and collaborative skills, has successfully increased public participation in technological innovation and knowledge-based economic activities. In the face of the Fourth Industrial Revolution and Society 5.0, education must equip learners with adaptive skills to navigate social, economic, and technological dynamics [5], [6], [7]. Twenty-first-century literacy encompasses six key dimensions: reading and writing, numeracy, science, finance, digital literacy, and cultural and civic literacy [8]. These dimensions cultivate various competencies, such as information comprehension, data problem-solving, economic management, technological navigation, and social participation. These pillars of literacy reflect academic proficiency and the readiness of individuals to make data-driven decisions and actively engage in the digital society.

The 4C skills Critical Thinking, Communication, Collaboration, and Creativity—are essential for addressing global challenges [9], [10], [11]. The Framework for 21st Century Learning [12] emphasizes that the 4C skills enhance academic achievement and prepare students for the workforce [13]. This approach effectively hones critical thinking, clear communication, solid teamwork, and innovation in solving complex problems [11], [14]. However, the integration of scientific and numerical literacy in developing these skills remains limited in Indonesia [3], [13]. For instance, Kartal (2020) demonstrated that using experiment-based methods can enhance students' evidence-based analytical abilities. Additionally, research by Lee et al. (2024) proved that collaboration in data-driven problem-solving can strengthen numerical literacy. Scientific and numerical literacy play a crucial role in fostering critical thinking and creativity through evidence-based analysis and innovative solutions [15], [16]. The Scientific Literacy Framework emphasizes hypothesis evaluation and evidence-based decision-making, while the Numerical Literacy Theory focuses on data comprehension and statistical interpretation [17], [18], [19]. Scientific literacy enhances the articulation of argumentative scientific concepts [20], whereas numerical literacy supports data-driven problem-solving through team analysis and evidence-based discussions [21]. This integration serves as a key strategy for improving the quality of education in Indonesia.

Countries that excel in PISA performance, such as Singapore and Finland, have successfully integrated scientific literacy and numeracy into 4C learning through inquiry-based learning and project-based learning. In Singapore, this approach is implemented through collaborative student experiments in laboratories that foster scientific concept exploration. Meanwhile, in Finland, students are encouraged to develop real-world, problem-based projects that involve complex mathematical problem-solving. This approach has proven effective in enhancing conceptual understanding, critical thinking, and creativity [9], [22], [23], [24]. Indonesia, however, still faces challenges in implementing 4C learning due to the dominance of rote memorization methods, limited exploration, and a lack of open discussion [25]. A study by Yulianto et al. (2024) revealed that 70% of teachers struggle to implement higher-order thinking skills (HOTS)-based learning. Additionally, data from the Ministry of Education and Culture (Kemendikbud, 2023) show that schools in rural areas have up to 50% less access to technology compared to urban schools. The 2013 Curriculum, which adopts 4C principles, has yet to be optimized due to limited pedagogical training on HOTS for teachers [9], [26], unequal access to technology [27], and pedagogical disparities between urban and rural schools (Kemendikbud, 2023).

Curriculum reform in Indonesia through the Merdeka Curriculum aims to address the limitations of the 2013 Curriculum in responding to 21st-century challenges, such as advancements in digital technology, globalization, and the demand for critical and collaborative thinking skills. This curriculum emphasizes competency-based learning, flexibility, and character development through the Pancasila Student Profile [27], while promoting the 4Cs: critical thinking, creativity, communication, and collaboration [9], [22]. Despite offering flexibility, its implementation faces challenges related to teacher readiness, equitable digital infrastructure, and access in remote areas. A study by the Ministry of Education and Culture (Kemendikbud, 2023) revealed that only 40% of teachers feel prepared to adopt new teaching methods, while 60% of schools in remote regions still lack adequate internet access. Teachers struggle with project-based and inquiry-based learning, which are key features 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 [16]

Indonesia faces significant challenges in literacy-based education and 21st-century skills development in Southeast Asia, as evidenced by its low PISA score (369.3), reflecting gaps in teaching quality, limited access to technology, and disparities between urban and rural areas [16]. In contrast, Singapore (PISA 559.7) excels through the integration of educational technology, such as the use of digital learning platforms, a problem-solving-based curriculum through the Mathematics Problem-Solving Curriculum program, and continuous teacher training via the National Institute of Education (NIE) initiatives [16]. Malaysia (424.7) and Thailand (394.0) have adopted STEM approaches to enhance scientific literacy and numeracy [16]. Indonesia's lagging performance stems from poor teaching quality, limited technological access, and urban-rural educational disparities. The reliance on rote learning and standardized testing hinders reasoning abilities, critical thinking, and the application of scientific concepts [25]. The low levels of scientific literacy and numeracy necessitate reforms in the "Kurikulum Merdeka," including enhancing pedagogy through project-based learning methods, increasing technological access via online learning platforms like "Rumah Belajar," and providing teacher training through the "Guru Penggerak" program. Curriculum evaluation should prioritize students' analytical skills rather than rote memorization for exams [28].

Scientific literacy and numeracy serve as the foundation of 21st-century education, fostering critical thinking, evidence-based problem-solving, and students' capacity for innovation through mastery of scientific concepts, data analysis, and the application of technology to create creative solutions to global challenges [15], [20]. Scientific literacy encompasses the understanding of scientific concepts, their application in solving real-world problems, and the evaluation of evidence-based information [16]. Meanwhile, numerical literacy emphasizes the comprehension, interpretation, and utilization of data for effective decision-making [29]. However, 56 out of 81 countries, including Indonesia, remain below the global average in scientific and numerical literacy due to a rote-learning-based education system, such as national examinations that focus on memorizing facts and formulas without a deep understanding or practical application of concepts in real-life situations [16], [25], [30]. In contrast, countries with high PISA scores, such as Finland and Singapore, implement inquiry-based learning and problem-solving approaches [22]. In Indonesia, the lack of exploratory learning and limited resources further exacerbate the literacy gap [31].

Gender disparities in literacy remain a persistent challenge, particularly in low- and middle-income countries. In Ghana, gender inequality widens as educational levels increase [32]. Despite rising primary school enrollment rates, girls remain vulnerable to school dropout and exhibit lower literacy levels [33]. The digital gender divide in Latin America exacerbates educational inequality [34] even in virtual learning environments [35]. Males tend to excel in numeracy, while females perform better in reading comprehension. This pattern is influenced by social and cultural norms that shape gender role perceptions from an early age, such as the stereotype that males are more adept at mathematics, while females excel in language [36], [37], [38], [39]. Gender Schema Theory posits that social constructs push males towards STEM fields and females towards verbal and communication domains [40]. Meanwhile, the Expectancy-Value Theory emphasizes that this disparity stems from the interaction between psychological factors and social expectations [41], [42]. 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 [43]. This inequality highlights how students' academic and professional trajectories are influenced by gender norms from an early age [42], [44]. Pedagogical approaches that fail to consider the distinct needs and learning styles of male and female students exacerbate literacy gaps. Discussion-based methods enhance reading literacy among female students, while problem-solving and laboratory experiments support numeracy development in male students [45], [46], [47], [48]. Implementing gender-inclusive curriculum reforms is essential to address these inequalities. STEM mentorship programs for female students can boost confidence in numeracy and science, as demonstrated in Sweden and Finland, where the gender gap in STEM fields is significantly lower [49].

Sundaland, encompassing Sumatra, Java, Kalimantan, and Bali, is a region renowned for its extraordinary cultural and linguistic diversity. This diversity includes a wide array of local languages, such as Javanese, Sundanese, and Dayak, as well as a rich tradition of arts, ranging from wayang kulit (shadow puppetry) to the Reog Ponorogo dance. The fragmentation of the region due to rising sea levels [50] and the presence of over 700 ethnic groups have significantly influenced social structures, learning methods, and the acquisition of academic literacy (Sholihah, 2020). For instance, in geographically isolated areas, community-based learning and indigenous wisdom are more prevalent, while in more urbanized and open regions, the use of technology and digital resources is prioritized. The multi-level framework of developmental dyslexia emphasizes the role of culture in transitioning from information processing to literacy skills [51]. Linguistic awareness serves as the foundation for cross-cultural literacy acquisition [52]. Although culturally based approaches to academic literacy are gaining recognition, further evidence is needed to establish the link between pedagogical practices and academic performance [53]. The Interdependence Hypothesis posits that a strong command of one's mother tongue supports second-language literacy [51]. For example, research conducted in bilingual communities in Yogyakarta revealed that students proficient in Javanese better grasped academic concepts in Indonesian compared to those lacking a solid foundation in their native language (Suharto, 2021). However, Indonesia's monolingual education system, dominated by the Indonesian language, tends to overlook the benefits of bilingualism and multilingualism [54]. Moreover, the excessive promotion of English poses a threat to the preservation of local languages [55].

Bilingual education has emerged as an effective strategy to navigate globalization, despite being hindered by outdated pedagogy, such as monotonous lecture-based methods that lack active student engagement and suboptimal teaching quality. An innovative approach that integrates bilingualism into academic literacy, particularly in higher education, is essential [54]. The transition to multilingual education can preserve local languages while adopting English as the lingua franca [55]. For instance, the learning program in the Basque Country, Spain, successfully incorporated Basque, Spanish, and English into the educational curriculum, leading to improved literacy and language skills among students. However, students from diverse ethnic backgrounds, especially those who speak local languages, face significant challenges. International assessments like PISA, which are based on global standards, often fail to reflect the reality of Indonesia's multilingual education system, potentially introducing bias in measuring student literacy [16]. A community-based approach is necessary for more contextual literacy assessments. This includes involving parents, community leaders, and local teachers in developing culturally relevant learning materials and forming study groups that use local languages as a medium of communication to enhance student comprehension.

The cultural diversity of Indonesia has shaped a varied educational system influenced by cultural values, traditions, and socio-economic conditions. In Aceh and Minangkabau, Islamic-oriented education through dayah, Islamic schools, and public schools [56], [57] preserves cultural identity (Alfurqan, 2020). However, this approach tends to emphasize rote learning and normative teaching, focusing on Islamic moral and ethical values, thereby limiting opportunities for students to explore innovative solutions and engage in critical thinking. This aligns with Vygotsky's Sociocultural Learning Theory, which highlights the importance of cognitive interaction in stimulating creativity and problem-solving. In Java, a technology and analysis-based approach reflects Constructivist Learning Theory [56], [57]. This includes the implementation of e-learning platforms, data-driven evaluation systems, and the use of simulation software for science experiments, allowing students to build understanding through hands-on experience and collaborative discussions. Meanwhile, in Kalimantan, the Contextual Teaching and Learning (CTL) approach addresses the limitations of educational infrastructure [16], [58]. In Bali, Culturally Responsive Teaching integrates local values such as Tri Pramana, the East-West method, and the Subak irrigation system, along with the flipped classroom approach via the "Kelas Maya Jejak Bali" platform [59], [60]. The literacy disparity in Sundaland is influenced by socio-economic factors and infrastructure inequality. Major cities like Medan and Padang have better access to educational facilities, while remote areas face technological and teaching staff shortages [61]. Data from BPS (2023) and PISA 2018 highlight literacy gaps exacerbated by traditional norms that restrict female education [62]. The Sekolah Garis Depan program aims to bridge these gaps, though its effectiveness depends on teacher incentives and culturally-based curriculum adaptation (BPS, 2023). For instance, in remote areas of Kalimantan, the program successfully increased student attendance by 20% within the first two years of implementation. However, it continues to face challenges in enhancing the quality of science and mathematics instruction due to limited laboratory facilities [58]. Comparative research with multicultural advanced countries such as Switzerland and Canada can provide valuable insights for designing more inclusive and competitive educational policies.

A study on the major ethnic groups in Sundaland, such as the Batak, Malay, Minangkabau, Betawi, Javanese, and others, reveals that culture and language play a pivotal role in Indonesian literacy. The Javanese community emphasizes hierarchical learning (Andriyanto et al., 2022), while the Sundanese prioritize interactive discussions [63]. Batak students excel in logic and analysis due to their argumentative culture (Parinduri et al., 2020), whereas the Minangkabau integrate religious teachings into the curriculum (Alfurqan, 2020). In Bali, contextual education merges traditional arts with modern curricula [59]. Linguistic diversity poses challenges to literacy acquisition, as Bahasa Indonesia serves as the primary medium of instruction. Students accustomed to their mother tongue excel in grasping fundamental concepts but struggle to transition to formal language due to differences in syntax and complex vocabulary [64], [65].

According to the Interdependence Hypothesis, proficiency in the first language supports second-language literacy. This study highlights the need for inclusive educational policies that support regional languages through culturally sensitive teacher training, the development of bilingual curricula, and the provision of learning materials in local languages to bridge the gap in multiethnic communities. The analysis of gender and cultural disparities in science and numeracy literacy among high school students in Sundaland considers ethnicity, socioeconomic status, linguistic diversity, and local educational practices. These findings are expected to contribute to more inclusive and adaptive educational policies in multicultural environments.

2. METHOD

This study emphasizes the urgency of inclusive education policies in enhancing scientific literacy and numeracy in the Sundaland region (Sumatra, Java, Kalimantan, and Bali). This region was selected due to its high diversity, which reflects the significant cultural, ethnic, and linguistic diversity of Indonesia, as highlighted in the OECD (2023) study on educational diversity in Southeast Asia. The research delves into the disparities arising from gender, culture, ethnicity, socioeconomic status, and linguistic diversity that affect student literacy outcomes. Gender plays a significant role in shaping students' perceptions and learning approaches. Meanwhile, culture and ethnicity influence the educational values upheld by specific communities. Socioeconomic status determines the level of access to quality educational resources. Furthermore, linguistic diversity can either serve as a catalyst or a barrier to literacy, depending on the support provided for mother-tongue instruction in the learning process. By employing a cross-sectional comparative research design, this study maps the disparities related to gender, culture, and linguistics empirically without intervention. This approach enables a comprehensive analysis to understand the contributing factors to literacy inequality in this diverse region.

Population and Research Sample

Based on the latest data from the Center for Data and Information Technology (Pusdatin) of the Indonesian Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) 2023 and the Central Bureau of Statistics (BPS) 2023, the total population of high school students in Indonesia is 4,853,305. For this study, only students from the Sundaland region are considered, with the distribution as follows:

Table 1. High School Student Population by Geographic Region and Gender

Region	Regional Proportion	Total Population	Urban Population	Rural Population	Male	Female
Java	58.5%	2,840,721	2,045,319	795,402	1,422,161	1,418,560
Sumatra	23%	1,117,249	581,674	535,575	561,812	555,437
Kalimantan	10%	484,191	208,201	275,990	242,895	241,296
Bali	4.5%	211,144	141,467	69,677	105,789	105,355
Total Sundaland	100%	4,853,305	2,976,661	1,876,644	2,332,657	2,320,648

Table 2. Student Population by School Accreditation

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	58,5%	955.847	785.326	304.146	312.879	256.138	226.385
Sumatra	23%	287.423	195.952	98.299	205.612	182.415	147.548
Kalimantan	10%	90.612	76.785	40.804	97.336	105.421	73.233
Bali	4,5%	75.248	45.398	20.821	30.489	25.366	13.822

Region	Regional Proportion	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Total Sundaland	100%	1.409.130	1.103.461	464.070	646.316	569.340	461.988

This study involved 2,250 students selected through Multistage Random Sampling to ensure proportional distribution based on geographic region, gender, ethnicity, and linguistic background. In the first stage, Stratified Random Sampling divided the population into four major regions of Sundaland: Sumatra, Java, Kalimantan, and Bali, to maintain sample balance (Creswell & Creswell, 2018). In the second stage, Cluster Random Sampling randomly selected schools from various districts/cities, considering accreditation status (Excellent, Very Good, Good), school type (public/private), and location (urban/rural) to reflect educational diversity (Fraenkel, Wallen, & Hyun, 2019). In the third stage, Simple Random Sampling was employed to randomly select students from the designated schools, ensuring gender and cultural background representation in line with probability sampling principles (Bryman, 2016). The final sample of 2,250 students was proportionally drawn from the total population of 4,853,305 high school students in Sundaland (BPS, 2023).

Table 3. Sample Data of Students Based on Geographic Region and Gender

Region	Regional Proportion	High School Student Sample	Geographical Sample		Gender	
			Urban	Rural	M	F
Jawa	58,5%	1.317	948	369	659	658
Sumatra	23%	518	269	249	260	258
Kalimantan	10%	225	97	128	113	112
Bali	4,5%	101	68	33	51	50
Total Sundaland	100%	2.250	1.382	779	1.083	1.067

Table 4. Sample Data Based on School Accreditation

Region	High School Student Sample	Urban Population			Rural Population		
		Excellent	Very Good	Good	Excellent	Very Good	Good
Jawa	1.317	464	382	156	154	125	36
Sumatra	518	184	135	68	93	78	50
Kalimantan	225	61	52	35	48	54	26
Bali	101	34	22	14	16	12	3
Total Sundaland	2.250	743	591	273	311	269	115

The selection of ethnic samples was conducted through three strategic stages to ensure proportional representation, aiming to obtain accurate and reliable data on the social and cultural dynamics of various ethnic communities. First, stratification based on region and ethnicity was carried out by referring to data from the Indonesian Central Bureau of Statistics (BPS) to reflect the composition of both majority and minority ethnic groups in each area. Second, Cluster Random Sampling was applied by randomly selecting schools from districts or cities with significant ethnic diversity. These areas were chosen due to their high levels of social interaction and cultural diversity, representing the characteristics of the Batak, Minangkabau, and Malay ethnic groups in Sumatra, as well as the Dayak and Banjar communities in Kalimantan. Third, Simple Random Sampling was employed to randomly select students from the chosen schools, ensuring proportional distribution in terms of gender and ethnicity. For instance, if the Dayak population in a school is 50% and the Banjar population is 40%, the sample is drawn in accordance with these proportions.

Table 5. 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%), Acehnese & Lampung (10%)	Batak: 207, Minangkabau: 181, Malay: 78, Acehnese & 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	

Test Instrument

This research instrument draws on the PISA, TIMSS, and UNESCO Global Framework on Literacy to assess scientific and numerical literacy. These three frameworks represent comprehensive international standards in literacy, with PISA emphasizing real-life problem-solving, TIMSS focusing on curriculum-based content, and UNESCO highlighting functional and contextual literacy. The instrument does not merely adopt existing questions but undergoes adaptation, modification, and validation to ensure alignment with Indonesia's educational, cultural, and socio-linguistic context. The development process involves identifying core competencies from PISA, TIMSS, and UNESCO, which are then adjusted to fit Indonesia's educational structure. PISA emphasizes problem-solving literacy, TIMSS focuses on national curriculum-based content, and UNESCO targets functional and contextual literacy. A total of 60% of the questions are adapted from PISA and TIMSS, while 40% are independently developed using UNESCO's approach to ensure relevance to local social, economic, and linguistic contexts. For instance, numeracy items involve analyzing energy consumption data across different regions of Indonesia, while science literacy questions address the impact of climate change on local ecosystems. An innovative bilingual format (in Bahasa Indonesia and regional languages such as Javanese, Sundanese, Minangkabau, and Banjarese) is employed to assess the influence of native languages on literacy comprehension.

This study employs a rubric based on PISA competency levels, chosen for its emphasis on scientific literacy and global problem-solving skills, to classify students' responses into low, medium, and high categories. The test instrument consists of 40% multiple-choice questions for basic concepts, 35% short-answer items for numeracy application, and 25% case studies for critical thinking skills, aligned with the PISA Scientific Literacy Framework. Content validation was conducted by experts from UPI through an in-depth evaluation of item alignment with the PISA and TIMSS frameworks, including an assessment of substance, difficulty level, and content relevance. The evaluation yielded an Aiken's V of 0.87, indicating high relevance to international literacy indicators. Construct validation through Confirmatory Factor Analysis (CFA) in AMOS produced the following results: Chi-Square/df = 2.85 (≤ 5.0), CFI = 0.93 (≥ 0.90), RMSEA = 0.047 (≤ 0.08), and SRMR = 0.035 (≤ 0.08), demonstrating excellent model fit. Reliability testing using Cronbach's Alpha and McDonald's Omega showed high results: Multiple Choice (Alpha = 0.84, Omega = 0.86), 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.

This study involved prospective teachers of mathematics, biology, physics, and chemistry from the Faculty of Science Education at La Tansa Mashiro University and Universitas Terbuka, Indonesia. These institutions were selected due to their reputation for producing high-quality educators and their strong partnerships with educational institutions in the region. The instruments used included tests on scientific and numerical literacy administered to students. Data were collected through a literature review of national reports, data from the Central Bureau of Statistics (BPS), and the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek), as well as through questionnaires and interviews. The questionnaire assessed six aspects of literacy: motivation, study habits, parental involvement, educational facilities, learning processes, and learning environments, adapted from Yulianto et al. (2024). Semi-structured interviews with selected high school teachers and students were conducted to validate the quantitative findings and clarify the relationship between literacy factors. The interviews consisted of 14 questions focused on learning patterns at school and home, as well as the socio-cultural factors influencing scientific and numerical literacy.

Data Analysis

This study analyzes gender and cultural disparities in scientific and numerical literacy by considering region, ethnicity, socioeconomic status, and linguistic diversity. The prerequisite tests include the Kolmogorov-Smirnov test for large samples and the Shapiro-Wilk test for small samples to assess normality, along with Levene's Test for homogeneity of variance. The normality test is essential to ensure that the data follows a normal distribution, a fundamental assumption for many parametric statistical methods. Meanwhile, the homogeneity of variance test is necessary to confirm equal variances between groups, which affects the validity of statistical comparisons. If the assumptions are met, ANOVA is applied, while the Kruskal-Wallis Test, followed by the Dunn-Bonferroni or Pairwise Mann-Whitney U test, is used for non-parametric data. Two-Way ANOVA evaluates the effects of gender, ethnicity, and region, while ANCOVA controls for confounding variables such as socioeconomic status. Multiple linear regression is conducted to assess the contribution of independent variables, with multicollinearity tested using the Variance Inflation Factor (VIF). Additionally, Hierarchical Linear Modeling (HLM) assesses multi-level effects on individuals, school institutions, and local education policies. Thematic analysis is employed to identify patterns and relationships among variables, integrating quantitative and qualitative data through data reduction, data presentation, and verification. Validity is confirmed through data triangulation, which involves using multiple data sources, analytical methods, and theories to strengthen findings. This approach includes triangulating quantitative and qualitative data via data reduction, presentation, and verification. Furthermore, comparisons with previous studies are conducted to ensure the consistency and accuracy of results. The findings are presented in tables, graphs, and narratives to provide a comprehensive understanding. The software used includes SPSS for ANOVA and linear regression, HLM for hierarchical analysis, and R or Python for data visualization. This study offers in-depth insights into scientific and numerical literacy in Indonesia, focusing on cultural and ethnic diversity (Batak, Minangkabau, Sundanese, Javanese, Balinese, Dayak, Banjar) and socioeconomic conditions. The findings aim to serve as a foundation for developing more inclusive and adaptive educational policies.

3. RESULTS 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 based on 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.

Table 5. 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 ± 2.70	67.13 ± 2.89	63.29 ± 4.19	64.14 ± 3.63
	Minangkabau	63.98 ± 3.02	64.32 ± 2.64	64.20 ± 3.96	64.65 ± 4.12
	Malay	64.85 ± 2.71	64.77 ± 2.83	65.61 ± 3.22	61.10 ± 3.71
	Aceh	66.80 ± 2.90	64.55 ± 3.51	67.02 ± 3.75	66.79 ± 3.40
Java	Javanese	69.18 ± 2.98	67.08 ± 3.76	67.13 ± 2.90	66.51 ± 3.61
	Sundanese	64.04 ± 3.20	68.96 ± 2.99	64.33 ± 4.16	64.68 ± 3.62
	Betawi	62.90 ± 3.20	66.36 ± 2.57	64.74 ± 3.10	69.20 ± 2.99
	Madura	62.80 ± 2.90	64.06 ± 3.23	66.98 ± 3.77	66.45 ± 3.88
Kalimantan	Dayak	66.52 ± 2.60	66.14 ± 2.72	63.70 ± 4.19	62.55 ± 3.58
	Banjar	63.43 ± 4.45	63.36 ± 4.34	64.61 ± 2.66	63.55 ± 2.76
	Malay	62.63 ± 4.90	62.00 ± 4.01	64.50 ± 3.30	61.98 ± 3.99
	Bugis	63.91 ± 4.30	63.50 ± 3.73	63.45 ± 4.53	62.41 ± 4.76
Bali	Balinese	63.41 ± 3.86	63.12 ± 4.07	64.50 ± 3.30	62.80 ± 4.01
	Javanese	62.50 ± 3.92	62.90 ± 3.20	67.10 ± 3.77	65.68 ± 3.20
	Sasak	62.45 ± 3.16	63.57 ± 3.55	62.14 ± 4.41	62.35 ± 3.69

To ensure the validity of the analysis, the Kolmogorov-Smirnov (KS) Test, Shapiro-Wilk Test, and Levene's Test were applied to the science and numeracy literacy scores based on region, ethnicity, and gender. The majority of groups met the assumption of normality ($p > 0.05$), allowing the use of parametric methods, which rely on a normal data distribution to yield accurate and valid estimates. For instance, Batak (Male, Science Literacy) $p = 0.947$, Javanese (Female, Science Literacy) $p = 0.763$, and Dayak (Male, Science Literacy) $p = 0.198$. However, some groups exhibited slight deviations, such as Bugis (Female, Science Literacy) $p = 0.253$, Sasak (Female, Numeracy Literacy) $p = 0.465$, and Malay (Female, Numeracy Literacy) $p = 0.275$. Further examination through Q-Q Plots and Boxplots confirmed the insignificance of these deviations by comparing the observed data distribution with the expected theoretical distribution and identifying outliers and divergent patterns. For substantial deviations, the Kruskal-Wallis Test was employed as an alternative to the Two-Way ANOVA.

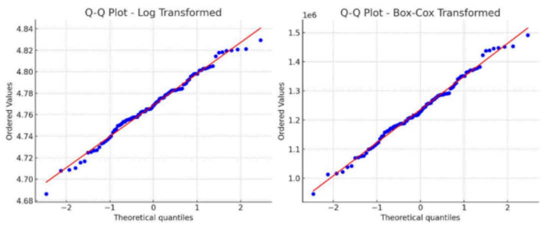

Figure 1. Normality Test

The homogeneity of variance test using Levene's Test demonstrated balanced variance across groups ($p = 0.391$ for science literacy and $p = 0.446$ for numeracy literacy), allowing for the analysis of performance differences based on region, ethnicity, and gender using Two-Way ANOVA.

Science and Numeracy Literacy in the Sundaland Region (Sumatra, Java, Kalimantan, and Bali)

The analysis of science and numeracy literacy in the Sundaland region revealed significant regional disparities, influenced by factors such as differences in educational quality, access to resources, and socio-economic conditions across regions. Java exhibited the highest performance, while Bali recorded the lowest outcomes. To assess the statistical significance of these differences, Two-Way ANOVA was employed due to its capability to evaluate the interaction effects between regional and gender variations simultaneously, as well as to identify factors contributing to literacy performance disparities. The analysis included the sum of squares, degrees of freedom (df), mean squares, F-value, and significance level (p-value). To control for confounding variables such as linguistic diversity and socio-economic status, Analysis of Covariance (ANCOVA) was applied. Furthermore, Hierarchical Linear Modeling (HLM) was utilized to explore intergroup differences and identify the hierarchical influences of individual, school-level, and regional policy factors.

Table 6. Statistical Calculation Results

Variable	Sum of Squares	df	Mean Square	F-Value	p-Value
Science Literacy	3562.506	3	1187.502	86.083	0.000
Numeracy	3022.581	3	1007.527	63.051	0.000
Male	1750.147	3	583.382	38.415	0.000
Female	4872.81	3	1624.27	111.545	0.000

Based on the analysis of Table 6, the Two-Way ANOVA reveals significant differences in scientific literacy ($F = 86.083$, $p = 0.000$) and numeracy ($F = 63.051$, $p = 0.000$) across Sundaland, with Java recording the highest scores and Bali the lowest, reflecting disparities in educational quality across regions. The data were collected through standardized scientific literacy and numeracy tests conducted in various schools in Sundaland. Gender-based differences were also significant, with female students exhibiting greater variability compared to their male counterparts ($F = 111.545$, $p = 0.000$ vs. $F = 38.415$, $p = 0.000$), indicating gender sensitivity to regional influences. Visual analysis through the Two-Way ANOVA interaction plot supports these findings.

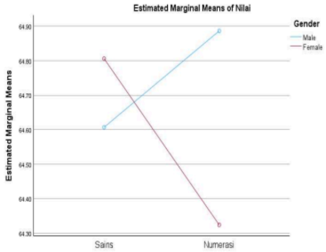

Figure 2. Science and Numeracy Proficiency by Gender Across Four Regions.

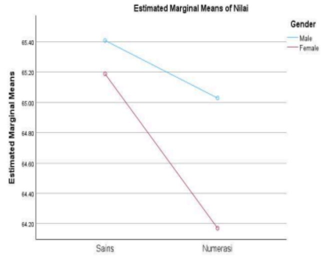

Figure 3. Science and Numeracy Proficiency by Gender in Sumatra.

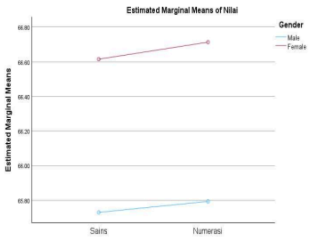

Figure 4. Science and Numeracy Proficiency by Gender in Java

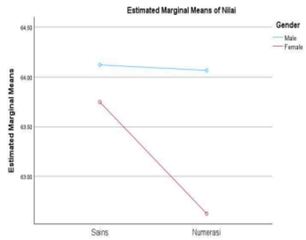

Figure 5. Science and Numeracy Proficiency by Gender in Kalimantan

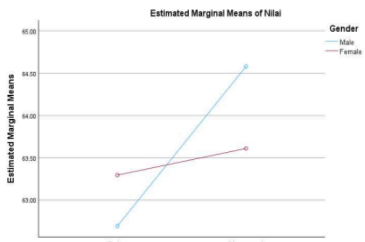

Figure 5. Science and Numeracy Proficiency by Gender in Bali

To control confounding variables such as SES, school accreditation, and access to education, the Post-Hoc Tukey Test and ANCOVA were employed. The Tukey Test identified significant differences between regions in science literacy and numeracy, highlighting the regions with the highest and lowest performance. The results of the post-hoc Tukey Test, as shown in Table 7, reveal significant differences in science literacy and numeracy across regions. Specifically, Java demonstrated significant differences compared to Sumatra ($p = 0.002$), Kalimantan ($p = 0.000$), and Bali ($p = 0.000$). Likewise, Sumatra exhibited significant differences with Kalimantan ($p = 0.015$) and Bali ($p = 0.000$). Furthermore, Kalimantan showed significant differences with Bali ($p = 0.010$). A p-value of less than 0.05 indicates that these regional differences are statistically significant, suggesting that geographical factors contribute to variations in literacy across regions.

Tabel 7. Post-Hoc Tukey Test (Identification of Sources of Differences)

Wilayah	Java	Sumatra	Kalimantan	Bali
Java	-	p = 0.002	p = 0.000	p = 0.000
Sumatra	p = 0.002	-	p = 0.015	p = 0.000
Kalimantan	p = 0.000	p = 0.015	-	p = 0.010
Bali	p = 0.000	p = 0.000	p = 0.010	-

The significant differences in science literacy and numeracy across Sundaland are influenced by varying access to educational resources, the quality of teaching, and technological support. Java excels due to superior infrastructure, while Bali lags behind due to limited educational facilities and the influence of local culture. Additional factors, such as socio-economic status (SES), the use of the mother tongue, and school accreditation, further exacerbate these disparities. Even after controlling for SES and school accreditation, regional differences remain significant, suggesting that cultural factors, teaching quality, and language use also impact literacy outcomes.

Table 8. 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*

Analysis of Table 8 ANCOVA, based on survey data collected through questionnaires and structured interviews, reveals that school accreditation, socioeconomic status (SES), and mother tongue influence scientific literacy and numeracy in Sundaland. Java excels in scientific literacy (71.20 ± 2.50) and numeracy (70.00 ± 2.85), driven by superior accreditation, high SES, and the Javanese language ($F = 18.40$; $p = 0.000$). Sumatra follows with the Minangkabau language ($F = 15.70$; $p = 0.001$), Kalimantan with the Dayak language ($F = 14.50$; $p = 0.003$), and Bali ranks lowest with the Balinese language ($F = 13.10$; $p = 0.004$). The Hierarchical Linear Model (HLM) reveals individual-level influences, such as gender affecting learning patterns, cognition determining analytical skills, and the mother tongue facilitating conceptual understanding. At the institutional level, high accreditation reflects better teaching quality, the use of technology enhances learning interactivity, and effective teaching methods strengthen conceptual comprehension. At the policy level, bilingual programs expand access to global resources, government support ensures adequate facilities, and equitable access to education supports optimal literacy outcomes.

Table 9. HLM Results by Region

Level	Variabel	Sumatra	Jawa	Kalimantan	Bali	p-value
Level 1 (Individual)	Gender	1.50 ± 0.30	1.80 ± 0.25	1.20 ± 0.35	1.00 ± 0.40	0.001*
	Cognitive Ability	2.80 ± 0.25	3.10 ± 0.20	2.50 ± 0.30	2.30 ± 0.28	0.000*
	Mother Tongue	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002*
Level 2 (Institution)	Accreditation	3.40 ± 0.40	3.80 ± 0.35	2.90 ± 0.45	2.70 ± 0.50	0.000*
	Teaching Quality	2.60 ± 0.35	3.20 ± 0.30	2.50 ± 0.40	2.30 ± 0.38	0.001*
	Technology Integration	2.90 ± 0.30	3.50 ± 0.28	2.80 ± 0.35	2.50 ± 0.40	0.002*
Level 3 (Region)	Bilingual Program	2.80 ± 0.50	3.10 ± 0.45	3.40 ± 0.55	3.20 ± 0.50	0.000*
	Government Support	2.70 ± 0.48	3.00 ± 0.42	3.10 ± 0.50	2.90 ± 0.45	0.001*
	Access to Educational Resources	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002*

Analysis of Table 9 The Hierarchical Linear Modeling (HLM) reveals that at Level 1 (Individual), gender significantly influences numeracy across all regions ($p = 0.001$), with the highest impact observed in Java (1.80 ± 0.25) and the lowest in Bali (1.00 ± 0.40). Cognitive factors serve as the primary determinant, particularly in Java (3.10 ± 0.20; $p = 0.000$), while the influence of mother tongue background is most pronounced in Kalimantan (1.40 ± 0.25; $p = 0.002$). At Level 2 (Institution), school accreditation and teaching quality contribute significantly, especially in Java (3.80 ± 0.35; $p = 0.000$), whereas the utilization of technology has the most substantial impact in the same region (3.50 ± 0.28; $p = 0.002$). At Level 3 (Regional), bilingual programs based on local languages exert the greatest influence on numeracy achievement in Kalimantan (3.40 ± 0.55; $p = 0.000$*), followed by government support and access to educational resources, with the highest impact also in Kalimantan (3.10 ± 0.50; $p = 0.001$*). These findings underscore that scientific literacy and numeracy in Sundaland are shaped by the interaction between individual, institutional, and regional policy factors.

Gender-Based Differences in Science and Numeracy Literacy in the Sundaland Region

A descriptive analysis reveals significant disparities in science and numeracy literacy across the Sundaland region based on gender and geography. The province of Java recorded the highest scores, while Bali had the lowest. A Two-Way ANOVA identified the effects of gender and region, while ANCOVA controlled for confounding variables such as linguistic diversity and socioeconomic status. Hierarchical Linear Modeling (HLM) was also employed to analyze individual, school environment, and regional policy factors. The results of the Independent t-test (Table 9) indicate that science literacy between males and females did not differ significantly ($t = -1.280$; $p = 0.201$), suggesting relatively balanced capabilities. However, in numeracy, males ($M = 64.89$, $SD = 3.99$) scored significantly higher than females ($M = 64.32$, $SD = 4.27$) ($t = 3.415$; $p = 0.001$). These findings confirm that gender influences numeracy achievement in the Sundaland region.

Table 9. Results of the Independent t-test

Variable	Males	Females	t-value	p-value
Science Literacy	64,61 (SD = 3,97)	64,81 (SD = 3,83)	-1,280	0,201

Numeracy	64,89 (SD = 3,99)	64,32 (SD = 4,27)	3,415	0,001

Based on the analysis of Table 10, the Two-Way ANOVA results reveal that the regional factor significantly influences science literacy (F = 86.467; p = 0.000) and numeracy (F = 64.123; p = 0.000). Moreover, the gender factor also exhibits a significant effect on numeracy (F = 13.656; p = 0.000). Although the effect of gender on science literacy is relatively smaller, the analysis still indicates statistical significance (F = 2.268; p = 0.002). Furthermore, the interaction between region and gender is also significant for both science literacy (F = 4.476; p = 0.004) and numeracy (F = 11.356; p = 0.000), suggesting that the impact of gender on learning outcomes is not uniform across regions but varies depending on the regional context.

Table 10. Two-Way ANOVA Results

Source of Variation	Science Literacy	Numeracy
Region	F = 86,467; p = 0,000	F = 64,123; p = 0,000
Gender	F = 2,268; p = 0,002	F = 13,656; p = 0,000
Region * Gender	F = 4,476; p = 0,004	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.

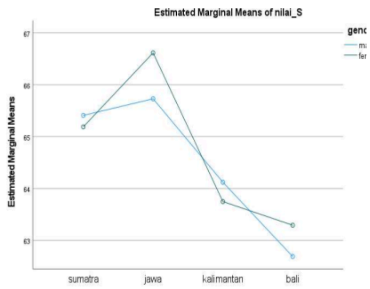

Figure 6. Science Proficiency by Gender

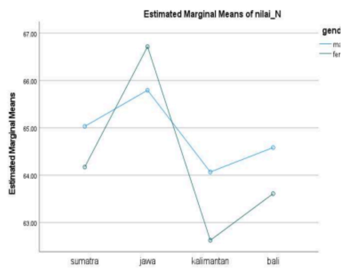

Figure 7. Numeracy Proficiency by Gender

The results of the Tukey HSD Post-Hoc test (Table 12) reveal significant differences in scientific literacy and numeracy based on gender and region within Sundaland. Females in Java and Bali excel in scientific literacy, whereas males dominate in numeracy a pattern similarly observed in Kalimantan and Sumatra. These disparities are influenced by social norms that shape academic expectations, where females are encouraged to excel in literacy, while males receive greater support in numeracy. Moreover, economic factors and educational infrastructure further contribute to these disparities, highlighting the need for more inclusive and context-specific educational policies.

Table 12. Tukey HSD Post-Hoc Test (Identifying Sources of Gender Differences)

Group Comparison	Gender	Sumatra		Jawa		Kalimantan		Bali	
		M	F	M	F	M	F	M	F

Sumatra	M	-	p = 0.458	p = 0.279	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
	F	p = 0.458	-	p = 0.051	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Jawa	M	p = 0.279	p = 0.051	-	p = 0.000	p = 0.000	p = 0.000	p = 0.008	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	-	p = 0.000	p = 0.000	p = 0.000	p = 0.000
Kalimantan	M	p = 0.000	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010	p = 0.000	p = 0.000
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-	p = 0.000	p = 0.000
Bali	M	p = 0.000	p = 0.000	p = 0.008	p = 0.000	p = 0.000	p = 0.000	-	p = 0.010
	F	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.000	p = 0.010	-

The results from Table 12 of the Tukey HSD Post-Hoc Test reveal significant differences in scientific literacy and numeracy based on gender across the four regions of Sundaland. Females in Java and Bali demonstrated superior scientific literacy compared to males in Sumatra ($p = 0.000$), while males in Kalimantan excelled in numeracy compared to females in other regions ($p = 0.000$). A significant difference was also observed between females in Kalimantan and those in other regions ($p = 0.010$). These findings underscore the influence of gender and cultural factors on academic achievement, highlighting the urgency for inclusive and contextually relevant educational policies. The ANCOVA analysis controlled for confounding variables, such as school accreditation, with Table 13 presenting the Adjusted Mean, F-value, and p-value to assess the significance of gender differences across regions.

Table 13. ANCOVA for Controlling Confounding Variables Based on School Accreditation

Group Comparison	School Accreditation	Gender	SES	Adjusted Mean: Science Literacy	Adjusted Mean: Numeracy	F-value	p-value
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*
Jawa	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*

Group Comparison	School Accreditation	Gender	SES	Adjusted Mean		F-value	p-value
				Science Literacy	Numeracy		
	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*

The ANCOVA results indicate that females excel in scientific literacy at high-SES, top-accredited schools in Java (71.40 ± 3.00; $p = 0.000$), while males dominate numeracy performance in Sumatra (67.80 ± 3.60; $p = 0.001$). The gender gap narrows in "Very Good" accredited schools with medium SES, though males maintain superiority in numeracy. In "Good" accredited schools with low SES, both literacy and numeracy performance decline, yet the gender disparity remains significant, particularly in Kalimantan and Bali. The Hierarchical Linear Modeling (HLM) analysis explores the gender gap in scientific literacy and numeracy across Sundaland, considering three levels: (1) Individual factors, including cognitive ability, mother tongue, and regional influences; (2) Institutional factors, such as school accreditation, teaching quality, and technology integration; and (3) Regional factors, encompassing bilingual programs, government support, and access to educational resources. Table 14 presents the HLM results, comparing male and female performance and the statistical significance (p-value) for each variable examined.

Table 14. HLM Results by Gender

Level	Variable	Male	Female	p-value
Level 1 (Individual)	Sundaland Region	2.50 ± 0.30	2.80 ± 0.28	0.002*
	Cognitive Ability	3.50 ± 0.28	3.80 ± 0.25	0.000*
	Mother Tongue Background	1.80 ± 0.30	2.10 ± 0.28	0.002*
Level 2 (Institutional)	School Accreditation	4.20 ± 0.40	4.50 ± 0.38	0.000*
	Teaching Quality	3.70 ± 0.35	4.00 ± 0.32	0.001*
	Technology Integration	3.80 ± 0.33	4.20 ± 0.30	0.002*
Level 3 (Regional)	Bilingual Program	3.90 ± 0.50	4.30 ± 0.45	0.000*
	Regional Government Support	3.60 ± 0.48	4.00 ± 0.42	0.001*
	Access to Educational Resources	3.40 ± 0.45	3.80 ± 0.43	0.002*

The results from Table 14 on Hierarchical Linear Modeling (HLM) reveal that females significantly outperform males in science literacy and numeracy in the Sundaland region ($p < 0.05$). At Level 1 (Individual), females demonstrated higher cognitive capacity, which was more influenced by their mother tongue background. At Level 2 (Institutional), they benefited more from school accreditation, teaching quality, and technology integration. At Level 3 (Regional), female superiority was evident in bilingual programs, local government support, and access to educational resources. Factors contributing to this advantage include more adaptive learning methods, higher levels of discipline, and a social environment and educational policies that better support female engagement in learning.

Differences in Science Literacy and Numeracy Based on Ethnicity in Sundaland

The analysis (Table 5) highlights 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.

Table 15. ANOVA Results

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups (Science Literacy)	6758.749	14	482.768	38.377	0.000
Within Groups	31511.714	2505	12.58		
Between Groups (Numeracy)	6628.616	14	473.473	32.407	0.000
Within Groups	36598.464	2505	14.61		

Figure 8: The visualization of interactions aims to provide a deeper understanding of the differences in science and numeracy literacy based on ethnicity in Sundaland. Through the interaction graph, the distribution patterns of literacy and numeracy scores can be observed more clearly, including identifying the ethnic groups with the highest and lowest performance, as well as the variations that occur across regions. This visualization also aids in determining whether the effect of ethnicity on science and numeracy literacy is consistent or varies across groups.

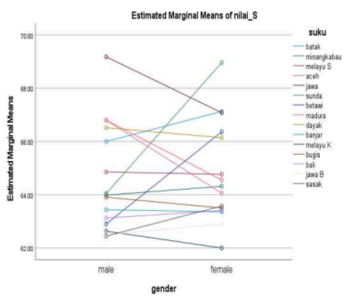

Figure 8. Science Proficiency by Gender and Ethnicity Across Four Regions.

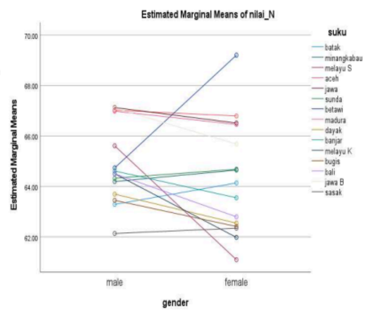

Figure 9. Numeracy Proficiency by Gender and Ethnicity Across Four Regions

The results of Table 16 from 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 16. Independent t-test Based on Gender Across Various Ethnic Groups in Sundaland

Etnis	Gender	Science Literacy	t-value	p-value	Numeracy	t-value	p-value
Batak	M	66.00 (2.70)	-2.608	0.010	63.29 (4.19)	-1.407	0.161
	F	67.13 (2.89)			64.14 (3.63)		
Aceh	M	66.80 (2.90)	4.527	0.000	67.02 (3.75)	0.411	0.681
	F	64.55 (3.51)			66.79 (3.40)		
Javanese	M	67.02 (3.75)	4.011	0.000	67.13 (2.90)	1.215	0.226
	F	66.79 (3.40)			66.51 (3.61)		
Sunda	M	64.04 (3.20)	-10.299	0.000	64.33 (4.16)	-0.596	0.552
	F	68.96 (2.99)			64.68 (3.62)		
Betawi	M	62.90 (3.20)	-7.728	0.000	64.74 (3.10)	-9.505	0.000
	F	66.36 (2.57)			69.20 (2.99)		

The results of the Tukey HSD test (Table 16) reveal significant differences in science and numeracy literacy among ethnic groups in Sundaland, influenced by culture, learning environment, and gender. The Javanese and Batak ethnic groups excel in science literacy, as evidenced by the Batak vs. Minangkabau comparison (MD = 2.41, p = 0.000) and Javanese vs. Malay S. (MD = 3.32, p = 0.000), reflecting an analytical learning culture and a more advanced educational system. In numeracy, the Dayak and Javanese ethnic groups demonstrate superior performance, such as in Dayak vs. Banjar (MD = 2.93, p = 0.000) and Javanese vs. Betawi (MD = 3.50, p = 0.000), supported by contextual learning approaches and the utilization of local technology. Gender-based differences are also evident, with Batak and Javanese females excelling in science literacy, while Dayak and Javanese males dominate in numeracy, as shown in Batak (F) vs. Malay S. (MD = 2.70, p = 0.000) and Javanese (M) vs. Sundanese (MD = 1.63, p = 0.003). Conversely, the Malay K. and Sasak ethnic groups exhibit the lowest performance, as seen in Dayak vs. 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.

Table 17. Tukey HSD Test for Science and Numeracy Literacy by Ethnicity

Etnis	Gender	Sumatra	Jawa	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)*

Etnis	Gender	Sumatra	Jawa	Kalimantan	Bali
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)

The results from Table 17 of the Tukey HSD test reveal significant differences in scientific literacy and numeracy across ethnic groups in Sundaland ($p < 0.001$). The Javanese and Batak ethnic groups consistently demonstrated superior performance, reflecting an analytical learning culture and a more advanced educational system. The Dayak excelled in numeracy, while the Minangkabau, Southern Malay, Acehnese, Sasak, and Kalimantan Malay scored lower, indicating limited access to quality education. The Betawi and Madurese exhibited performance variability, underscoring the importance of environmental factors and social support in academic outcomes. Gender differences also played a role, with Batak and Javanese women showing greater stability in scientific literacy while Dayak men excelled in numeracy. A striking disparity was observed in Bali, where the Javanese-Balinese significantly outperformed the native Balinese ($p < 0.000$), reflecting the successful integration of local culture with modern learning methods. These findings affirm that ethnicity, gender, and socio-cultural environment significantly influence scientific literacy and numeracy. Therefore, the development of a culturally responsive curriculum, enhancement of teacher capacity, integration of educational technology, and implementation of mentoring and psychosocial support programs for disadvantaged groups are essential.

Table 18. ANCOVA for Scientific Literacy and Numeracy Based on Ethnicity.

Wilayah	Etnis	SES	Bahasa Ibu	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

Wilayah	Etnis	SES	Bahasa Ibu	Science Literacy	Numeracy	F-value	p-value
		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

Based on Table 18, the ANCOVA analysis reveals significant differences in scientific literacy and numeracy across ethnic groups in Sundaland, influenced by socioeconomic status (SES) and mother tongue. Ethnic groups with high SES, such as the Batak in Sumatra (68.50 ± 2.60; 67.40 ± 3.00), Javanese in Java (71.20 ± 2.50; 70.00 ± 2.85), Dayak in Kalimantan (66.90 ± 2.85; 65.80 ± 3.40), and Balinese in Bali (65.40 ± 3.20; 64.50 ± 3.80), exhibited the highest scores. Conversely, ethnic groups with low SES, particularly in remote areas like the Dayak and Sasak, experienced significant declines due to limited access to education. The mother tongue serves as a mediator in literacy comprehension. Therefore, culturally inclusive educational policies are necessary to enhance access and quality education for ethnic groups with low SES.

Table 19. HLM for Differences in Scientific Literacy and Numeracy by Ethnicity

Level	Variable	Batak	Minang kabau	Javanese	Dayak	Balinese	p-value
Level 1 (Individual)	Gender	1.60 ± 0.28	1.50 ± 0.30	1.80 ± 0.25	1.40 ± 0.35	1.20 ± 0.40	0.001
	Cognitive Ability	2.90 ± 0.24	2.80 ± 0.26	3.20 ± 0.20	2.70 ± 0.30	2.50 ± 0.28	0.000
	Mother Tongue Background	1.20 ± 0.18	1.10 ± 0.20	1.30 ± 0.18	1.40 ± 0.25	1.20 ± 0.22	0.002
Level 2 (Institutional)	School Accreditation	3.50 ± 0.38	3.40 ± 0.40	3.80 ± 0.35	3.00 ± 0.45	2.80 ± 0.50	0.000
	Teaching Quality	2.70 ± 0.30	2.60 ± 0.35	3.30 ± 0.30	2.60 ± 0.40	2.40 ± 0.38	0.001
	Technology Integration	3.00 ± 0.28	2.90 ± 0.30	3.60 ± 0.28	2.90 ± 0.35	2.60 ± 0.40	0.002
Level 3 (Regional)	Bilingual Program	2.90 ± 0.45	2.80 ± 0.50	3.20 ± 0.45	3.40 ± 0.55	3.10 ± 0.50	0.000
	Regional Government Support	2.80 ± 0.42	2.70 ± 0.48	3.00 ± 0.42	3.20 ± 0.50	2.90 ± 0.45	0.001
	Access to Educational Resources	2.60 ± 0.40	2.50 ± 0.44	2.80 ± 0.40	2.90 ± 0.48	2.70 ± 0.43	0.002

The HLM analysis reveals significant differences in scientific literacy and numeracy across Sundaland, influenced by individual, institutional, and ethnic factors. The Javanese ethnic group achieved the highest scores in cognitive abilities, native language use, school accreditation, teaching methods, and technology utilization, reflecting superior educational quality. The Batak and Minangkabau ethnic groups also demonstrated high scores, while the Dayak and Balinese scored lower due to limited access to education. The Dayak stood out in bilingual programs, whereas the Javanese excelled in government support and access to educational resources. These findings underscore the critical role of cultural factors, institutional support, and educational policies in enhancing literacy. Therefore, strengthening teaching quality, leveraging technology, and integrating local languages are essential to bridging the literacy gap among ethnic groups.

Discussion

The disparity in science and numeracy literacy across the Sundaland region, encompassing Sumatra, Java, Kalimantan, and Bali, is a complex phenomenon influenced by socioeconomic factors, educational infrastructure, local culture, and linguistic diversity. Java, as the national educational hub, demonstrates superior performance in science and numeracy literacy due to technological support, modern science laboratories, and continuous teacher training programs (Indonesian Ministry of Education and Culture, 2021; Coşkun et al., 2019). However, the gap between urban and rural areas remains a challenge that needs to be addressed. In Sumatra, particularly within the Batak and Minangkabau ethnic communities, which possess strong learning cultures and high community support, academic performance tends to be higher (Harahap et al., 2020). Nevertheless, remote areas still face limitations in infrastructure and teaching resources, which can be mitigated through the integration of ethnomathematics and the use of local languages in learning [31]. In Kalimantan, digital inequality, inadequate educational infrastructure, and linguistic barriers remain significant obstacles that limit student participation in STEM literacy (Psaki et al., 2022; Hafni & Aiyub, 2021). Meanwhile, Bali, despite being renowned as a tourist destination, faces challenges in integrating science and numeracy literacy into its culturally rooted education system. However, the Tri Hita Karana philosophy can serve as a holistic approach to enhancing sustainable STEM literacy [59]. Therefore, the recommended strategies include increasing funding allocation for educational infrastructure in remote areas, developing curricula based on local wisdom, providing continuous teacher training, and fostering collaboration between schools and local communities to enhance student learning motivation. This holistic and sustainable approach is expected to reduce gender and cultural disparities and create a more inclusive and equitable education system in the Sundaland region.

Gender disparities in science and numeracy literacy across the Sundaland region are influenced by diverse cultural and linguistic factors. In urban areas, women tend to excel in numeracy literacy due to broader access to technology and STEM education [37], [43]. However, in rural communities, entrenched gender stereotypes and the limited representation of women in science remain significant barriers [35], [45]. In Java, women demonstrate superior numeracy literacy, driven by advanced educational infrastructure, the integration of technology in learning, and 21st-century skills development programs that promote gender equality. Nevertheless, men continue to dominate in mastering technical concepts and scientific experimentation (Ministry of Education and Culture of Indonesia, 2021). In Sumatra, Batak, and Minangkabau women excel in science literacy, particularly in analytical and scientific evaluation skills, supported by a strong learning culture and high community support (Harahap et al., 2020). Conversely, in Kalimantan, women face significant challenges due to limited access to science laboratories and the use of instructional languages that are inconsistent with local culture, leading to male dominance in technical numeracy (Psaki et al., 2022; Hafni & Aiyub, 2021). In Bali, women lag behind in numeracy literacy due to patriarchal cultural influences that restrict their participation in STEM education. However, they excel in science literacy, particularly in environmental analysis and sustainability, which aligns with the Tri Hita Karana philosophy [59]. Therefore, targeted strategies are needed to enhance women's participation in STEM, integrate ethnomathematics into the curriculum, and develop gender-based mentoring programs [40], [41].

Linguistic factors play a crucial role in shaping scientific literacy and numeracy skills in Sundaland. The linguistic diversity across ethnic regions affects the comprehension of scientific and numerical concepts, particularly when there is a disparity between the language of instruction in schools and the native language used in daily life [65]. In Sumatra, the Batak and Minangkabau ethnic groups, known for their strong literacy culture, demonstrate superior academic performance. However, the use of Bahasa Indonesia as the medium of instruction often poses a challenge for students from rural areas with low socioeconomic backgrounds (Harahap et al., 2020; Hafni & Aiyub, 2021). In Java, the complexity of the Javanese language hierarchy, such as ngoko, krama, and krama inggil, as well as the Sundanese language, creates unique challenges in understanding abstract STEM concepts (Andriyanto et al., 2022). Meanwhile, in Kalimantan, the grammatical differences between the Dayak and Banjar languages and Bahasa Indonesia lead to difficulties in grasping scientific and numerical terminology [58]. The lack of teachers who can bridge STEM concepts with local languages further exacerbates students' learning outcomes [6]. In Bali, the culturally rich symbolism embedded in the Balinese language supports the understanding of ecological and environmental concepts. However, the mismatch between scientific terminology in Bahasa Indonesia presents a challenge in numeracy literacy [59]. Therefore, integrating local languages into STEM education [31], developing bilingual teaching materials [54], and providing teacher training that considers students' linguistic backgrounds [7] are effective strategies for enhancing scientific literacy and numeracy in Sundaland.

Inclusive and contextually grounded educational policies have proven effective in enhancing scientific literacy and numeracy across various ethnic groups in Sundaland. In Bali, the integration of Hindu values into environmental education fosters students' ecological awareness, contributing to a deeper understanding of scientific concepts [59]. Similarly, a project-based approach rooted in Minangkabau culture in Sumatra enhances students' analytical skills through the contextual application of STEM concepts [31]. A parallel strategy is implemented in Java, where Sundanese ethnomathematics is integrated to improve students' numeracy skills [1]. In Kalimantan, collaboration between schools and the Dayak community within local wisdom-based programs has strengthened students' understanding of scientific and environmental concepts [58]. Thus, culturally responsive approaches, STEM integration, and strategies for empowering women in science are key to addressing literacy disparities in the Sundaland region.

Implications

The findings of this study offer strategic contributions to the development of more inclusive and culturally responsive educational policies in Indonesia, particularly in multi-ethnic regions such as Sundaland. The results emphasize that disparities in science and numeracy literacy are not solely shaped by individual factors such as gender and cognitive ability, but are also significantly influenced by institutional variables including school accreditation, teaching quality, and technological integration as well as regional policies, such as bilingual education programs, local government support, and access to educational resources. Consequently, the study recommends the reinforcement of culturally grounded and gender-sensitive policies, alongside curriculum reforms that prioritize problem-based and project-based learning (PBL), and the expansion of digital learning infrastructure in underprivileged areas. Furthermore, the integration of multilingual education and ethnomathematics is seen as a vital strategy to bridge interethnic literacy gaps, strengthen local identity, and better equip students to face 21st-century global challenges.

Limitations

Although this study provides a comprehensive overview of literacy disparities across gender and cultural lines, several methodological limitations should be acknowledged. First, the geographical scope of the research is restricted to the Sundaland region, limiting the generalizability of the findings to Eastern Indonesia or international contexts. Second, the study adopts a cross-sectional quantitative design, which excludes longitudinal data and, therefore, cannot assess the long-term impact of proposed inclusive education interventions or policies. Third, despite the triangulation of data through interviews and questionnaires, the depth of qualitative analysis, especially regarding the learning experiences of students from minority groups or remote regions, remains limited. Fourth, some critical control variables such as individual learning styles, community support, and the quality of teacher training, were not fully explored. As a result, while the statistical and policy relevance of this study is substantial, its application must be accompanied by an awareness of contextual constraints and unmeasured variables.

Suggestions

To strengthen the future impact of inclusive education policies and practices, the following recommendations are proposed. First, follow-up studies should adopt longitudinal designs to track students' literacy development over time and to assess the long-term effectiveness of culturally and gender-based interventions. Second, research coverage should be expanded to include Eastern Indonesia and isolated indigenous communities to explore literacy dynamics within more linguistically and culturally diverse contexts. Third, a more balanced integration of mixed methods combining both quantitative and qualitative approaches should be pursued to capture a deeper understanding of the challenges faced by students and teachers in addressing literacy barriers. Fourth, professional development programs for teachers should be designed to focus on inclusive pedagogical approaches, the use of local languages in instruction, and the development of community-based adaptive curricula. Fifth, international collaboration with multicultural nations such as Finland, Canada, and New Zealand is highly recommended to serve as a benchmark for designing sustainable, multilingual, and multicultural education policies.

4. CONCLUSION

This study asserts that scientific literacy and numeracy in Sundaland are influenced by the interaction of gender, culture, and linguistics. Java excels due to better access to education, while Bali demonstrates the lowest performance due to limited infrastructure. Males outperform in numeracy, whereas females excel in scientific literacy, reflecting social norms and cultural expectations. The use of the mother tongue has been shown to enhance conceptual understanding, highlighting the urgency of educational policies that accommodate linguistic diversity. The interaction between individual factors (gender, cognitive abilities), institutional factors (school accreditation, teaching quality), and regional policies (bilingual programs, government support) significantly contributes to literacy outcomes. The Batak and Minangkabau ethnic groups excel due to their strong learning culture, while the Dayak and Banjar communities face linguistic barriers and lack social support. To bridge the literacy gap in a multiethnic society, inclusive educational policies are needed that uphold national standards while adapting to regional linguistic variations. Key strategies include integrating ethnomathematics into the curriculum, enhancing teacher capacity in culturally responsive teaching, and fostering collaboration among schools, communities, and research institutions. Further studies are necessary to evaluate the effectiveness of multilingual education and the impact of inclusive policies on reducing literacy disparities in Indonesia.

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AUTHOR CONTRIBUTION STATEMENT

DY conceived the research design, led the writing process, and supervised the data analysis. YJ coordinated data collection in the Sundaland region and contributed to the statistical analysis. EAJ was responsible for the development and validation of research instruments and contributed to the literature review. SA conducted fieldwork, managed interviews, and participated in qualitative data interpretation. MRU assisted with model design, data visualization, and technical editing of the manuscript. JM contributed to the ethnographic context analysis and the discussion of regional educational disparities. All authors reviewed and approved the final version of the manuscript.

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