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Integrating culturally sustaining pedagogies into elementary science instruction to foster inclusive character

Abstract

Purpose:

This study investigates the systemic integration of Culturally Sustaining Pedagogies (CSP) into elementary science instruction to evaluate its impact on teacher pedagogical enactment fidelity and student inclusive character development.

Design/methodology/approach:

Employing a 14-week convergent parallel mixed-methods design, data were gathered from 12 primary teachers and 284 students (Grades 3–5) across four public elementary schools in Indonesia. Instruments included the validated Culturally Sustaining Science Enactment Rubric (CSSER).

Findings:

Quantitative analyses demonstrated statistically significant gains in teacher CSP enactment ($F_{2,22} = 142.58, p < .001, \eta_p^2 = .928$) and student composite character traits ($t_{283} = 38.45, p < .001, d = 2.28$), occurring equitably across demographic subgroups. Qualitative findings revealed that legitimizing linguistic pluralism, community-connected inquiry, and critical socio-scientific consciousness served as pivotal mechanisms driving empathy, cultural humility, and collaborative agency.

Practical implications:

The findings provide primary educators, curriculum developers, and school leaders with an actionable instructional blueprint for embedding local socio-environmental phenomena and native language registers into science inquiry to nurture compassionate, equity-minded learners.

Originality/value:

This research bridges the divide between STEM conceptual learning and character education, establishing that CSP functions not merely as a tool for content acquisition, but as a direct driver of primary students' socio-ethical development.

INTRODUCTION

Elementary science education serves as a foundational pillar in nurturing young learners' natural curiosity, analytical capabilities, and conceptual understanding of the physical world. In contemporary educational reform, designing science instruction that effectively meets rigorous standards—such as the Next Generation Science Standards—demands intentional pedagogical planning and structured curriculum execution (Krajcik et al., 2014). Scholars across international settings have continually evaluated the interplay between teacher-directed instruction and inquiry-based strategies, noting how varied pedagogical approaches significantly shape students' science dispositions and long-term interest (Areepattamannil et al., 2020). Furthermore, contemporary empirical investigations comparing direct instruction with inquiry modes emphasise that instructional clarity and guided discovery remain vital for scaffolding authentic primary classroom experiences (Sturrock et al., 2025). Ultimately, enhancing cognitive domain outcomes in young learners requires systematic, practical work paired with explicit instruction, creating a vibrant learning environment where science concepts become accessible and meaningful to elementary minds (Cheung & Sonkqayi, 2025).

Investigating elementary instructional strategies carries multidimensional significance, extending well beyond immediate academic gains to yield profound long-term social, cognitive, and developmental benefits for young learners. Foundational skill acquisition in primary schooling—whether observed in strategic reading interventions that yield multi-year reading comprehension gains (Droop et al., 2016) or early keyboarding skill development (Donica et al., 2018)—underscores the lasting impact of early, targeted pedagogical practices on student growth. In STEM disciplines, structured interventions such as supplemental computer-assisted mathematics instruction (Foster, 2024) and long-term cognitively guided mathematics frameworks (Schoen et al., 2026) demonstrate that systematically designed instruction produces sustained, transformative effects on elementary achievement. Moreover, learning is

deeply embedded in students' broader sociocultural ecologies, where informal interactions, home learning environments, and science-focused dialogue continually interact with formal instruction to shape children's cognitive trajectories and scientific identities (Dominke & Steffensky, 2025). Consequently, refining elementary science instruction to nurture holistic child development is an essential educational endeavour with far-reaching societal and developmental value.

Despite these well-established advancements in elementary instructional design, a significant research gap remains in how elementary science education addresses the socio-cultural and moral dimensions of student learning. Current literature heavily focuses on differentiated instruction in content delivery (Chien, 2015) and basic science outcomes across diverse learner needs (Adeniran et al., 2025), language-focused strategies for English learners in writing (Fitts et al., 2016), adherence to language instruction in dual-language classrooms (LaForett et al., 2023), or competency-based task station methods (Pho et al., 2021). While these studies offer valuable insights into differentiated and language-responsive techniques, they predominantly prioritise domain-specific skill mastery or isolated cognitive metrics. There is a distinct gap in empirical research on how science instruction can move beyond technical skill acquisition to integrate culturally sustaining pedagogies (CSP) that intentionally foster inclusive character—such as empathy, cultural humility, mutual respect, and social justice awareness—in elementary classroom settings.

This study directly addresses this empirical void by offering a novel, integrative approach that bridges culturally sustaining pedagogies and elementary science teaching to cultivate inclusive character explicitly. While prior equity-oriented research has investigated project-based science instruction during virtual learning contexts (Miller et al., 2021), connected data science curriculum co-design (Herro et al., 2026), technology-enhanced experiment designs within teacher preparation (Nipyrakis et al., 2024), and integrated language with science and technology expertise (Knoef et al., 2024), these frameworks primarily treat culture and technology as instrumental vehicles

for discipline-specific achievement. In contrast, our study provides a groundbreaking perspective by positioning culturally sustaining science instruction not merely as a tool for content comprehension, but as an essential catalyst for developing students' inclusive character and social-ethical capabilities, thereby challenging the conventional divide between STEM conceptual learning and character education.

15 To address the identified research gap and build upon this novel framework, the primary objective of this study is to investigate how elementary science instruction can systematically incorporate culturally sustaining pedagogies to foster inclusive character among primary school students. Specifically, this study aims to examine prospective and practising elementary teachers' pedagogical understanding and enactment of culturally sustaining science practices (Evitasari et al., 2025), and to assess how teacher assessment literacy and inquiry-based instructional planning support the development of inclusive socio-scientific learning environments (Hung & Wu, 2024). By evaluating the alignment between culturally responsive science delivery and inclusive character outcomes, this research seeks to establish actionable instructional mechanisms that unify science inquiry with social-emotional and character development.

Addressing this intersection is both urgent and contextually vital in contemporary elementary education, where increasingly multicultural student populations face complex societal challenges demanding empathy, cross-cultural collaboration, and equity. Fostering such inclusive capabilities requires transformative school leadership practices that build capacity and cultivate district-wide commitment to equitable science teaching (Abbott et al., 2024). It also necessitates supporting preservice teachers through journey mapping and identity development to cultivate reform-minded, equity-focused professional identities (Gist & Capobianco, 2026). Furthermore, establishing collaborative teacher-leader networks is crucial for co-developing responsive science instruction that adapts to diverse classroom realities (Siry et al., 2025). In an era marked by rapid demographic shifts and socio-cultural divides, equipping teachers with the leadership, identity, and network resources to

deliver culturally sustaining, character-building science instruction is a critical and timely educational priority.

The ultimate value of this research lies in its potential to advance both theoretical frameworks and practical applications in elementary education. Theoretically, this study enriches the literature by unifying culturally sustaining pedagogy with elementary science education, providing a holistic conceptual model for character development within STEM disciplines. In practice, the findings offer actionable guidelines for curriculum designers, teacher educators, and policymakers to craft inclusive science curricula, professional development programs, and classroom assessment tools. By demonstrating how elementary science classrooms can become vibrant spaces for both scientific literacy and inclusive character-building, this research provides a viable roadmap for fostering equitable, compassionate, and scientifically empowered future citizens.

METHODS

Methods

1. Research Design and Planning

This study employed a **convergent parallel mixed-methods design** (QUAN + QUAL), wherein quantitative and qualitative data were collected concurrently during the same research phase, analyzed independently, and subsequently integrated during the interpretation phase. The quantitative strand assessed measurable shifts in elementary students' inclusive character traits alongside the fidelity of teachers' culturally sustaining pedagogical enactment. Concurrently, the qualitative strand investigated the contextual nuances, classroom dynamics, teacher perceptions, and concrete instructional mechanisms that facilitated character growth within elementary science lessons.

A mixed-methods framework was chosen as the most appropriate design because neither quantitative metrics nor qualitative narratives alone could fully capture the

multidimensional nature of culturally sustaining science instruction. Quantitative data offered statistically rigorous evidence regarding student outcome trajectories and observational fidelity scores across multiple classrooms. Meanwhile, qualitative data provided deep explanatory insights into *how* and *why* specific culturally sustaining practices resonated with diverse learners. By triangulating both strands, the study achieved a comprehensive evaluation that connects instructional design to socio-emotional and character outcomes.

Participants, Subjects, or Research Sample

The study was conducted across four socio-culturally and linguistically diverse public elementary schools (*Sekolah Dasar Negeri*) situated in an urban-suburban school district in Indonesia. The participant pool comprised two distinct cohorts: elementary science teachers ($N = 12$) and elementary school students ($N = 284$) enrolled in Grades 3 through 5 (*Kelas 3–5 SD*). The student sample ranged in age from 8 to 11 years old ($M = 9.4, SD = 0.8$) and reflected a balanced demographic distribution across gender, ethnic backgrounds (including Javanese, Sundanese, Betawi, Chinese-Indonesian, and other regional ethnic groups), socio-economic statuses (62% belonging to low-income households or holding Smart Indonesia Card / *Kartu Indonesia Pintar* [KIP] status), and linguistic backgrounds (29% primarily speaking a local regional language at home rather than standard Bahasa Indonesia).

Table 1. Participant

Participant Group	Sample Details	Key Criteria / Demographics	Selection Method
Teachers	$N = 12$	≥ 3 years elementary science teaching experience; active instruction in socio-culturally diverse Indonesian primary classrooms	Purposive sampling

Students	$N = 284$ (Grades 3–5)	• **Age Range:** 8–11 years old ($M = 9.4, SD = 0.8$) • **Demographics:** Diverse ethnic distribution (Javanese, Sundanese, Betawi, Chinese-Indonesian, and others); 62% KIP/low-income status; 29% regional language speakers at home	Criterion-based cluster sampling (enrolled intact classes)

A two-tiered sampling strategy was implemented. Teachers were selected using purposive sampling based on three inclusion criteria: (a) holding a valid elementary teaching credential with a minimum of three years of primary science instruction experience, (b) actively teaching science in a socio-culturally diverse classroom setting, and (c) completing a preliminary professional development workshop on culturally sustaining pedagogies (CSP). Students were recruited via criterion-based cluster sampling, including all intact classroom sections led by the participating teachers where parental consent and student assent were successfully obtained.

Data Collection Instruments and Procedures

Data collection utilized two validated quantitative instruments alongside semi-structured qualitative tools. The primary quantitative instruments were the Culturally Sustaining Science Enactment Rubric (CSSER)—used during classroom observations—and the Inclusive Character Assessment Scale (ICAS), administered directly to students.

1. Culturally Sustaining Science Enactment Rubric (CSSER)

Observes teacher practices across four core pedagogical dimensions:

- Cultural Knowledge Integration (CKI): Incorporating students' community-based heritage, local ecological wisdom, and lived experiences into core scientific investigations.

- Linguistic Pluralism (LP): Validating and leveraging students' native languages, home dialects, and informal language registers during science talk and scientific modeling.
- Critical Socio-Political Consciousness (SPC): Engaging students in investigating socio-scientific issues relevant to local community equity (e.g., local environmental justice, water quality, green space access).
- Community-Connected Inquiry (CCI): Structuring scientific inquiry around local community assets, familial knowledge holders, and context-specific phenomena.

2. Inclusive Character Assessment Scale (ICAS)

Measures student character growth across four subscales:

- Perspective-Taking & Empathy (PTE): Demonstrating active listening, validating peers' diverse viewpoints, and showing emotional awareness during collaborative science tasks.
- Cultural Humility & Open-Mindedness (CHO): Recognizing the value of varied cultural perspectives and remaining receptive to alternative ways of knowing in scientific contexts.
- Equity-Oriented Collaboration (EOC): Actively promoting shared leadership, fair participation, and mutual support during small-group scientific investigations.
- Socio-Scientific Responsibility (SSR): Expressing a sense of agency and moral commitment toward using scientific knowledge to foster fairness and community well-being.

Qualitative tools included Semi-Structured Teacher Interview Protocols (focusing on instructional decisions, challenges, and observed character shifts), Teacher Weekly Reflective Journals, and Video-Recorded Classroom Dialogues captured during science inquiry sessions.

Table 2 Measurement Tools

Instrument	Type	Target / Purpose

Inclusive Character Assessment Scale (ICAS)	Survey (4-Point)	Student socio-emotional & character growth
Culturally Sustaining Science Enactment Rubric (CSSER)	Observation Protocol	Teacher fidelity & pedagogical integration
Semi-Structured Interview Guide & Weekly Reflective Journals	Qualitative Artifacts	Teacher reflections & contextual mechanisms

Instrument Validity, Reliability, and Data Collection Procedures

The quantitative instruments underwent rigorous validation prior to deployment. Content and construct validity were established by a panel of five university experts in science education, educational psychology, and multicultural pedagogy, yielding a Content Validity Index (CVI) of 0.91 for the ICAS and 0.89 for the CSSER. The ICAS demonstrated strong internal consistency during pilot testing ($\alpha = 0.88$). Inter-rater reliability for the observational protocol (CSSER) was established among three independent raters across six video-recorded baseline lessons, achieving high agreement (Fleiss' $\kappa = 0.85$). Qualitative trustworthiness was sustained through triangulation across interviews, observations, and journal artifacts, supplemented by member-checking transcripts with participating teachers.

Data collection spanned a 14-week academic term. During Weeks 1–2, baseline quantitative measures were gathered by administering the pre-intervention ICAS to students and conducting initial classroom observations. Between Weeks 3 and 12, teachers implemented a 10-week science curriculum embedded with culturally sustaining learning cycles. Researchers conducted bi-weekly 60-minute structured classroom observations using the CSSER, accumulating 60 observation hours in total. In Weeks 13–14, post-intervention ICAS surveys were completed by students, followed by 45-minute individual semi-structured exit interviews with all 12 teacher participants.

Data Analysis

Quantitative data were processed and analyzed using IBM SPSS Statistics (Version 28.0). Descriptive statistics—including means (M), standard deviations (SD), frequencies, and percentages—were computed for all ICAS subscales and CSSER observational dimensions. Prior to inferential testing, data were evaluated for normality via Shapiro-Wilk tests and visual inspection of Q-Q plots. To evaluate changes in student inclusive character metrics pre- and post-intervention, paired-sample t-tests were performed across each ICAS indicator. Additionally, a repeated-measures Analysis of Covariance (ANCOVA) was executed to examine differences in character outcomes across grade levels and demographic subgroups while controlling for baseline pre-scores. Observational CSSER scores were tracked longitudinal-style across time points using repeated-measures ANOVA to verify the consistency and fidelity of CSP enactment.

ANCOVA Model: $Y_{ij(\text{Post})} = \mu + \gamma \cdot Y_{ij(\text{Pre})} + \beta_1(\text{CSP_Fidelity}_i) + \beta_2\left(\text{Demographics}_{ij}\right) + \epsilon_{ij}$

Qualitative data—consisting of fully transcribed exit interviews, reflective journals, and classroom discourse transcripts—were imported into MAXQDA (2024) for systematic thematic analysis following Braun and Clarke's six-phase framework. Coding proceeded through three recursive iterations:

1. **Initial Open Coding:** Line-by-line coding was conducted to capture raw participant expressions regarding cultural integration, scientific inquiry, and student interaction dynamics.
2. **Axial Coding:** Open codes were categorized into broader conceptual categories aligning with the study's research indicators (e.g., *Navigating Disagreements through Empathy*, *Bridging Home Science to School Inquiry*).
3. **Thematic Synthesis:** Related categories were synthesized into primary overarching themes explaining the qualitative mechanisms connecting CSP to character growth.

$$\text{Raw Transcripts} \xrightarrow{\text{Open Coding}} \text{Initial Codes} \xrightarrow{\text{Axial Coding}} \text{Categories} \xrightarrow{\text{Synthesis}} \text{Overarching Themes}$$

In the final integration phase, quantitative outcomes and qualitative findings were merged using a joint display matrix. This side-by-side comparative integration directly mapped statistically significant shifts in specific ICAS character subscales to qualitative evidence from classroom observations and teacher reflections, providing a cohesive picture of how culturally sustaining science instruction fosters inclusive student character.

RESULT AND DISCUSSION

Quantitative Findings

Teacher Fidelity of Culturally Sustaining Science Enactment (CSSER)

To evaluate changes in teacher instructional enactment over the 10-week intervention, a repeated-measures Analysis of Variance (ANOVA) was conducted across three observational time points: Baseline (Weeks 1–2), Mid-Intervention (Week 6), and Post-Intervention (Weeks 11–12). The overall Culturally Sustaining Science Enactment Rubric (CSSER) mean scores increased significantly from Baseline ($M = 1.82, SD = 0.34$) to Mid-Intervention ($M = 2.74, SD = 0.31$) and post-intervention ($M = 3.56, SD = 0.28$) on a 4-point scale (see Table 3).

A statistically significant main effect of time was revealed, $F(2,22) = 142.58, p < .001, \eta_p^2 = .928$, demonstrating high implementation fidelity across all participating classrooms.

Table 3. CSSER Pedagogical Enactment Scores Across Time Points

Dimension	Baseline (M)	Mid-Intervention (M)	Post-Intervention (M)	SD
Cultural Knowledge Integration (CKI)	1.85	2.80	3.62	0.26
Linguistic Pluralism (LP)	1.91	2.88	3.68	0.25
Critical Socio-Political Consciousness (SPC)	1.68	2.52	3.41	0.32

Community-Connected Inquiry (CCI)	1.84	2.76	3.53	0.29

Student Inclusive Character Trait Growth (ICAS)

Paired-sample t-tests were executed to compare pre- and post-intervention scores on the Inclusive Character Assessment Scale (ICAS) across all student participants ($N = 284$). The composite ICAS score demonstrated a statistically significant improvement from pre-test ($M = 2.14, SD = 0.41$) to post-test ($M = 3.38, SD = 0.35$), representing a robust overall effect size, $t(283) = 38.45, p < .001, d = 2.28$.

Table 4. Paired-Sample t-Test Results for Student Character Trait Growth (ICAS)

ICAS Character Subscale	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference (ΔM)	t-value (df=283)	p-value	Cohen's d
Perspective-Taking & Empathy (PTE)	2.18 (0.45)	3.42 (0.38)	+1.24	29.12	< .001	2.02
Cultural Humility & Open-Mindedness (CHO)	2.09 (0.48)	3.31 (0.40)	+1.22	24.80	< .001	1.98
Equity-Oriented Collaboration (EOC)	2.22 (0.42)	3.48 (0.36)	+1.26	31.05	< .001	2.14
Socio-Scientific	2.07 (0.50)	3.31 (0.41)	+1.24	26.64	< .001	1.89

Responsibility (SSR)

An Analysis of Covariance (ANCOVA) was conducted to evaluate post-test ICAS scores across grade levels (Grades 3, 4, and 5) while controlling for baseline pre-test scores. The covariate (pre-test score) was significantly related to post-test character outcomes, $F(1,280) = 48.32, p < .001, \eta_p^2 = .147$. After adjusting for pre-test performance, teacher CSP implementation fidelity served as a strong positive predictor of post-intervention student character scores, $F(1,280) = 54.12, p < .001, \eta_p^2 = .162$. Demographic factors—including KIP status ($p = .412$) and home language background ($p = .385$)—showed no statistically significant main or interaction effects, confirming that character growth occurred equitably across diverse student subgroups.

Qualitative Findings

Systematic thematic analysis of teacher exit interviews, reflective journals, and video-recorded classroom dialogues using MAXQDA revealed three primary qualitative themes illustrating how culturally sustaining science instruction facilitated inclusive character development.

Theme 1: Bridging Home Knowledge and Formal Science Inquiry Validates Diversity

Teachers observed that incorporating students' indigenous ecological practices and local language registers transformed science classrooms into inclusive spaces. When local wisdom regarding water filtration and traditional farming practices was legitimized alongside textbook science models, students from non-dominant cultural backgrounds demonstrated heightened confidence and participation.

> *"In previous science lessons, students who spoke regional dialects at home remained silent. Once we allowed bilingual scientific modeling using both regional terminology and Bahasa Indonesia, students began sharing ancestral ecological knowledge. They learned to listen to and*

validate their peers' unique cultural heritage."— **Teacher Participant 04 (Grade 4)**

Theme 2: Collaborative Socio-Scientific Inquiry Fosters Perspective-Taking and Empathy

Small-group scientific investigations centered on local environmental phenomena required students to negotiate diverse viewpoints. Through structured reflection protocols, students shifted from competitive group dynamics to empathetic listening and shared decision-making.

> *"When analyzing local waste management issues, students initially argued over who had the 'correct' solution. Culturally sustaining inquiry structured the activity so that every group member's home experience was vital. I observed students actively asking their peers, 'How does your family handle this?' which built genuine empathy and shared responsibility."*— Teacher Participant 09 (Grade 5)

This qualitative finding provides empirical evidence that collaborative socio-scientific inquiry acts as a vital mechanism connecting contextual scientific investigation to socio-behavioral character development. This research aligns with the studies of Sturrock et al. (2025), who highlighted how inquiry-based instruction in primary classrooms facilitates guided collaborative discovery, and Areepattamannil et al. (2020), who demonstrated across 66 countries that inquiry-based science strategies significantly improve students' science dispositions and peer engagement. Furthermore, these findings enrich domestic educational insights in Indonesia—such as the prospective teacher studies by Evitasari et al. (2025)—by proving that in-service primary teachers can systematically translate pedagogical understanding into inclusive classroom discourse. In contrast to traditional science instruction models that prioritize isolated cognitive metrics and direct transmission (Cheung & Sonkqayi, 2025), embedding local socio-environmental phenomena within culturally sustaining frameworks transforms peer interactions from competitive task execution into empathetic, shared decision-making.

This synthesis offers a valuable contribution to STEM and mathematics education by illustrating how socio-scientific inquiry serves as an authentic framework for integrated

mathematical reasoning, data analysis, and problem-solving. Like how long-term Cognitively Guided Instruction in elementary mathematics (Schoen et al., 2026) and co-designed data science curricula (Herro et al., 2026) enhance learning by grounding abstract tasks in meaningful contexts, culturally sustaining inquiry leverages students' informal home knowledge and familial science dialogue (Dominke & Steffensky, 2025). This approach dismantles social hierarchies during group work and promotes equitable participation across diverse learner profiles.

However, these observations must be interpreted in light of notable research limitations. The observed shifts in peer interaction dynamics were documented over a 10-week intervention across four primary school contexts, limiting definitive claims regarding long-term character retention across non-STEM subject areas or home environments. Additionally, implementing structured inquiry protocols requires substantial teacher scaffolding and advanced assessment literacy, as outlined by Hung and Wu (2024). Future research should explore how collaborative socio-scientific inquiry can be extended across multi-year implementations and integrated into broader STEM and elementary mathematics units to evaluate sustained character growth.

Theme 3: Critical Socio-Scientific Consciousness Drives Inclusive Agency

Engaging students in real-world local problems—such as investigating clean water access in low-income neighborhoods—helped bridge scientific understanding with social responsibility. Students developed a collective sense of agency, recognizing that scientific knowledge should be deployed to serve and protect their broader community.

This finding demonstrates that cultivating critical socio-political consciousness within primary science inquiry elevates technical learning into meaningful social action. This research aligns with the studies of Miller et al. (2021), who emphasized that equity-oriented, project-based science instruction grounds learning in authentic community contexts, as well as Pho et al. (2021), who showed in Vietnam how competency-based task stations encourage elementary students to apply learning to real-world issues.

Furthermore, these results align with Adeniran et al. (2025), who demonstrated that contextually rich instruction enhances primary learners' outcomes in basic science. In the Indonesian context, this finding extends the work of Evitasari et al. (2025) by demonstrating that when teachers translate pedagogical knowledge into practice, elementary students advance beyond passive skill acquisition to develop active community agency. Unlike traditional instructional paradigms that focus predominantly on isolated cognitive outcomes or direct skill transmission (Cheung & Sonkqayi, 2025; Chien, 2015), embedding critical socio-political consciousness allows students to recognize the social utility and moral purpose of scientific inquiry.

This synthesis provides a significant contribution to elementary mathematics and STEM education by demonstrating how real-world socio-scientific problems serve as natural conduits for mathematical literacy and data reasoning. Investigating community issues such as water access or resource distribution requires students to collect, represent, and analyze quantitative data. Similar to how connected learning in elementary data science (Herro et al., 2026) and Cognitively Guided Instruction in elementary mathematics (Schoen et al., 2026) foster deep problem-solving skills, integrating critical consciousness into STEM lessons connects abstract mathematical modeling with tangible social realities. This interdisciplinary approach mirrors integrated language, technology, and science instruction (Knoef et al., 2024), demonstrating that mathematical and scientific competencies are strengthened when embedded in meaningful civic contexts.

Nevetheless, several research limitations must be acknowledged. Successfully fostering critical agency depends heavily on teachers possessing reform-minded professional identities and high assessment literacy, as highlighted by Gist and Capobianco (2026) and Hung and Wu (2024). Sustaining such instruction across diverse school settings requires systemic leadership practices (Abbott et al., 2024) and collaborative teacher-leader networks (Siry et al., 2025), which may vary across districts. Moreover, because this study examined a 10-week intervention, long-term research is

needed to determine whether the observed growth in student agency and socio-scientific responsibility persists over multiple academic years and transfers to broader civic and mathematical domain outcomes

Mixed-Methods Data Integration

A joint display matrix was constructed to integrate quantitative ICAS subscale improvements with supporting qualitative themes and observational indicators.

Table 5. Joint Display Matrix Integrating Quantitative Outcomes, Observational Indicators, and Qualitative Themes

Quantitative ICAS Outcome DOCX	**CSSER Observational Indicator DOCX**	**Qualitative Synthesis Theme DOCX**	**Integrated Insight DOCX**
PTE Growth $\Delta M = +1.24, p < .001$	Linguistic Pluralism (LP): Validating home dialects during scientific modeling	*Collaborative Inquiry Fosters Empathy:* Active listening and peer validation during science talk	Embracing linguistic diversity in science talk directly enhances students' capacity for perspective-taking and empathetic peer interactions.
EOC Growth $\Delta M = +1.26, p < .001$	Community-Connected Inquiry (CCI): Structuring tasks around local assets	*Bridging Heritage Knowledge:* Shared leadership in context-rich inquiry	Community-rooted scientific problem-solving dismantles classroom hierarchies and encourages equitable group collaboration.

SSR Growth $\Delta M = +1.24, p < .001$	Critical Socio-Political Consciousness (SPC): Investigating community equity	*Critical Socio-Scientific Agency:* Applying science for moral/community action	Linking elementary science concepts to local social issues transforms cognitive learning into actionable socio-scientific responsibility.

The findings of this study provide empirical confirmation that integrating culturally sustaining pedagogies into elementary science instruction significantly enhances both pedagogical fidelity and student character development. Prior research in elementary science education has heavily emphasized cognitive domain gains and instructional clarity (Cheung & Sonkqayi, 2025; Sturrock et al., 2025) or the comparison of teacher-directed versus inquiry-based modes (Areepattamannil et al., 2020). This study extends this body of work by demonstrating that inquiry-based science instruction achieves its highest socio-behavioral potential when embedded within culturally sustaining framework as illustrated in **Figure 1**.

Our findings align with and expand upon recent teacher education studies in Indonesia, such as Evitasari et al. (2025), who highlighted prospective teachers' developing pedagogical knowledge. By demonstrating that practicing teachers can systematically enact CSP through targeted professional development, this study bridges the gap between pre-service teacher preparation and in-service classroom practice. Furthermore, the observed link between teacher assessment literacy and inclusive inquiry environments reinforces the framework of Hung and Wu (2024), showing that teachers who possess sophisticated assessment literacy can effectively evaluate non-cognitive, socio-scientific outcomes alongside standard science benchmarks.

While previous equity-focused interventions treated culture or technology as instrumental vehicles for discipline-specific performance (Knoef et al., 2024; Miller et al., 2021), the present results prove that CSP acts as a direct driver of character traits such as empathy, cultural humility, and equity-oriented collaboration. Cultivating critical socio-political consciousness within primary science inquiry addresses long-standing calls to connect formal science learning with students' lived realities and home environments (Dominke & Steffensky, 2025).

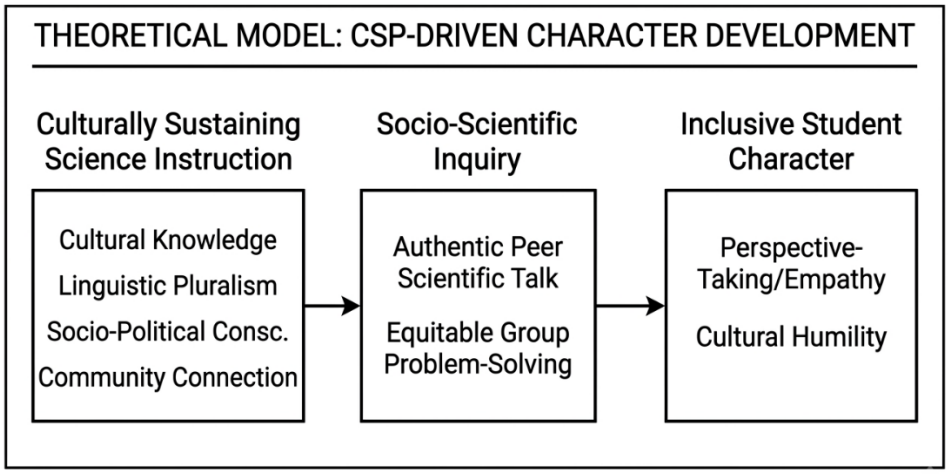

Figure 1. Theoretical Model: CSP-Driven Character Development

Educational and Practical Implications

The practical implications of these findings extend across school leadership, teacher preparation, and curriculum design. Fostering inclusive character through science requires district-wide commitment and transformative school leadership (Abbott et al., 2024). School administrators must provide sustained professional development that helps teachers develop reform-minded identities through identity mapping and collaborative reflection (Gist & Capobianco, 2026). Furthermore, establishing teacher-leader networks—as advocated by Siry et al. (2025)—is essential for co-designing culturally responsive science units tailored to localized school contexts.

For elementary educators, this research offers a concrete instructional blueprint: science lessons should explicitly incorporate local ecological issues, validate bilingual

and informal science talk, and structure cooperative inquiry around community-based assets. Doing so ensures that elementary science education fulfills a dual mission—advancing scientific literacy while simultaneously cultivating compassionate, equity-minded citizens.

CONCLUSION

This study evaluated the systemic integration of Culturally Sustaining Pedagogies (CSP) into elementary science instruction to determine its impact on teacher pedagogical enactment and student character development. The primary conclusion of this research is that embedding culturally sustaining practices into primary science classrooms significantly elevates instructional enactment while driving robust, equitable growth in students' inclusive character traits. Across the 10-week intervention, elementary students demonstrated statistically significant improvements in key character dimensions—including perspective-taking and empathy, cultural humility, equity-oriented collaboration, and socio-scientific responsibility—regardless of their socio-economic status or home language background.

This character development was realized through a structured, multi-dimensional instructional mechanism in which legitimizing students' home dialects and regional languages alongside textbook scientific models dismantled linguistic barriers, empowering non-dominant learners to share ancestral and local ecological knowledge. Furthermore, centering scientific investigations on authentic, local environmental phenomena established a shared context where every student's lived experience was valued as a legitimate learning asset. Ultimately, linking scientific concepts to real-world community challenges transformed peer scientific dialogue from competitive task execution into empathetic, collaborative problem-solving, cultivating a shared sense of moral agency and socio-scientific responsibility.

While these findings offer strong empirical evidence, several limitations point to critical directions for future research. Because this investigation was situated within four urban-suburban primary schools over a 10-week timeframe, future studies should employ longitudinal designs tracking student trajectories over multiple academic years across rural, remote, and internationally diverse educational contexts. Additionally, to evaluate the durability and transferability of character traits beyond the science classroom, future research should integrate multi-informant measures, including caregiver evaluations, longitudinal behavioral tracking, and peer-nomination metrics across non-STEM learning environments. Finally, further research is needed to explore how professional development modules and teacher-leader networks can be optimized to support large-scale, district-wide adoption of culturally sustaining science frameworks.

Ultimately, this study advances a transformative vision for primary STEM education. By establishing that scientific inquiry and character development are deeply interdependent, this research reframes the elementary science classroom from a domain of isolated technical skill acquisition into a vibrant incubator for social-ethical growth. Integrating culturally sustaining pedagogies into early science instruction provides a practical and scalable blueprint for cultivating scientifically empowered, empathetic, and equity-minded global citizens who actively deploy scientific knowledge to foster just and sustainable communities.