# Students' chemical literacy improvement in culturally responsive teaching oriented toward green chemistry for stoichiometry topic

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**Abstract.** This pre-experimental study aimed to investigate the improvement of students' chemical literacy through culturally responsive teaching oriented toward green chemistry (CRT-GC) in stoichiometry topic. A total of 108 high school students from two public schools in Yogyakarta, Indonesia, participated in the study, selected through random sampling. Data were collected using an adapted chemical literacy test and analyzed through a paired sample t-test and n-gain analysis. The results revealed a significant improvement in students' chemical literacy after the implementation of CRT-GC learning approach, with an n-gain score categorized as high. Students demonstrated enhanced understanding of chemical concepts and showed the ability to relate them to real-life contexts such as the use of natural dyes in batik production, eco-friendly food preservation, and sustainable materials in cultural practices. These findings indicate that integrating culturally relevant and environmentally conscious contexts into chemistry learning can strengthen students' chemical literacy by making scientific knowledge more meaningful and applicable. The study suggests that CRT-GC learning provides an effective pedagogical approach for fostering contextualized science learning and encouraging responsible scientific thinking among students.

**Keyword.** chemical literacy, culturally responsive teaching, green chemistry, stoichiometry, contextual learning

## 1 Introduction

Chemical literacy is a fundamental goal of chemistry education because it enables students to apply chemical knowledge to real-world contexts, make informed decisions, and develop awareness of the role of chemistry in sustainable development [1]. However, several studies have shown that students often struggle to connect abstract chemical concepts such as stoichiometry with their daily lives and broader societal issues [2-3]. This gap indicates the need for instructional approaches that make chemistry learning more meaningful, contextual, and socially relevant.

Culturally responsive teaching (CRT) has emerged as a promising pedagogical approach to address this challenge [4]. CRT emphasizes the integration of students' cultural backgrounds, local experiences, and community values into the learning process to enhance engagement and understanding [5]. In chemistry learning, this approach can be implemented by linking concepts to local cultural practices that involve chemical principles. For example, teachers can explore the chemistry of traditional food preservation using fermentation, natural dyeing processes in batik making, metal corrosion in local crafts, or soap-making traditions that use natural oils [6-8]. These contexts allow students to see chemistry not as an isolated discipline but as part of their cultural heritage and daily life. By recognizing and valuing cultural diversity in the classroom, CRT promotes inclusive learning environments where students can construct scientific meaning through contexts that are personally and culturally relevant [9].

In addition to making learning culturally meaningful, students also need to be guided to think critically about the broader implications of chemical applications on the environment and society [10]. Many industrial and household chemical processes contribute to pollution, waste generation, and unsustainable resource use, which can harm ecosystems and human health. Teaching chemistry through such real-world issues encourages students to analyze how chemical reactions and production methods can be improved to reduce their negative impacts [11-12]. This educational orientation, which focuses on minimizing hazardous substances, conserving materials, and promoting sustainability, is captured in the concept of green chemistry [13]. Integrating the principles of green chemistry into culturally responsive learning allows students to not only master scientific calculations and reasoning but also to understand the ethical and environmental responsibilities that accompany chemical knowledge [14]. Through this synthesis, chemistry learning becomes a space for developing chemical literacy that is both contextually grounded and environmentally conscious.

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Stoichiometry, as one of the core topics in chemistry, offers an excellent opportunity to implement culturally responsive teaching oriented green chemistry (CRT-GC) learning. Despite its importance, students often find stoichiometry abstract and mathematically demanding [15]. Embedding culturally relevant and sustainability-based contexts such as traditional food production that involves chemical reactions, eco-friendly local industry practices, or community-based waste management can make stoichiometry learning more tangible and meaningful [3].

Therefore, this study aims to examine the improvement of students' chemical literacy through CRT-GC in stoichiometry topic. By applying this integrated approach in a classroom setting, the study seeks to determine whether culturally and environmentally contextualized learning can improve students' understanding, reasoning, and awareness in chemistry.

## 2 Methods

This study employed a pre-experimental method with a one-group pretest–posttest design. A total of 108 students of the 10th grade were taken by cluster random sampling technique from two senior high school in Yogyakarta city, Indonesia. The same teacher taught all classes with students that had the same socio-cultural background, an age range of 16–17 year olds, and equal prior knowledge about chemistry.

The teaching intervention was carried out over six sessions, each lasting 90 minutes, covering three main topics: chemical equations, the basic laws of chemistry, and the concept of the mole. During the lessons, students worked collaboratively in small groups of four to five members. The learning process was guided by the principles of the CRT approach, which emphasizes five features, namely, considering content integration, facilitating knowledge construction, prejudice reduction, social justice, and academic development. Table 1 illustrates the learning conditions during the third meeting of the CRT-GC learning.

Data were collected through an open-ended questionnaire of a chemical literacy test instrument adapted from adapted from Wiyarsi et al. [16]. The adapted instrument consisted of four main aspects, including chemical content, culturally relevant contexts oriented toward green chemistry, higher-order learning skills (HOLS), and an affective aspect represented by students' learning interest. The test measured students' ability to apply chemical knowledge within culturally contextualized and environmentally oriented (green chemistry) scenarios. Data analysis employed a paired-sample t-test and n-gain analysis to examine the significance and magnitude of improvement between students' pretest and posttest scores. Additionally, descriptive statistics were employed to present the mean scores of students' chemical literacy, as well as to calculate the frequencies and percentages related to students' argumentation patterns in chemistry learning with cultural and sustainability contexts.

**Table 1.** An outline of the third lesson about the basic laws of chemistry.

| Features | Activities |
|---|---|
| Content integration | Students read a passage titled "Batik sebagai Warisan Budaya Indonesia" presented in the worksheet to connect cultural knowledge with chemical concepts. Students also compared the mass of batik cloth before and after washing to relate culturally familiar activities to the concept of mass changes in chemical processes. |
| Facilitating knowledge construction | Students discussed the application of the law of conservation of mass based on the information provided in the worksheet. They also identified the factors that caused the mass of batik to decrease during the washing process and formulated conclusions regarding the law of conservation of mass. |
| Prejudice reduction | Students completed practice problems related to the law of conservation of mass to strengthen their conceptual understanding and minimize misconceptions. |
| Academic development | Through the completion of structured exercises, students reinforced their mastery of stoichiometric ideas within meaningful cultural contexts. |
| Social justice | The teacher guided students through a question and answer session that encouraged inclusive participation, enabling all learners to access and articulate their understanding. |

## 3 Results

The paired sample t-test results revealed a significant difference in students' chemical literacy before and after the implementation of the CRT-GC learning approach (see Table 2). The negative t-value indicates that posttest scores were significantly higher than the pretest scores, suggesting an overall improvement in students' chemical literacy following the intervention.

This finding demonstrates that the CRT-GC learning approach effectively enhanced students' understanding and appreciation of chemical concepts integrated with environmental values and local wisdom in chemistry learning. The increase in chemical literacy implies that students not only engaged cognitively with chemistry content but also developed affective and reflective competencies that align with CRT principles.

**Table 2.** Paired t-test for chemical literacy in CRT toward green chemistry learning.

| | N | Mean | SD | df | t-value | P* | Conclusion (* |
|---|---|---|---|---|---|---|---|
| Pre-Post | 108 | -70.194 | 14.3 | 107 | -51.012 | .000 | Significantly different |

*(*) Computed using alpha: 0,05.*

These results support previous studies emphasizing that CRT can create more inclusive and meaningful learning experiences by connecting scientific knowledge with students' cultural backgrounds and real-life contexts [17-18]. Furthermore, integrating

green chemistry principles likely encouraged students to reflect on sustainable practices rooted in their local traditions, thereby strengthening the relevance of science education to everyday cultural and environmental issues. Overall, the significant improvement in chemical literacy highlights the potential of CRT-GC learning as a holistic instructional approach that bridges scientific understanding and socio-environmental responsibility.

Table 3 presents the n-gain of students' chemical literacy after the CRT-GC in stoichiometry learning. The average pretest score was 15.87, which increased to 85.98 in the posttest. The n-gain value of 0.831 indicates a high category of improvement according to Hake's classification [19]. These results show that students experienced a substantial increase in chemical literacy after participating in CRT-GC learning.

**Table 3.** n-Gain of students' chemical literacy.

| N | Average Score | | | Category |
|---|---|---|---|---|
| | Pretest | Posttest | n-Gain | |
| 108 | 15.87 | 85.98 | 0.831 | High |

The results showing the improvement in students' chemical literacy were further supported by their responses to various culturally and environmentally relevant contexts. While the quantitative findings demonstrated a high n-gain score, a closer look at students' contextual responses provides deeper insight into how they applied their understanding within culturally meaningful chemistry issues. Table 4 presents students' argumentation across four cultural contexts that integrated green chemistry principles. The findings show that students were able to connect scientific understanding with social and cultural considerations in a meaningful way. In the context of the batik industry, most students supported the use of natural dyes and appropriate waste management practices. This tendency suggests that they were aware of the chemical consequences of synthetic dyes and understood how chemistry can contribute to solving local environmental problems. Their reasoning reflects the application of stoichiometric ideas to real situations, particularly in minimizing waste and improving process efficiency within community-based practices.

Furthermore, students' responses in the Serabi Solo context indicate that they viewed traditional knowledge and modern science as complementary rather than opposing forces. Many of them emphasized maintaining traditional preparation methods while adopting eco-friendly innovations. This combination shows that students were able to balance cultural preservation with sustainability, demonstrating higher-order learning skills and the ability to integrate cultural relevance into chemical reasoning. Such thinking is essential in developing contextual chemical literacy, where scientific understanding is applied to support sustainable local practices.

In a similar way, arguments in the Jamasan Pusaka context reveal both cognitive understanding and emotional engagement. A large number of students emphasized the importance of continuing this cultural ritual while ensuring the safe use of chemicals. This response illustrates that students recognized the connection between cultural heritage and responsible scientific practice. Nevertheless, the small portion of students who considered the tradition outdated indicates that some lacked prior exposure to local cultural practices. This highlights the importance of culturally responsive instruction that reintroduces students to the value of local traditions through scientific exploration.

Finally, the responses related to the Ngaben ceremony demonstrate students' growing awareness of environmental responsibility. Most participants agreed that the ceremony should be preserved while incorporating sustainable materials and methods to reduce emissions. This view reflects the development of ethical reasoning and ecological awareness, which are essential aspects of chemical literacy. By integrating cultural and environmental perspectives, students were able to see how chemistry can contribute to both sustainability and cultural continuity.

Taken together, these results demonstrate that the CRT-GC learning approach not only improved students' conceptual understanding but also encouraged them to apply chemistry meaningfully within their cultural and environmental contexts. Such outcomes affirm that CRT-GC learning helps students internalize chemistry as a human-centered and socially relevant science, fostering the growth of meaningful and responsible chemical literacy.

## 4 Discussion

The findings of this study revealed a significant positive effect of the CRT-GC on students' chemical literacy in stoichiometry learning. The paired sample t-test result ($t(107) = -51.012$, $p < .001$) demonstrated a substantial increase in students' post-test scores. This confirms that CRT-GC learning effectively enhanced their understanding of chemical concepts, environmental relevance, and cultural integration. This improvement suggests that when chemistry instruction acknowledges students' cultural backgrounds and local wisdom while simultaneously linking them with sustainable practices, students develop a more profound understanding of the real-world implications of chemical phenomena.

The demonstrated efficacy of the CRT-GC approach can be theoretically explained through the five major characteristics of this pedagogical model [20]. The first feature, content integration, played a central role in helping students relate abstract stoichiometric concepts to familiar cultural and ecological issues. When students analyzed the use of natural dyes in the batik industry or calculated material efficiency in rituals such as Ngaben and Jamasan Pusaka, they experienced chemistry as a living discipline embedded in their daily lives. This connection increased the meaningfulness of chemical content and fostered stronger engagement. In line with Thomas's [21] framework of multicultural education, integrating culturally relevant content provides access to knowledge that resonates with students' experiences, thus fostering both academic and affective learning outcomes. Therefore, the students' improved chemical literacy, specifically in the domains of chemical content and contexts, reflects how cultural relevance transforms

abstract scientific knowledge into a meaningful and humanized learning experience.

The second characteristic, facilitating knowledge construction, encouraged students to actively interpret, reason, and reconstruct their understanding rather than merely receiving information [6]. During CRT-GC based discussions, students were invited to evaluate the sustainability of local traditions and to justify their viewpoints using stoichiometric principles. This dialogic learning process aligns with constructivist learning theory, which emphasizes that meaningful knowledge emerges from interaction between prior experiences and new information. In this sense, students not only developed conceptual understanding but also strengthened their higher-order learning skills (HOLS), encompassing critical analysis, decision making, and reflective reasoning. The iterative process of prediction, explanation, and reflection embedded in CRT-GC activities resembles inquiry based learning, which has been shown to promote students' scientific reasoning and problem solving abilities in chemistry contexts.

Meanwhile, the third feature, prejudice reduction, emerged as a subtle yet meaningful dimension of change. Through culturally grounded chemistry discussions, students became more appreciative of traditional wisdom and less dismissive of cultural practices often perceived as unscientific. For instance, many students acknowledged the scientific logic embedded in local dyeing processes or food preservation techniques that utilize natural fermentation. This shift in perception signifies the reduction of epistemic prejudice, defined as the tendency to view western scientific practices as superior to local knowledge systems. This reflects a broader affective growth within students' learning interest and openness to multiple ways of knowing, resonating with Chaiwanichsiri's assertion [22] that culturally responsive pedagogy nurtures empathy, respect, and inclusivity within science classrooms.

The fourth characteristic, social justice, provided students with a moral and civic dimension of chemistry learning. Specifically through the examination of socio-environmental issues such as pollution from synthetic dyes or emissions during cultural ceremonies, students learned that chemistry is not value neutral but a discipline deeply connected to societal well being. These discussions guided students to see themselves as agents of change who can apply chemical principles to solve community based problems sustainably. Interestingly, several students proposed creative alternatives, such as using plant based materials to reduce environmental waste, showing an integration of scientific reasoning with social responsibility. This finding aligns with Kuo's [23] argument that socio culturally grounded science instruction can foster critical consciousness and environmental ethics, particularly when students are encouraged to address real problems relevant to their local contexts.

The fifth and final characteristic, academic development, was strengthened through structured learning tasks that combined conceptual mastery with cultural and ecological reflection. Students were not only assessed based on their understanding of stoichiometric calculations but also on their ability to apply these concepts to environmental management and sustainable resource use. This holistic development reflects the goal of CRT-GC to balance cognitive, affective, and ethical growth in science learning. In this study, students demonstrated more advanced reasoning and engagement when they could connect the principles of atom economy or reaction efficiency with cultural practices that value harmony between humans and nature. Therefore, academic development within CRT-GC does not solely refer to test performance but to the cultivation of literate, critical, and responsible scientific thinkers.

These findings are consistent with previous studies emphasizing that culturally responsive teaching enhances students' engagement, academic achievement, and identity in science learning [24-26]. Similarly, integrating green chemistry principles has been shown to promote environmental literacy, critical thinking, and sustainability awareness. What distinguishes the present study is the synergistic integration of CRT and GC, forming a bridge between cultural relevance and ecological responsibility. While CRT ensures that learning is emotionally and culturally meaningful, GC grounds that meaning in scientific and ethical awareness. This dual orientation likely explains the significant improvement in students' chemical literacy, encompassing not only cognitive comprehension but also emotional engagement and value based reflection.

The Indonesian sociocultural context also plays an important role in shaping these results [27-28]. In a collectivist society where communal harmony and respect for tradition are highly valued, connecting chemistry learning to cultural practices provides an avenue for deeper engagement and identification with the subject [29]. However, this same context can also constrain open debate or critical questioning, as students tend to value consensus over confrontation [30-32]. Therefore, the CRT-GC learning, which promotes culturally sensitive dialogue and inquiry, becomes a powerful tool to balance respect for tradition with critical analysis, thereby helping students develop scientific reasoning without disregarding their cultural roots.

More broadly, the enhancement in chemical literacy observed in this study can be interpreted as a chain of interrelated developments: culturally relevant contexts stimulated curiosity, which in turn strengthened motivation to learn; motivated engagement promoted knowledge construction; and sustained inquiry cultivated critical and reflective thinking. These interconnected processes demonstrate that the CRT-GC approach fosters a comprehensive literacy that integrates knowledge, skills, and attitudes necessary for 21st century scientific citizenship.

**Table 4.** Percentages of coding for students' argumentation toward cultural and green chemistry contexts in chemical literacy test.

| Cultural oriented toward green chemistry contexts | Responses/ Frequencies (percentages) | | |
|---|---|---|---|
| **Synthetic dye in batik industry** Students make arguments about efforts to reduce environmental pollution caused by synthetic dye waste from the batik industry. | Fully disagree: 8 (7.40%) | Agree with using natural dyes and waste control: 82 (75.90%) | Neutral or unsure about the issue: 18 (16.70%) |
| **Traditional food preservation in Serabi Solo** Students make arguments about ways to sustain the popularity of traditional foods like Serabi Solo while supporting environmental sustainability. | Prefer modern packaging and instant process: 10 (9.30%) | Support traditional methods with ecofriendly innovation: 78 (72.20%) | Indifferent toward preservation: 20 (18.50%) |
| **Cultural heritage of Jamasan Pusaka** Students make arguments about the importance of preserving the Jamasan pusaka tradition that is becoming less practiced among younger generations. | Tradition no longer relevant in modern life: 12 (11.10%) | Important to preserve as cultural identity with safe chemical use: 85 (78.70%) | Neutral or unfamiliar with the tradition: 11 (10.20%) |
| **Balancing tradition and sustainability in Ngaben ceremony** Students make arguments about how to balance the preservation of the Ngaben ceremony with environmental sustainability efforts. | Should continue without change: 9 (8.30%) | Maintain tradition with sustainable materials and reduced emissions: 80 (74.10%) | Ceremony should be simplified to reduce pollution: 19 (17.60%) |

## 5 Conclusion

The implementation of CRT-GC learning in stoichiometry topic effectively improves students' engagement and understanding of chemistry concepts through the integration of environmental values, sustainability issues, and local wisdom. This learning approach fosters meaningful connections between chemical concepts and students' everyday experiences, thereby improving their chemical literacy. The high n-gain score further confirms that the improvement achieved through CRT-GC learning is not only statistically significant but also substantial in magnitude. By uniting the principles of CRT and green chemistry, chemistry education can transcend traditional content delivery, empowering students not only to master stoichiometric calculations but also to interpret chemistry as a meaningful practice rooted in culture, sustainability, and social responsibility.

Although the enhancement in chemical literacy was significant, some students still faced challenges in transferring conceptual understanding to broader socio-environmental contexts. The important implication is that chemistry teachers should continuously integrate cultural and environmental dimensions into chemistry instruction to promote both scientific understanding and responsible citizenship. This study has several limitations, including the relatively small sample size, limited observation during laboratory sessions, and restricted range of contextual materials used in learning activities. Future studies may involve diverse local green chemistry contexts and broader samples to further explore the long-term impact of CRT-GC learning on students' chemical literacy.

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