Journal of Turkish Science Education, 2026, *23*(3), 455-469
DOI no: 10.36681/tused.2026.022

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Uncovering culturally responsive teaching to biology problem solving through cultural literacy, environmental literacy, and students' social attitudes

Nurlia[1], Nurhayati B[2], Syamsiah[3], Hilda Karim[4], Asham Bin Jamaluddin[5]

[1]*Faculty of Mathematics and Natural Science, Universitas Negeri Makassar, Indonesia, ORCID ID: 0009-0003-8349-0040*
[2]*Faculty of Mathematics and Natural Science, Universitas Negeri Makassar, Indonesia, Corresponding author:* nurhayati.b@unm.ac.id, *ORCID ID: 0000-0003-2923-0857*
[3]*Faculty of Mathematics and Natural Science, Universitas Negeri Makassar, Indonesia, ORCID ID: 0009-0009-2644-6709*
[4]*Faculty of Mathematics and Natural Science, Universitas Negeri Makassar, Indonesia, ORCID ID:* 0009-0008-6830-2765
[5]*Faculty of Mathematics and Natural Science, Universitas Negeri Makassar, Indonesia, ORCID ID: 0000-0003-0562-072X*

This section is part of the dissertation and provides a comprehensive theoretical foundation and a review of relevant empirical studies that support the research framework.

ABSTRACT
A culturally responsive teaching approach is an important strategy for fostering meaningful learning by integrating learning materials with cultural contexts to improve concept understanding, social skills and awareness of environmental issues. This study aims to explain the effect of culturally responsive teaching on students' biology problem solving, mediated by cultural literacy, environmental literacy and social attitudes. This study used a quantitative approach with a cross-sectional survey design and structural equation modeling, implemented using Smart Partial Least Squares 3.3.2. The research subjects were 302 students from the biology education and biology study programs at 16 universities in the Sulawesi region, Indonesia. The data collection instrument was a closed-ended Likert-scale questionnaire that had undergone expert validation. The results of the analysis indicated that culturally responsive teaching had a significant effect in increasing cultural literacy, environmental literacy and social attitudes, all of which had a positive impacted biology problem solving.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 18.07.2025
Accepted: 26.09.2025
Available Online: 14.09.2026

KEYWORDS: Culturally responsive teaching, biology problem solving, cultural literacy, environmental literacy, social attitudes.

To cite this article: Nurlia., B, Nurhayati., Syamsiah, Karim, H., & Bin Jamaluddin, A. (2026). Uncovering culturally responsive teaching to biology problem solving through cultural literacy, environmental literacy and students' social attitudes. *Journal of Turkish Science Education, 23*(3), 455-469. http://doi.org/10.36681/tused.2026.022

Introduction

Culturally responsive teaching (CRT) emphasizes the integration of students' cultural references, experiences and backgrounds into all aspects of the learning process (Gay, 2002). By connecting students' cultural backgrounds with instructional practices, CRT can promote more meaningful and relevant learning experiences (Villegas & Lucas, 2002). The integration of culture into education can also strengthen students' academic understanding while fostering social awareness and appreciation of cultural diversity (Banks & Banks, 2019). A deeper understanding of learning materials, therefore, is important not only for developing academic competence but also for fostering critical thinking and cross-cultural empathy, which are essential competencies in increasingly multicultural educational contexts (Suprapto et al., 2024). These perspectives indicate that culturally responsive learning should move beyond the inclusion of cultural content as supplementary material and instead position students' cultural knowledge and experiences as resources for constructing meaningful knowledge.

The importance of culturally responsive learning is increasingly relevant in the context of globalization and digitalization. Contemporary education is expected to equip learners with complex thinking skills, social competencies and digital literacy to respond effectively to rapid socio-cultural and technological changes (González-Pérez & Ramírez-Montoya, 2022). At the same time, globalization may create challenges for the continuity of traditional knowledge and cultural identities. Education, cultural documentation, community participation, and supportive policies are therefore important in maintaining traditional identities in the 21st century (Hiswara et al., 2023). Within education, this effort can be realized by integrating local cultural values, traditional knowledge and local wisdom into learning activities. Such integration enables students to recognize the relevance of their cultural heritage while connecting it with contemporary scientific knowledge and real-life challenges.

The integration of culture into science education is particularly important because scientific concepts are often taught in abstract forms that may be disconnected from students' everyday experiences. Connecting scientific knowledge with local contexts can provide meaningful entry points for students to understand concepts, interpret phenomena and apply knowledge to problems in their surroundings. In biology education, local plants and their uses represent a particularly relevant cultural context because communities possess diverse knowledge concerning plant identification, utilization, traditional medicine, food, rituals and environmental management. Bringing such knowledge into the learning process can create opportunities for students to compare local knowledge with scientific explanations, identify similarities and differences and develop a more contextual understanding of biological concepts. Thus, culturally responsive approaches have the potential to position local cultural knowledge not merely as an illustration but as a starting point for scientific inquiry and knowledge construction.

This perspective is closely related to the development of cultural literacy, environmental literacy, social attitudes and biology problem solving. Cultural literacy enables learners to understand, interpret and appreciate cultural knowledge and practices, while environmental literacy supports their ability to understand environmental issues and make responsible decisions (Hungerford & Volk, 1993). Social attitudes are also important because learning requires students to interact, collaborate, respect different perspectives and take responsibility within their social environment. Meanwhile, problem solving enable learners to identify problems, analyze causes, evaluate alternatives and formulate appropriate solutions (Parkin et al., 2004). These competencies are not independent; rather, they can reinforce one another when learning is designed around authentic cultural and environmental contexts.

The relationship among these competencies becomes particularly evident when students are engaged in biological problems that emerge from their immediate cultural and environmental surroundings. For example, learning about local plants can involve students in identifying species, investigating their traditional uses, examining their ecological significance and considering potential threats to their sustainability. Such activities require students to mobilize cultural knowledge, scientific understanding, environmental awareness, social interaction and higher-order thinking simultaneously. Students' ability to analyze, evaluate and solve biological problems therefore requires not only cognitive competence but also an understanding of cultural and environmental contexts and the capacity to collaborate and act responsibly in social settings. This suggests that culturally responsive learning has the potential to provide an integrated learning environment for developing multiple competencies rather than addressing them separately.

Nevertheless, the integration of local culture into biology learning remains challenging. Learning materials frequently emphasize scientific concepts while providing limited opportunities for students to connect these concepts with the cultural knowledge and experiences present in their communities. As a result, students may understand biological concepts at a theoretical level but have fewer opportunities to recognize their relevance to local environmental and cultural issues. Digital learning resources provide an opportunity to address this gap because they can integrate text, images, videos, interactive activities, local examples and contextual problems within a single learning environment. When designed according to culturally responsive principles, digital materials can facilitate independent learning while simultaneously connecting scientific knowledge with students' cultural experiences.

Taken together, the literature suggests that culturally responsive learning can serve as an important pedagogical foundation for connecting students' cultural backgrounds with scientific learning and for developing broader competencies needed in the 21st century. However, the literature also indicates a need for learning resources that systematically integrate cultural knowledge with biological concepts while simultaneously fostering cultural literacy, environmental literacy, social attitudes and biology problem solving. This gap is particularly relevant in plant taxonomy, a field that can be closely connected to local biodiversity and community knowledge of plants. Therefore, developing an e-module based on culturally responsive teaching (CRT) for plant taxonomy represents a promising approach to bridge scientific knowledge with local cultural knowledge and to provide students with contextual learning experiences that support the development of interconnected cognitive, cultural, environmental and social competencies.

Preliminary observations and analyses of learning activities and assessment results indicates that students' biology problem solving, cultural literacy, environmental literacy and social attitudes indicated low levels according to established indicators. In biology learning, assessment results indicated that many students had difficulty identifying biological problems, applying relevant concepts and analyzing data to formulate solutions. In terms of cultural literacy, students demonstrated limited knowledge of cultural diversity, insufficient understanding of local and global cultural contexts and low ability to communicate across cultural differences. Environmental literacy assessments indicated low awareness of environmental issues and limited engagement in environmentally responsible behaviors.

Furthermore, observations of learning interactions revealed low levels of empathy, a high degree of individualistic behavior and minimal participation in collaborative or socially oriented activities. These findings indicate gaps in students' higher-order thinking skills, social awareness and engagement with real-world biological and environmental issues. CRT emphasizes the importance of linking students' experiences and cultural values to the learning process, making it easier for them to understand and apply concepts in biology problem solving.

The objective of this study is to examine the effect of culturally responsive teaching (CRT) on students' biology problem solving and to investigate the mediating roles of cultural literacy, environmental literacy and social attitudes. The contribution of this research lies in its interdisciplinary framework, which integrates biology education, cultural literacy, environmental literacy, social attitudes and biology problem solving within the context of CRT. This study offers a comprehensive model that explains the relationships among these variables, which have often been examined separately in previous research.

Based on the proposed conceptual framework, the research questions are formulated as follows:

1. How does culturally responsive teaching influence students' cultural literacy, environmental literacy and social attitudes?
2. How do cultural literacy, environmental literacy and social attitudes influence students' biology problem solving?
3. How does culturally responsive teaching influence students' biology problem solving?
4. To what extent do cultural literacy, environmental literacy, and social attitudes mediate the relationship between culturally responsive teaching and students' biology problem solving?

Literature Review

Biology Education and Problem Solving

Biology education is expected not only to transfer factual knowledge but also to cultivate students' problem solving, environmental awareness and social attitudes that support responsible scientific action (Gay, 2018; Guerrero, 2020). Conventional curricula often remain abstract and disconnected from students' lived experiences, limiting the development of higher-order thinking skills. Embedding cultural and environmental contexts into biology learning enhances relevance, motivation and engagement, which in turn contribute to better problem solving outcomes.

Problem solving skills are central to learning, reflecting critical, analytical and creative thinking abilities necessary to address real-world challenges. Students with well-developed problem solving can identify problems, gather and analyze information, evaluate alternatives and propose solutions based on scientific reasoning (Mahanal et al., 2022; Nurhayati et al., 2023; Sari et al., 2021). These skills are particularly important for addressing environmental challenges, applying biological knowledge and making decisions that consider ethical, social and ecological implications.

In biology education, connecting learning with students' environmental and cultural experiences can make biological problems more meaningful and encourage students to relate scientific concepts to issues in their surroundings. These findings suggest that biology problem solving can be strengthened when learning integrates cognitive processes with contextual, environmental, cultural and social dimensions. However, the extent to which culturally responsive teaching contributes to biology problem solving, particularly through cultural literacy, environmental literacy and social attitudes, remains insufficiently explored. This gap provides a basis for examining the relationships among these variables in the present study.

Culturally Responsive Teaching (CRT)

CRT views students' cultural backgrounds as pedagogical assets, linking academic content with cultural practices, values and lived experiences (Gay, 2018; Villegas & Lucas, 2002). Research indicates that CRT increases engagement, strengthens identity and improves academic performance in science classrooms (Barron et al., 2021). In biology education, CRT has been implemented in laboratory-based instruction and higher education contexts to promote inclusivity and deepen conceptual understanding.

Previous studies have shown that culturally responsive learning can support biology problem solving by providing meaningful contexts in which students connect academic concepts with their prior knowledge, cultural experiences and community practices. Keehne et al. (2018) reported that incorporating students' cultural experiences into learning can promote engagement and create opportunities for students to develop reasoning and problem solving. Similarly, Rahmawati et al. (2023) and Indarwati et al. (2024) found that culturally contextualized learning encouraged students to analyze real-life problems, relate scientific concepts to their surroundings and develop appropriate solutions.

These findings suggest that CRT may contribute to biology problem solving not only by improving students' understanding of subject matter but also by making learning more relevant and encouraging students to draw on culturally situated knowledge when addressing problems. Nevertheless, existing studies have largely focused on learning engagement, conceptual understanding, or general higher-order thinking, while empirical evidence examining the direct effect of CRT on measurable biology problem solving abilities remains limited. Therefore, further investigation is needed to determine whether CRT can directly enhance students' biology problem solving abilities and how this effect may be associated with other competencies developed through culturally responsive learning.

Cultural Literacy

Cultural literacy is defined as the ability to recognize, interpret and apply cultural knowledge in learning (Maine et al., 2019; Ochoa et al., 2018). It enables students to contextualize scientific content within familiar cultural narratives and practices. Incorporating cultural perspectives into biology problem solving tasks, such as local agricultural techniques, community health beliefs, or indigenous ecological knowledge, enhances conceptual understanding and critical thinking (Gay, 2018). In biology education, this connection is particularly relevant because local knowledge of plants, agriculture, health and the environment can provide authentic contexts for understanding biological concepts and addressing real-world problems.

Cultural literacy may therefore contribute to biology problem solving by helping students recognize the cultural dimensions of a problem, integrate multiple perspectives, and formulate solutions that are scientifically appropriate while remaining relevant to the local context. However, most previous studies have examined cultural literacy as an educational or sociocultural outcome, rather than investigating its role as a mechanism through which culturally responsive teaching contributes to students' biology problem solving abilities. This indicates a research gap concerning the mediating role of cultural literacy in the relationship between CRT and biology problem solving.

Environmental Literacy

Environmental literacy encompasses knowledge of ecological systems, pro-environmental attitudes and the skills needed for responsible decision-making (McBeth & Volk, 2010; McBride et al., 2013). Both formal and non-formal education significantly influence environmental awareness and behavior (Syamsiah et al., 2024). Problem-based learning (PBL) in environmental contexts has been shown to enhance ecological understanding and the ability to apply biological knowledge to real-world problems (Hollweg et al., 2011; Lewinsohn et al., 2019). Environmental literacy provides a meaningful context for assessing biology problem solving because addressing ecological challenges requires analyzing evidence, evaluating alternatives and making ethically informed decisions.

These findings suggest that environmental literacy can contribute to biology problem solving by providing students with the knowledge, awareness and decision-making skills required to address complex ecological problems. However, previous research has more frequently examined environmental literacy as an outcome of environmental education or as a predictor of environmental behavior, while its role in the relationship between culturally responsive teaching and biology problem solving has received limited empirical attention. This gap highlights the need to investigate whether environmental literacy mediates the effect of CRT on students' biology problem solving.

Social Attitudes

Social attitudes including empathy, cooperation, social responsibility and respect for collective norms, are essential for collaborative scientific problem solving (Bustami et al., 2017; Martínez et al., 2020). Culturally responsive learning environments, these attitudes can be strengthened because students' identities, experiences and cultural perspectives are recognized and valued, creating opportunities for respectful interaction and inclusive classroom discourse. Such social interactions are particularly important in biology problem solving, where students may need to negotiate different interpretations of a problem, evaluate alternative solutions and reach decisions collaboratively.

Thus, social attitudes may contribute to biology problem solving by supporting effective communication, collaboration and responsible decision-making. However, previous studies have predominantly examined social attitudes as outcomes of inclusive or culturally responsive education, with limited attention to their potential role as a mediator linking CRT with students' biology problem solving. This gap warrants further investigation into whether social attitudes function as an important pathway through which CRT contributes to the development of biology problem solving.

Integration of CRT, Literacy and Social Attitudes in Problem Solving

Recent studies provide evidence that culturally responsive approaches can support multiple dimensions of science learning. Culturally responsive and sustaining pedagogies can connect students' cultural experiences with scientific knowledge and create more inclusive science learning environments (Smith et al., 2022). Empirical research has also shown that problem-based culturally responsive learning can significantly improve students' critical thinking and cultural literacy (Ernawati et al., 2026), while culturally responsive transformative teaching has been found to significantly enhance environmental literacy (Wijayanti et al., 2025). In addition, ethnoscience-based learning can strengthen critical thinking and cultural literacy by connecting scientific concepts with local knowledge and cultural practices (Atmojo et al., 2025). These findings suggest that CRT, cultural literacy and environmental literacy can complement one another in developing students' capacity to understand and solve contextual scientific problems. However, previous studies have generally examined these competencies separately or in limited combinations and empirical evidence concerning their interconnected relationships with social attitudes and biology problem solving remains limited. Therefore, examining these relationships within a single model may provide a more comprehensive understanding of how culturally responsive biology education develops students' cognitive, cultural, environmental and social competencies.

Methods

Research Design

This study employs non-experimental quantitative methods (Hair et al., 2021), involving systematic data collection and analysis, to examine the influence of the CRT approach on students' biology problem solving mediated by cultural literacy, environmental literacy and social attitudes. Data were collected using a cross-sectional design to investigate the relationships between the implementation of CRT in learning and students' cultural literacy, environmental literacy, social attitudes and biology problem solving.

Participants and Research Implemention

The participants in this study were undergraduate students from the biology education and biology programs at various state and private universities in the Sulawesi region of Indonesia. The respondents in this research were active students in semesters 2, 4, 6 and 8, as the study was conducted during the even semesters. The research sample was randomly selected and consisted of 302 students, comprising 42 males and 260 females. A total of sixteen universities participated in the study, all offering degree programs in the two fields of Biology Education and Biology**.** This study employed a survey method to identify the levels of cultural literacy, environmental literacy, social attitudes and biology problem solving among undergraduate students.

Research Instrument

This research used a questionnaire containing 31 statements across 5 variables. Questionnaire statements were developed based on a review of the relevant literature (Androsov & Zhang, 2023; Bustami et al., 2017; Halbert & Chigeza, 2015; McBeth & Volk, 2010; Shahat et al., 2013), as show in Appendix. The questionnaire used was a closed-ended instrument presented as a list of statements with answer choices on a four-point Likert scale: Strongly Agree, Agree, Disagree and Strongly Disagree. The questionnaire went through validated by academic experts for item relevance and alignment with the research variables. All items met the validity criteria, with scores ranging from 4.25 to 4.50 (≥ 4.0), while the reliability analysis showed Cronbach's alpha values ranging from 0.730 to 0.910 (≥ 0.70), indicating adequate validity and reliability. The questionnaire used consisteds of two parts: the respondent's identity and statement items.

Data Analysis

The study structural equation modeling (SEM) using SmartPLS 3.3.2. This method is suitable for testing the relationships between independent and dependent variables (Hair et al., 2019). The SEM approach was used to examine the relationships among the CRT approach, cultural literacy, environmental literacy, social attitudes, and biology problem solving abilities. Validity was assessed using outer loadings (>0.60) (Ghozali & Latan, 2015). Reliability and internal consistency were evaluated through Cronbach's alpha (>0.70), rho A (>0.70), composite reliability (>0.70) and convergent validity using the average variance extracted (AVE > 0.50). Discriminant validity was assessed using the Fornell-Larcker criterion and cross-loadings (Barclay & Thomson, 1995; Hair et al., 2019). According to the Fornell-Larcker criterion, the square root of the AVE for each construct (on the diagonal) must exceed its correlations with other constructs (Fornell & Larcker, 1981; Hair et al., 2019). Additionally, each cross-loading should be highest for its respective construct compared to other constructs (Hair et al., 2021). The internal consistency benchmark ranges from 0 to 1. T-tests and F-tests via bootstrapping were performed to determine the significance of path coefficients in the structural model ($T > 1.96$ and $p < 0.05$) at a 95% confidence interval with 5,000 subsamples (Henseler, 2012).

Finding

Based on the results of the SEM analysis, the outer loading values for each variable item which is a student perception indicate that of the 31 statements, 11 did not exceed the threshold of 0.60. This suggests that these items failed to represent the constructs being measured adequately. This could be due not only to inconsistencies in respondents' answers but also to factors such as ambiguous statement wording, misinterpretation of items, or insufficient alignment of certain items with the underlying constructs. The highest outer loading value for each variable item was observed for CRT2 (0.860), CLL5 (0.863), ELL3 (0.843), SOC4 (0.890) and PRO8 (0.828). The values obtained for Cronbach's alpha, rho A and composite reliability for each variable exceed the minimum threshold (0.70) so it can be concluded that the reliability is in the good category. The AVE convergent validity assessment demonstrates that the AVE is greater than 0.50, indicating that the convergent validity criterion is met. In detail, the results of the outer loading analysis, Cronbach's alpha, rho A, composite reliability and AVE are depicted in Table 1.

Table 1

The results of the reflective measurement model analysis

Variable	Item variables	Outer loadings	Cronbach's alpha	Rho A	Composite reliability	AVE
Culturally Responsive Teaching	CRT1	0.850	0.788	0.791	0.876	0.702
	CRT2	0.860				
	CRT3	out				
	CRT4	0.803				
Cultural Literacy	CLL1	out	0.848	0.854	0.898	0.688
	CLL2	out				
	CLL3	0.775				
	CLL4	0.847				
	CLL5	0.863				
	CLL6	0.830				
	CLL7	out				

Environmental Literacy	ELL1	0.818	0.712	0.723	0.839	0.636
	ELL2	out				
	ELL3	0.842				
	ELL4	0.727				
Social Attitudes	SOC1	out	0.891	0.900	0..921	0.702
	SOC2	0.678				
	SOC3	0.838				
	SOC4	0.890				
	SOC5	0.881				
	SOC6	0.882				
	SOC7	out				
	SOC8	out				
Problem Solving	PRO1	0.794	0.844	0.847	0.889	0.615
	PRO2	0.769				
	PRO3	out				
	PRO4	0.765				
	PRO5	out				
	PRO6	0.765				
	PRO7	out				
	PRO8	0.828				

Table 2 presents an assessment of the discriminant validity of each variable using the Fornell-Larcker approach. According to the Fornell-Larcker criteria, the square root of AVE for culturally responsive teaching (0.838) is higher than that for cultural literacy (0.540), social attitudes (0.499), environmental literacy (0.484) and biology problem solving (0.424). This indicates that the constructs demonstrate adequate discriminant validity, as each variable explains more variance within its own indicators than it does across indicators of other constructs in the model.

Table 2

Descriptive correlation between variables and AVE (Fornell-Larcker criterion)

Variable	CRT	CLL	ELL	SOC	PRO
CRT	0.838				
CLL	0.540	0.829			
ELL	0.484	0.657	0.797		
SOC	0.499	0.655	0.678	0.838	
PRO	0.424	0.553	0.644	0.660	0.784

Cross-loadings for all variables are presented in Table 3 which shows that each item correlates strongly with its main variable. This finding indicates that each variable has greater variance across measurement items. Overall, discriminant validity for each measurement item was established.

Table 3

Item variable (indicator) cross-loading

	CRT	CLL	ELL	SOC	PRO
CRT1	0.850	0.488	0.401	0.408	0.352
CRT2	0.860	0.431	0.436	0.470	0.376
CRT4	0.803	0.439	0.378	0.373	0.337
CLL3	0.388	0.775	0.499	0.480	0.430
CLL4	0.425	0.847	0.522	0.505	0.412
CLL5	0.502	0.863	0.527	0.562	0.473
CLL6	0.465	0.830	0.621	0.611	0.510
ELL1	0.415	0.561	0.818	0.567	0.528
ELL3	0.461	0.593	0.842	0.554	0.519
ELL4	0.264	0.402	0.727	0.498	0.496
SOC2	0.387	0.427	0.402	0.678	0.489

SOC3	0.439	0.525	0.573	0.838	0.577
SOC4	0.435	0.565	0.581	0.890	0.563
SOC5	0.418	0.609	0.626	0.881	0.572
SOC6	0.414	0.599	0.629	0.882	0.559
PRO1	0.390	0.445	0.566	0.513	0.794
PRO2	0.297	0.351	0.418	0.460	0.769
PRO4	0.288	0.491	0.528	0.532	0.765
PRO6	0.312	0.408	0.462	0.516	0.765
PRO8	0.368	0.459	0.535	0.558	0.828

These results indicatesd that based on the correlation results, culturally responsive teaching (CRT) positively influences students' cultural literacy (CLL), environmental literacy (ELL), social attitudes (SOC) and biology problem solving (PRO), with the strongest effects observed for cultural literacy and social attitudes and relatively lower effects for biology problem solving. Cultural literacy, in turn, significantly impacts environmental literacy, social attitudes and biology problem solving, serving as an important mediator in students' learning outcomes. Environmental literacy also contributes positively to social attitudes and biology problem solving, while social attitudes, in turn, have a substantial effect on biology problem solving. Overall, the findings suggest that CRT indirectly enhances students' biology problem solving by influencing cultural literacy, environmental literacy and social attitudes, highlighting the interconnected roles of cognitive, cultural and social dimensions in the development of students' competencies.

The results of the R-squared analysis indicated that the contribution of culturally responsive teaching to cultural literacy was 29.1%, the contribution of culturally responsive teaching and cultural literacy to environmental literacy was 45.5% and the contribution of culturally responsive teaching, cultural literacy and environmental literacy towards social attitudes was 54.8%. In contrast, the contribution of culturally responsive teaching, cultural literacy, environmental literacy and social attitudes towards biology problem solving was 51.2%. These results indicate that while the influence between the variables is relatively strong, other factors also contribute to enhancing students' biology problem solving.

Table 4 presents a summary of descriptive and inferential statistics for the measured variables, including means, standard deviations, t-values and p-values. These statistics provide an overview of the central tendency, variability and significance of the observed data, facilitating the interpretation of the relationships and differences among the variables.

Table 4

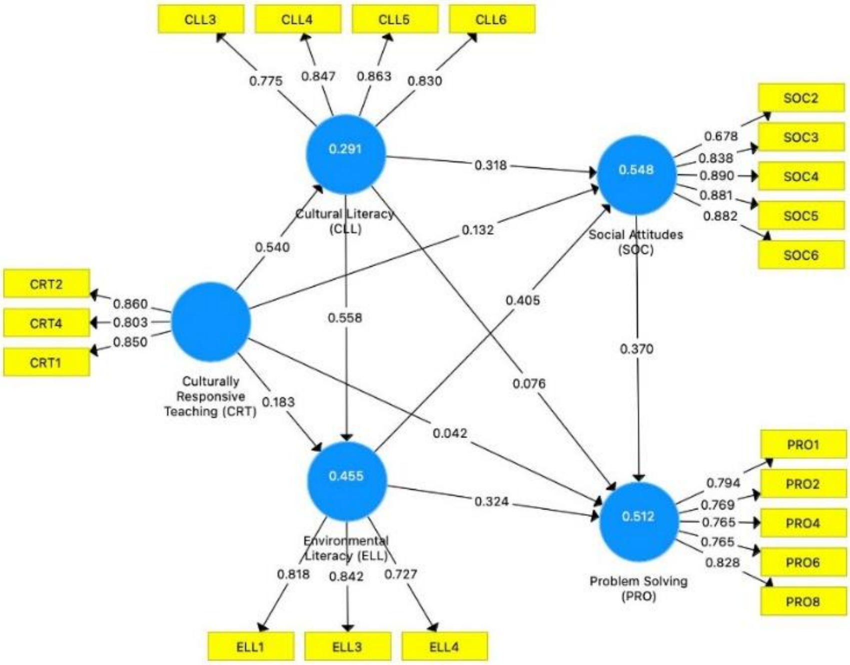
Data description: Mean, standard deviation, T-values and p-values

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
CRT -> CLL	0.540	0.539	0.071	7.610	0.000
CRT -> ELL	0.183	0.184	0.065	2.829	0.005
CRT -> SOC	0.132	0.134	0.053	2.494	0.013
CRT -> PRO	0.042	0.045	0.059	0.709	0.479
CLL -> ELL	0.558	0.559	0.065	8.631	0.000
CLL -> SOC	0.318	0.320	0.065	4.908	0.000
CLL -> PRO	0.076	0.079	0.066	1.139	0.255
ELL -> SOC	0.405	0.401	0.063	6.399	0.000
ELL -> PRO	0.324	0.322	0.068	4.776	0.000
SOC -> PRO	0.370	0.366	0.062	5.979	0.000

Figure 2 illustrates the structural model showing the relationships among culturally responsive teaching (CRT), cultural literacy (CLL), environmental literacy (ELL), social attitudes (SOC) and biology problem solving (PRO). The model presents the path coefficients between latent constructs and their observed indicators, highlighting both direct and indirect effects of CRT on students' competencies in biology problem solving, literacy and social attitudes.

Figure 2

SEM analysis results (Source: SmartPLS 3.3.2)



Discussion

The analysis indicates the relationships between culturally responsive teaching (CRT) and various aspects of student learning. CRT demonstrates notable associations with cultural literacy (CLL), environmental literacy (ELL) and social attitudes (SOC). In contrast, the direct effect of CRT on students' biology problem solving (PRO) appears to be low and not statistically significant, suggesting that any influence of CRT on biology problem solving may occur indirectly through variables such as CLL, ELL and SOC. Overall, the findings highlight how CRT is connected to multiple dimensions of learning, with potential indirect pathways affecting students' biology problem solving.

In more detail, CRT demonstrates a significant influence on cultural literacy, environmental literacy and social attitudes ($p < 0.005$). This occurs because CRT links the subject matter to students' local cultural contexts. encouraging active involvement, cross-cultural understanding and sensitivity to environmental and social issues. Hutchison & McAlister-Shields (2020) observe that CRT helps students strengthen their cultural identity and integrate it into the learning process. creating a sense of ownership and relevance in what they learn. Blanchet-Cohen & Reilly (2013) argue that embedding local values and cultural perspectives in biology education increases students' awareness of the ecological impact of both traditional and modern practices, leading to stronger engagement in sustainable action. Similarly, Nurbatra & Masyhud (2022) found that CRT fosters student agency by providing flexibility in choosing culturally relevant topics and promoting inclusive discussions across diverse backgrounds.

Furthermore, the findings demonstrate that cultural literacy significantly influences both environmental literacy and social attitudes ($p < 0.005$). Students who are familiar with local norms, traditions and wisdom tend to respect biodiversity, conserve natural resources and appreciate multicultural coexistence. Veisi et al. (2018) demonstrated that cultural and social dynamics shape students' environmental awareness and their behaviors toward ecological preservation. Similarly, Leung et al. (2011) highlighted that individuals' understanding of environmental issues is deeply embedded in their sociocultural frameworks, affecting how they interpret and respond to ecological knowledge. In line with this, Jegede & Fraser (1989) emphasized that socio-cultural values influence students' dispositions toward science learning, thereby affecting their motivation and readiness to apply scientific concepts in real-life contexts.

Environmental literacy, in turn, has a significant effect on both social attitudes and biology problem solving ($p < 0.005$). This suggests that students comprehend the interconnections between human activity and environmental systems. They not only develop environmentally responsible behaviors but also cultivate collaborative and empathetic social attitudes. Such dispositions prepare students to approach complex problems holistically, incorporating ecological, cultural and social perspectives. Consequently, this nurtures higher-order biology problem solving that are contextualized and sustainable. Tran et al. (2024) support this conclusion by showing that integrating social issues into the biology curriculum increases both student engagement and the application of biological knowledge to real-world challenges. Wahyuningtyas (2022) also emphasizes that culture-based instructional modules can enhance relevance and stimulate critical reflection, serving as an effective strategy for bridging cultural experiences and scientific inquiry.

The results further indicate that social attitudes significantly affect biology problem solving ($p < 0.005$). This finding indicates that students who are more open to diverse perspectives, empathetic toward others and collaborative in nature are better equipped to address complex, multidimensional problems. These interpersonal and intrapersonal qualities complement cognitive skills in devising effective and innovative solutions. Therefore, social attitudes serve as an important mediating bridge between culturally responsive pedagogy and the cultivation of higher-order thinking skills.

The study also indicates that CRT and cultural literacy do not directly influence biology problem solving ($p > 0.005$). This outcome suggests that while CRT and CLL lay the foundation for identity development, inclusivity and empathy. They may not directly train students in analytical reasoning or systematic problem solving. Instead, their role is more supportive, shaping dispositions and contextual awareness that subsequently facilitate biology problem solving through other mediating competencies such as environmental literacy and social collaboration. The absence of a direct effect may also reflect instructional design, in which CRT-based activities tend to emphasize awareness, discussion and cultural engagement rather than explicit practice in logical reasoning or biology problem solving.

However, evidence from previous studies indicates that integrating CRT is integrated with more strategy-oriented approaches. such as problem-based learning (PBL), it can significantly enhance students' biology problem solving. Ernawati et al. (2024) demonstrated that the synergy between CRT and PBL creates an inclusive and contextualized learning environment that simultaneously strengthens cultural literacy, fosters critical thinking and improves biology problem solving. This implies that CRT alone may not be sufficient to develop biology problem solving directly. However, it becomes highly effective when combined with active learning models that emphasize inquiry, critical reflection and real-world application.

Taken together, the literature indicates that CRT can strengthen students' cultural literacy, environmental literacy and social attitudes by connecting scientific learning with their cultural experiences, local environments and social interactions (Ladson-Billings, 1995; Gay, 2018; Aronson & Laughter, 2016). These competencies are interconnected with problem solving because students need to interpret contextual information, analyze evidence, consider different perspectives and develop responsible solutions to biological and environmental problems (McBride et al., 2013; Freeman et al., 2014; Tanner, 2017). Thus, integrating CRT with inquiry- or problem-based learning may enhance both the socio-cultural relevance and cognitive demands of biology learning. However, limited empirical research has examined the relationships among CRT, cultural literacy, environmental literacy, social attitudes, and biology problem solving simultaneously, highlighting the need for an integrated model of culturally responsive biology education.

Conclusion and Limitations

Based on the results of the analysis. It can be concluded that culturally responsive teaching (CRT) has a significant influence on students' cultural literacy, environmental literacy and social attitudes. However, its influence on biology problem solving is indirect. The significant influence of CRT on cultural literacy facilitates students' active involvement and contextual understanding of cultural and environmental values, thus encouraging the formation of social attitudes and environmental literacy. Strong cultural literacy has been shown to contribute significantly to environmental literacy and social attitudes. At the same time, environmental literacy and social attitudes play an important role in significantly improving students' biology problem solving. Even though CRT and cultural literacy do not directly show a significant influence on biology problem solving, this approach remains relevant because it can create a foundation of values and an inclusive learning context, which, when combined with strategies such as problem-based learning (PBL), proves to be effective in fostering critical thinking skills and sustainable biology problem solving.

This study has several limitations that may affect the generalizability and interpretation of the findings. The limitations of the study, namely, first, the use of a cross-sectional survey design limits the ability to capture the dynamics of change or long-term causal relationships between variables. Second, the sample included 16 universities in Sulawesi; the results may not generalize to other regions in Indonesia with different levels of cultural diversity. In addition, the data were obtained entirely through a closed questionnaire, which may limit the depth of understanding of students' experiences and perceptions of the application of CRT in the learning context.

References

Androsov, A., & Zhang, B. (2023). Students as co-creators: Bringing culturally responsive teaching into a doctoral course for international students in China. *SAGE Open, 13*(1), 1–16. https://doi.org/10.1177/21582440221145914

Aronson, B., & Laughter, J. (2016). The theory and practice of culturally relevant education: A synthesis of research across content areas. *Review of Educational Research, 86*(1), 163–206. https://doi.org/10.3102/0034654315582066

Atmojo, S. E., Anggriani, M. D., Rahmawati, R. D., Skotnicka, M., Wardana, A. K., & Anindya, A. P. (2025). Bridging STEM and culture: The role of ethnoscience in developing critical thinking and cultural literacy. *Jurnal Pendidikan IPA Indonesia, 14*(2), 251–266. https://doi.org/10.15294/jpii.v14i2.23505

Banks, J. A., & Banks, C. A. M. (Eds.). (2019). *Multicultural education: Issues and perspectives*. John Wiley & Sons.

Barclay, D. W., & Thomson, R. (1995). The partial least squares (PLS) approach to causal modeling, personal computer adoption and use as an illustration. *Technology Studies, 2*, 285–309. https://doi.org/10.1007/978-3-030-80519-7

Barron, L., Grim, J., & Pineda, R. (2021). Applying culturally responsive teaching in undergraduate biology laboratories: Impacts on engagement and learning. *Journal of College Science Teaching, 50*(5), 28–35.

Blanchet-Cohen, N., & Reilly, R. C. (2013). Teachers' perspectives on environmental education in multicultural contexts: Towards culturally-responsive environmental education. *Teaching and Teacher Education, 36*, 12–22. https://doi.org/10.1016/j.tate.2013.07.001

Bustami, Y., Corebima, A. D., Suarsini, E., & Ibrohim. (2017). The social attitude empowerment of biology students: Implementation of the JiRQA learning strategy in different ethnics. *International Journal of Instruction, 10*(3), 15–30. https://doi.org/10.12973/iji.2017.1032a

Ernawati, T., Rosana, D., Atun, S., & Susanti. (2024). Exploration of culturally responsive teaching and problem-based learning in the diverse learning of prospective science teachers. *International Journal of Religion, 5*(3), 353–365. https://doi.org/10.61707/t1bg2083

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39–50. https://doi.org/10.2307/3151312

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.

Gay, G. (2002). Preparing for culturally responsive teaching. *Journal of Teacher Education, 53*(2), 106–116. https://doi.org/10.1177/0022487102053002003

Gay, G. (2018). *Culturally responsive teaching: Theory, research and practice* (3rd ed.). Teachers College Press.

Ghozali, I., & Latan, H. (2015). *Partial least squares: Konsep, teknik dan aplikasi menggunakan program SmartPLS 3.0*. Badan Penerbit Universitas Diponegoro.

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st century skills frameworks: Systematic review. *Sustainability, 14*(3), 1493. https://doi.org/10.3390/su14031493

Guerrero, M. A. (2020). Scientific and environmental literacy in culturally diverse classrooms: A critical review. *International Journal of Science Education, 42*(3), 345–364.

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review, 31*(1), 2–24. https://doi.org/10.1108/EBR-11-2018-0203

Hair, J. F., Ringle, C. M., Hult, G. T. M., & Sarstedt, M. (2021). *Partial least squares structural equation modeling (PLS-SEM) using R*. Springer.

Halbert, K., & Chigeza, P. (2015). Navigating discourses of cultural literacy in teacher education. *Australian Journal of Teacher Education, 40*(11), 155–168. https://doi.org/10.14221/ajte.2015v40n11.9

Henseler, J. (2012). PLS-MGA: A non-parametric approach to partial least squares-based multi-group analysis. In W. A. Gaul, A. Geyer-Schulz, L. Schmidt-Thieme, & J. Kunze (Eds.), *Challenges at the interface of data analysis, computer science, and optimization* (pp. 495–501). Springer.

Hiswara, A., Aziz, A. M., & Pujowati, Y. (2023). Cultural preservation in a globalized world: Strategies for sustaining heritage. *West Science Social and Humanities Studies, 1*(3), 98–106. https://doi.org/10.58812/wsshs.v1i03.250

Hollweg, K. S., Taylor, J. R., Bybee, R. W., Marcinkowski, T. J., McBeth, W. C., & Zoido, P. (2011). *Developing a framework for assessing environmental literacy*. North American Association for Environmental Education.

Hungerford, H. R., & Volk, T. L. (1993). *Environmental education in the 21st century: Theory, practice, progress and promise*. Cambridge University Press.

Hutchison, L., & McAlister-Shields, L. (2020). Culturally responsive teaching: Its application in higher education environments. *Education Sciences, 10*(5), 124. https://doi.org/10.3390/educsci10050124

Indarwati, R., Choyrunisa, R. V., & Sanjaya, I. G. M. (2024). Culturally responsive teaching approach to improve the questioning ability of junior high school students through PBL. *Jurnal PTK dan Pendidikan, 10*(1), 49–55. https://doi.org/10.18592/ptk.v10i1.12777

Jegede, O. J., & Fraser, B. J. (1989). Influence of socio-cultural factors on secondary school students' attitude toward science. *Research in Science Education, 19*, 155–164. https://doi.org/10.1007/BF02356855

Keehne, C. N. K., Sarsona, M. W., Kawakami, A. J., & Au, K. H. (2018). Culturally responsive instruction and literacy learning. *Journal of Literacy Research, 50*(2), 141–166. https://doi.org/10.1177/1086296X18767226

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465–491. https://doi.org/10.3102/00028312032003465

Leung, A. K. Y., Qiu, L., Ong, L. S., & Tam, K. (2011). Embodied cultural cognition: Situating the study of embodied cognition in socio-cultural contexts. *Social and Personality Psychology Compass, 5*(9), 591–608. https://doi.org/10.1111/j.1751-9004.2011.00373.x

Lewinsohn, T., Grillo, O., & Carmo, A. (2019). Integrating environmental literacy into problem-based biology education: Evidence from higher education classrooms. *Environmental Education Research, 25*(9), 1305–1322.

Mahanal, S., Zubaidah, S., Setiawan, D., Maghfiroh, H., & Muhaimin, F. G. (2022). Empowering college students' problem-solving skills through RICOSRE. *Education Sciences, 12*(3), 1–17. https://doi.org/10.3390/educsci12030196

Maine, F., Cook, V., & Lahdesmaki, T. (2019). Reconceptualizing cultural literacy as a dialogic practice. *London Review of Education, 17*(3), 383–392. https://doi.org/10.18546/LRE.17.3.12

Martínez, C., Valle, A., & Almeida, L. (2020). Becoming culturally responsive: Teachers' practices and students' experiences in science classrooms. *Teaching and Teacher Education, 95*, 103129.

McBeth, W., & Volk, T. L. (2010). The National Environmental Literacy Project: A baseline study of middle grade students in the United States. *The Journal of Environmental Education, 41*(1), 55–67. https://doi.org/10.1080/00958960903210031

McBride, B. B., Brewer, C. A., Berkowitz, A. R., & Borrie, W. T. (2013). Environmental literacy, ecological literacy, ecoliteracy: What do we mean and how did we get here? *Ecosphere, 4*(5), 67. https://doi.org/10.1890/ES13-00075.1

Nurbatra, L. H., & Masyhud, M. (2022). Infusing culturally responsive teaching in higher education: Insights for multicultural education in Indonesia. *Journal of Innovation in Educational and Cultural Research, 3*(4), 722–730. https://doi.org/10.46843/jiecr.v3i4.321

Nurhayati, B., Jamaluddin, F. J., Daud, F., Saenab, S., Hadis, A., Hadis, H. I. R., & Remiza. (2023). An extraordinary duet: Integration of PjBL and STEM to promote students' motivation, scientific literacy skills, and students' learning outcomes. *European Journal of Education and Pedagogy, 4*(3), 42–47. https://doi.org/10.24018/ejedu.2023.4.3.639

Ochoa, G. G., McDonald, S., & Monk, N. (2018). Adapting open-space learning techniques to teach cultural literacy. *Open Cultural Studies, 2*(1), 510–519. https://doi.org/10.1515/culture-2018-0046

Parkin, S., Johnston, A., Buckland, H., Brookes, F., & White, E. (2004). *Learning and skills for sustainable development: Developing a sustainability literate society*. Higher Education Partnership for Sustainability.

Rahmawati, Y., Mardiah, A., Taylor, E., Taylor, P. C., & Ridwan, A. (2023). Chemistry learning through culturally responsive transformative teaching (CRTT): Educating Indonesian high school students for cultural sustainability. *Sustainability, 15*(8), 6925. https://doi.org/10.3390/su15086925

Sari, Y. I., Sumarmi, U., D. H., & Astina, I. K. (2021). The effect of problem-based learning on problem-solving and scientific writing skills. *International Journal of Instruction, 14*(2), 11–26. https://doi.org/10.29333/iji.2021.1422a

Shahat, M. A., Ohle-Peters, A., Treagust, D. F., & Fischer, H. E. (2013). Design, development, and validation of a model of problem-solving for Egyptian science classes. *International Journal of Science and Mathematics Education, 11*(5), 1157–1181. https://doi.org/10.1007/s10763-012-9367-7

Smith, T., Avraamidou, L., & Adams, J. D. (2022). Culturally relevant/responsive and sustaining pedagogies in science education: Theoretical perspectives and curriculum implications. *Cultural Studies of Science Education, 17*, 637–660.

Suprapto, N., Rizki, I. A., Saphira, H. V., Alfarizy, Y., & Jannah, S. N. (2024). Exploration of science concepts in Indonesian indigenous culture: Actualization of the Indonesian curriculum. *Journal of Turkish Science Education, 21*(3), 410–429. https://doi.org/10.36681/tused.2024.022

Syamsiah, Jamaluddin, A. B., & Pratiwi, A. C. (2024). Exploring the impact of educational background, spiritual beliefs, and media exposure on environmental knowledge and attitudes. *EURASIA Journal of Mathematics, Science and Technology Education, 20*(11), em2537. https://doi.org/10.29333/ejmste/15644

Tanner, K. D. (2012). Promoting student metacognition. *CBE—Life Sciences Education, 11*(2), 113–120. https://doi.org/10.1187/cbe.12-03-0033

Tran, S., Tirado, J., Miyasato, H., & Lee, S. W. (2024). Students' perceptions of social issues in biology courses. *Journal of Microbiology and Biology Education, 25*(1), 1–10. https://doi.org/10.1128/jmbe.00194-23

Veisi, H., Lacy, M. G., Mafakheri, S., & Razaghi, F. (2018). Assessing environmental literacy of university students: A case study of Shahid Beheshti University in Iran. *Applied Environmental Education & Communication, 17*(1), 13–23. https://doi.org/10.1080/1533015X.2018.1431163

Villegas, A. M., & Lucas, T. (2002). Educating culturally responsive teachers: A coherent approach. *The Journal of Negro Education, 73*(4), 461. https://doi.org/10.2307/4129631

Wahyuningtyas, R. S. (2022). Culture-based learning model in the biology module to develop students' critical thinking skills. In *Proceedings of the 3rd International Conference of Education and Science (ICES) 2021*. https://doi.org/10.4108/eai.17-11-2021.2318628

Wijayanti, S. R. A., Probosari, R. M., Wati, I. K., Hudha, M. N., Gunawan, K. D. H., Mahardiani, L., & Indriyanti, N. Y. (2025). The effect of culturally responsive transformative teaching (CRTT) model in science learning on the environmental literacy of seventh grade students. *Journal of Advanced Sciences and Mathematics Education, 5*(2). https://doi.org/10.58524/jasme.v5i2.950

Appendix

Statement of each variable in the research instrument

Item Variables	Item Statement
CRT1	The classroom learning environment supports the diversity of students' cultures and backgrounds.
.CRT2	The learning methods used by lecturers help develop students' knowledge and skills.
CRT3	Students are not allowed to relate the learning material to their cultural background.
CRT4	Classroom learning helps me see the relationships between subject matter and cultural values.
CLL1	I understand that culture influences the way students respond to learning materials.
CLL2	I am not able to analyze the cultural bias that appears in the learning process.
CLL3	I am interested in learning about other cultures through learning in class.
CLL4	I appreciate the cultural differences that my classmates bring to the learning process.
CLL5	Cultural diversity enriches the learning experience in the classroom.
CLL6	I can interact with classmates from other cultures without causing misunderstandings.
CLL7	I do not feel responsible for helping create an inclusive learning environment.
ELL1	I understand basic environmental concepts. such as climate change. recycling. and biodiversity
ELL2	I am unable to analyze environmental problems and formulate effective solutions.
ELL3	I care about environmental issues and contribute to preserving nature.
ELL4	I actively take environmentally friendly actions on campus.
SOC1	I do not always express my opinions honestly in the learning process.
SOC2	I always arrive on time for every learning activity.
SOC3	I show a positive and enthusiastic attitude in participating in learning activities
SOC4	I feel responsible for ensuring that my group completes the assignment.
SOC5	I respect my classmates' differences of opinion during learning activities
Item Variables	Item Statement
SOC6	I actively collaborate with my group of friends in completing learning tasks.
SOC7	I do not dare to take the initiative in learning activities. such as leading discussions
SOC8	I cannot always accept my classmates' different cultural backgrounds.
PRO1	I can recognize problems relevant to biology.
PRO2	I can explain biological problems using appropriate terms.
PRO3	I cannot formulate criteria for success in solving biological problems.
PRO4	I can gather information from various sources to solve biological problems.
PRO5	I am not always able to choose the most effective solution to a biological problem.
PRO6	I can review information used to solve biological problems.
PRO7	I am unable to evaluate the advantages and disadvantages of each chosen solution.
PRO8	I can evaluate whether the implemented solution has achieved the expected results.