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Embedding Anti-Racism as a Socio-Scientific Issue in Higher-Education Biology: A Mixed-Methods Needs Analysis and Instructional Design Recommendations for Preservice Teacher Education in Indonesia

Erik Perdana Putra[1]*, Aceng Ruyani[2], M. Lutfi Firdaus[3]

[1]*Department of Science Education (Tadris IPA), UIN Fatmawati Sukarno Bengkulu, Indonesia*
[2,3]*Science Education, Doctor of Education Program, Universitas Bengkulu, Indonesia*

✉* erik.perdana@uinfasbengkulu.ac.id

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Abstract

Background: Socio-scientific issues (SSI) have been widely recommended as a context-based approach to strengthen scientific literacy, argumentation, and reflective judgment in biology learning. However, anti-racism remains underrepresented as an explicit SSI theme in many higher-education biology curricula, despite its social urgency in multicultural societies and the historical misuse of biological arguments to justify inequality. This study aimed to examine: (1) how biology educators conceptualize anti-racism as an SSI topic, (2) the extent to which anti-racism is embedded in course plans and instructional documents, and (3) what instructional resources and assessment supports are needed to enable systematic implementation in preservice biology teacher education.
Methods: An exploratory mixed-methods design was employed, integrating bibliometric mapping, curriculum/document analysis, and educator-oriented needs exploration through semi-structured interviews and a structured needs questionnaire.
Results: The analysis indicates that the strongest integration opportunities occur in human genetics and evolution, particularly through discussions of human genetic variation, clinal adaptation of skin pigmentation, common ancestry, and the misconception of biological race. Nevertheless, explicit alignment between these scientific concepts and anti-racist learning outcomes is rarely articulated in learning plans, and educators report limited support for facilitating sensitive ethical discussions and assessing students' socio-scientific reasoning.
Conclusion: The study proposes a practical SSI–problem-based learning (SSI-PBL) framework and recommends a set of resources (case repositories, facilitation scripts, argumentation rubrics, and attitude measures) to guide preservice biology teacher education. These results provide design directions for developing inclusive biology learning that integrates scientific evidence with social justice-oriented civic competencies.

INTRODUCTION

Biology education is expected to prepare learners not only to understand scientific concepts but also to use scientific knowledge to interpret real-world phenomena, evaluate evidence-based claims, and participate responsibly in societal decision making. In higher-education biology, teaching still often prioritizes disciplinary content and assessment, while providing relatively limited opportunities for students to engage biological ideas in relation to societal, cultural, and ethical issues. Recent studies show that such connections remain underrepresented in biology learning objectives and assessments, even though students value more socially and ethically connected biology curricula (Busch et al., 2026; Dunk et al., 2025; Scheuermann et al., 2024; Zeidler et al., 2019b). When learning is framed primarily as the acquisition of factual knowledge, students may struggle to understand why biology matters for citizenship and for navigating complex social realities (Busch et al., 2026; Hancock et al., 2019b).

Socio-scientific issues (SSI) have emerged as a powerful instructional approach to address this challenge. SSI refers to complex, ill-structured problems that are socially significant and scientifically informed (e.g., genetic technologies, climate change, public health, biodiversity governance). SSI instruction requires learners to coordinate scientific evidence with moral values and social considerations. In this way, SSI offers an authentic context for practicing scientific argumentation, informal reasoning, and reflective judgment abilities that are central to scientific literacy (Eryasar & Kilinc, 2022; Tytler et al., 2025; Zeidler et al., 2019a; Zidny & Eilks, 2022).

Despite the growth of SSI research and curriculum development worldwide, SSI has long been recognized as a context-based approach that connects science learning with social and ethical issues in meaningful ways (Sadler, 2009; Zeidler & Nichols, 2009). However, recent review studies suggest that the field still tends to prioritize themes such as argumentation, decision-making, nature of science, climate change, sustainability, and other environmental or health-related issues. For example, a systematic review of 87 SSI articles published in five leading science education journals between 2011 and 2022 found that argumentation and decision-making were the most frequently discussed themes, followed by nature of science, rather than issues related to racism or anti-racism (Falah et al., 2024). Similarly, a systematic review of 61 environmental SSI studies reported that climate change and nuclear power were the most common contexts, while argumentation and decision-making were the most frequently targeted skills (Kumar et al., 2024). In higher-education biology, recent studies also indicate that social issues are still not consistently embedded in biology courses, and that explicit engagement with race, racism, or racial equity remains limited rather than mainstream (Scheuermann et al., 2024; Tran et al., 2024). Therefore, although SSI has developed substantially in science education, anti-racism remains underrepresented as an explicit SSI theme in biology education, despite the history of science including well-documented cases in which biological arguments were misused to justify racism and inequality.

This gap is important because racism and racial prejudice are not merely interpersonal matters, they are embedded in cultural narratives, institutional practices, and broader social structures. Education therefore plays a crucial role in preventing prejudice and promoting inclusive social relationships. For Indonesia, a nation characterized by ethnic, cultural, linguistic, and religious diversity, the cultivation of anti-racist dispositions is highly relevant for strengthening social cohesion and democratic citizenship. Anti-racism education, however, should not rely solely on declarative moral messages. It can be strengthened when students engage with scientific evidence that challenges biological essentialism and questions the misconception that "race" is a robust biological category (Banks, 2016; Bonilla-Silva, 2014; Omi & Winant, 2015).

From a contemporary biological perspective, the concept of human "race" has weak explanatory power for genetic variation. Population genetics research indicates that most human genetic diversity occurs within populations rather than between populations. Meanwhile, visible phenotypic traits such as skin pigmentation are best understood as products of adaptation to environmental pressures (e.g., ultraviolet radiation) and human migration histories. These scientific insights provide a strong foundation for anti-racist learning messages: human biological variation is real, but it does not map cleanly onto discrete racial categories nor justify social hierarchies (Jablonski, 2004; Jorde & Wooding, 2004; Ousley et al., 2009; Templeton, 2013).

However, translating this scientific potential into higher-education teaching practice requires more than conceptual coverage. Integrating anti-racism into biology as an SSI topic may pose practical challenges, including educators' confidence in facilitating sensitive classroom discourse, availability of context-rich learning materials, and suitable assessment instruments for socio-scientific reasoning and attitudinal outcomes. Before developing teaching modules or interventions, a systematic needs analysis is necessary to identify integration opportunities within existing biology topics and to clarify what resources educators consider feasible and valuable (Ratcliffe & Grace, 2003; Walker & Zeidler, 2007).

To determine whether this gap was also evident in the local context, a preliminary scoping exercise was undertaken prior to the formal mixed-methods study in Bengkulu-based higher-education biology settings. This initial exploration involved a focused reading of accessible course plans and exploratory communication with lecturers teaching biology-related subjects. The scoping results indicated that topics such as genetics, heredity, evolution, and biodiversity already offer scientifically relevant entry points for discussing human variation, common ancestry, and the misuse of biological arguments about race. Nevertheless, anti-racism was not explicitly articulated in course learning outcomes, discussion prompts, student assignments, or assessment practices. Thus, while the curricular content contained implicit opportunities for such integration, anti-racism had not yet been positioned as an intentional pedagogical orientation.

These preliminary indications reinforced the need for a more systematic investigation. They suggested that the central problem was not the absence of scientifically relevant biology content, but the lack of explicit pedagogical framing and instructional support needed to connect that content with anti-racist learning goals. Accordingly, this study aims to generate design-relevant evidence for embedding anti-racism as an SSI theme in higher-education biology for preservice teacher education in Indonesia. Specifically, it addresses three questions: (1) How do biology educators conceptualize anti-racism as an SSI topic? (2) To what extent is anti-racism explicitly embedded in course plans and instructional documents? and (3) What instructional resources and assessment supports are needed to enable systematic implementation? By answering these questions, the study contributes a practical SSI-PBL framework and resource recommendations for developing inclusive biology education modules.

METHODS

An exploratory mixed-methods design was employed to produce an in-depth needs profile and actionable instructional design recommendations. The study integrated three complementary components: (1) bibliometric mapping to identify trend visibility and topic gaps, (2) curriculum and document analysis to examine explicit and implicit integration of anti-racism across biology course planning artifacts, and (3) educator-oriented needs exploration through semi-structured interviews and a structured needs questionnaire. This combination was selected to triangulate evidence and ensure that the recommendations are both research-informed and implementable in real teaching contexts (Creswell, 2021; Creswell & Clark, 2017).

The study was situated in higher-education biology and biology education settings relevant to preservice teacher education in Indonesia. Participants comprised biology educators (lecturers/instructors) teaching courses with strong integration potential, especially human genetics, evolution, biodiversity, and related courses. Participant selection followed purposive criteria: (a) teaching responsibility in relevant courses, (b) experience with student discussion-based learning or interest in contextual pedagogy, and (c) willingness to contribute to needs exploration. In addition to educators, the needs questionnaire may be administered to preservice biology teachers to capture learner-side readiness and perceived learning needs. In practice, institutions may adjust sampling procedures based on course size and accessibility.

Three categories of data were collected. First, bibliometric mapping was conducted using topic keywords related to socio-scientific issues, biology education, genetics, evolution, race, racism, and anti-racism to determine whether anti-racism has been positioned as an SSI focus in science education publications. Second, curriculum and instructional documents were collected, including course learning plans/syllabi, learning outcomes, weekly topics, learning methods, learning resources, and assessment plans. A directed content analysis coding sheet was developed, with indicators covering: (1) explicit references to equity, diversity, social justice, ethics, and anti-discrimination; (2) opportunities for SSI activities (evidence evaluation, debate, decision making, reflection); and (3) alignment across outcomes, activities, and assessments. Third, educator needs were explored using a semi-structured interview guide and a structured needs questionnaire focusing on the availability and priority of instructional resources, facilitation supports, and assessment tools. These procedures follow current recommendations for bibliometric mapping and qualitative content analysis in applied education research (Donthu et al., 2021; Mayring, 2021).

Table 1. Overview of Data Sources and Analytical Purposes

Component	Data source	Instrument/technique	Main analytic output
Bibliometric mapping	SSI–biology education publications	Keyword scan and thematic clustering	Trend visibility and topic gaps
Document analysis	Syllabi/RPS, outcomes, assessments	Directed content analysis coding sheet	Explicit/implicit integration profile
Needs exploration	Educator perspectives	Interviews and needs questionnaire	Priority resource requirements and constraints

Data collection proceeded in four stages. (1) Bibliometric mapping established a preliminary trend profile and helped identify which biology content areas may naturally connect to anti-racism discourse. (2) Course document collection and content coding identified explicit and implicit integration patterns. (3) Interviews were conducted to elicit educators' conceptual understanding of SSI and anti-racism, their experiences with sensitive classroom discussions, and their perceived barriers and opportunities. (4) The needs questionnaire was used to prioritize resource supports, such as case repositories, student worksheets, facilitation scripts, and assessment tools. Triangulation across these data sources strengthened confidence in the design recommendations and is consistent with current guidance for mixed-methods inquiry, bibliometric mapping, and qualitative analysis (Braun & Clarke, 2021; Creswell & Clark, 2017; Donthu et al., 2021).

Document analysis applied directed content analysis. Codes were informed by SSI frameworks (argumentation, evidence-based decision making, reflection) and by anti-racism education constructs (equity, inclusion, recognition of structural discrimination). Documents were

coded for the presence of explicit integration (e.g., anti-racism stated as a learning outcome or assessed competence) and implicit integration (e.g., relevant scientific concepts present without explicit anti-racist framing). Interview data were analyzed thematically to identify recurring patterns in educators' perceived needs, constraints, and feasibility considerations. Questionnaire results were summarized using descriptive statistics (e.g., frequency and priority ranking) to guide resource development priorities (Creswell & Creswell, 2017; Miles et al., 2020).

The study followed principles of voluntary participation, anonymity, confidentiality, and respect for the sensitivity of race-related discourse. Participants were informed about the study aims, data use for publication, and their right to withdraw. During interviews, educators were encouraged to discuss pedagogical concerns without disclosing sensitive personal data about students. Recommendations emphasize psychologically safe classroom discourse, including norms for respectful dialogue and prevention of stereotyping or harm.

RESULT AND DISCUSSION

This research was conducted using three main approaches: (1) a literature review on the integration of anti-racism concepts into biology education, (2) an analysis of biology teaching materials at the university level, and (3) interviews with biology educators (lecturers). The results of these three components provide an initial overview of the extent to which anti-racism concepts have been integrated into the Biology curriculum and instruction, Biology lecturers' perspectives and practices regarding the integration of anti-racism-themed socio-scientific issues, and the need to develop instructional materials to support the integration of anti-racism topics into Biology instruction. The following narrative outlines the findings from each of these components in an integrated manner. As shown in Figure 1, the original inquiry was organized through four connected activities literature review, analysis of biology-topic coverage, analysis of instructional instruments/documents, and needs analysis.

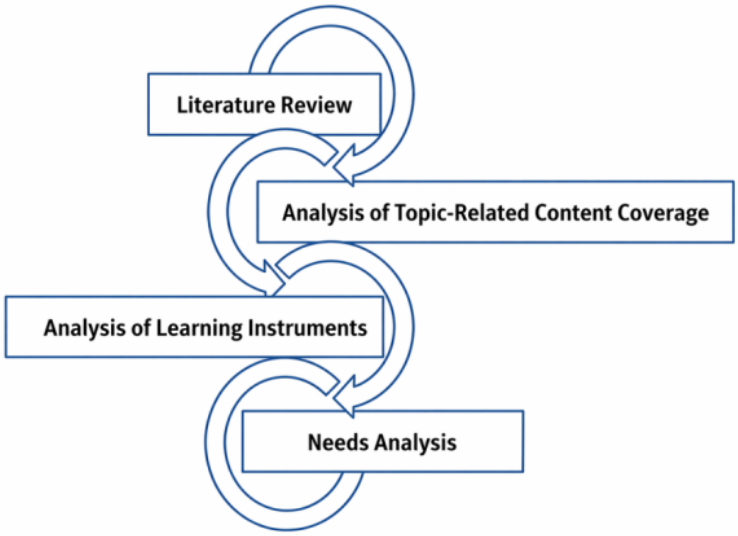

Figure 1. Research workflow adapted from the academic report

This visual clarifies how the article synthesizes several strands of evidence. The bibliometric scan was used to identify the novelty and gap position of anti-racism in biology education, the curriculum and topic mapping identified where integration is scientifically defensible, and the lecturer-oriented needs analysis translated those opportunities into concrete design requirements for SSI-based instruction.

Bibliometric mapping: literature visibility and topic gap

The bibliometric mapping confirms that anti-racism remains weakly visible as an explicit socio-scientific issue (SSI) theme in biology education. Across the broader SSI landscape, the dominant topics still revolve around sustainability, biotechnology ethics, health risk communication, and environmental decision making. This indicates that, although SSI has developed substantially as a context-based approach for science learning, race-related discourse has not yet been systematically positioned as a biology-integrated issue that links scientific evidence with justice-oriented civic learning (Falah et al., 2024; Nardi, 2021; Tran et al., 2024).

This pattern became clearer when the article evidence was read together with the academic report. The national search in Google Scholar returned 671 Indonesian language records using a keyword phrase related to anti-racism in biology learning, yet screening did not identify a study that explicitly examined the integration of anti-racism into higher education biology instruction or the development of biology teaching materials framed as anti-racist SSI. The international search, conducted through Publish or Perish with the keyword 'antiracism in biology learning' and limited to the 2014–2024 period, returned 200 English language records. However, the retrieved publications were mostly distributed across adjacent areas such as biochemistry, neuroscience, anti-oppressive curriculum work, and general science-classroom equity rather than systematic curriculum integration in biology teacher education. Taken together, these two searches show the same trend: the topic is visible at the margins of science education, but still absent as a clearly established biology-SSI theme. This gap supports the originality of positioning anti-racism as an explicit SSI topic in preservice biology teacher education in Indonesia (Nardi, 2021; Scheuermann et al., 2024; Subiantoro, 2023).

Table 2. Summary of bibliometric mapping results from the academic report

Search context	Platform / query	Records identified	Main finding
National literature	Google Scholar; keyword related to anti-racism in biology learning	671 Indonesian-language records	No publication was found that explicitly integrates anti-racism into higher-education biology learning.
International literature	Publish or Perish / Google Scholar; 'antiracism in biology learning' (2014–2024)	200 English-language records	Related works exist, but they are scattered across adjacent fields and are not focused on systematic biology curriculum integration.
Overall interpretation	Combined reading of both searches	871 records mapped at the search stage	Anti-racism is still an underexplored SSI theme in biology education, especially in preservice teacher education.

Figures 2 and 3 reproduce the search stage evidence from the academic report. They are included here to make the numerical findings of the literature scan transparent and easier to verify.

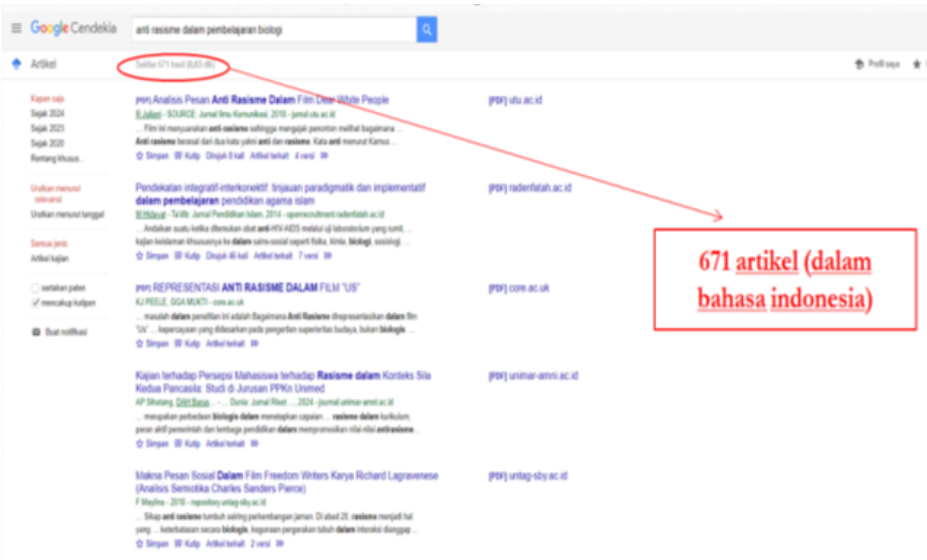

Figure 2. Indonesian-language search results related to anti-racism in biology learning (Google Scholar)

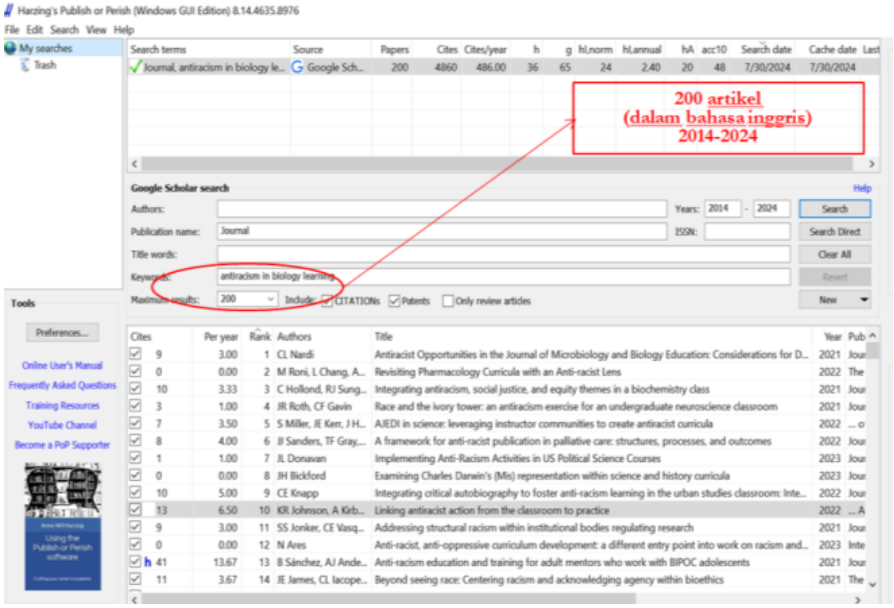

Figure 3. International search results related to antiracism in biology learning (Publish or Perish / Google Scholar; 2014–2024)

Document analysis: conceptual entry points and an implicit opportunity profile

Analysis of course plans, syllabi, and teaching materials shows that higher-education biology already contains several strong scientific entry points for anti-racism integration. The most strategic areas are human genetics and evolution, especially topics related to human genetic variation, heredity, common ancestry, adaptation, and skin pigmentation. The academic report further broadens this map by identifying additional opportunities in biodiversity and classification, cell and genetic material, biotechnology and bioethics, and even ecology, health, and stigma. These topics provide conceptual resources for helping students distinguish biological variation from socially constructed racial hierarchy and for demonstrating why race should not be treated as a fixed biological taxonomy (Donovan et al., 2024; Fuentes et al., 2019; Lujan & DiCarlo, 2024; National Academies of Sciences and Medicine, 2024).

However, the same documents also reveal that this potential remains largely implicit. Anti-racism is rarely written as an explicit learning outcome, discussion theme, assignment focus, or

assessment target in the reviewed RPS and instructional materials. In several documents, genetics-related content is taught only as conceptual and procedural knowledge, without connecting heredity and human variation to public misconceptions about race, discrimination, or the historical misuse of biology. This means that students may encounter the scientific concepts needed to challenge racism, but they are not yet systematically guided to use those concepts in socio-ethical reasoning or inclusive civic reflection. This interpretation is in line with recent reports showing that many biology courses still provide limited and uneven opportunities for engagement with social issues and race-related content (Fitria Ningrum et al., 2021; Scheuermann et al., 2024; Tran et al., 2024).

Table 2 synthesizes the conceptual entry points identified in the article template and enriches them with the curriculum mapping reported in the academic document. The table therefore should be read not merely as a theoretical matrix, but as a redesign map showing where existing biology topics can be reframed into anti-racist SSI learning opportunities.

Table 2. Mapping Biology Topics to SSI Prompts and Anti-Racist Learning Orientations

Biology topic	Core scientific concept(s)	SSI prompt/example dilemma	Learning orientation (anti-racism)
Human genetics	Genetic variation; polygenic traits; population structure	Is "race" a biological category? How should genetic evidence be communicated in society?	Challenge biological essentialism; emphasize equality and within-population diversity
Human evolution	Natural selection; adaptation; migration; common ancestry	Why do humans have different skin colors? Can skin pigmentation justify social hierarchy?	Explain clinal adaptation; reject stereotypes and racial hierarchy claims
Biodiversity & classification	Variation; phylogeny; classification systems	How can scientific classification be misused to legitimize discrimination?	Reframe difference as diversity; cultivate respect for variation
Biotechnology & ethics	Genomics; gene editing; bioethics; justice in innovation	Who benefits from genetic technologies? Are there biases in genomic research?	Promote equity and responsible innovation; critique bias in science
Ecology, health, and stigma	Determinants of health; misinformation; stigma	How do stigma and stereotypes affect health outcomes and social inclusion?	Counter stigma with evidence; build empathy and inclusive actions

The broader topic-level map can be further sharpened at the subtopic level. The academic report identified inheritance and human genetics as the most strategic focus not only because they address variation, heredity, and human relatedness, but also because they provide direct entry points for confronting scientific racism, eugenics, and genetic essentialism. Table 3 expands this focal area by showing how specific inheritance subtopics can be translated into anti-racist learning messages within biology instruction. This focus is strongly supported by recent work showing that genomics instruction can reduce essentialist beliefs and improve students' understanding of human variation when teaching moves beyond simplified hereditarian models (Donovan et al., 2024; Fuentes et al., 2019; National Academies of Sciences and Medicine, 2024)

Table 3. Inheritance Subtopics and Potential Anti-Racism Integration

Subtopic in inheritance/genetics	Potential anti-racism integration
Introduction to heredity	Emphasize that all humans share the same basic genetic mechanisms; heredity should not be framed as a basis for ranking human groups.
History of genetics	Critically discuss eugenics and the misuse of genetics to justify scientific racism and exclusionary social policies.
Mendelian laws	Show that simple Mendelian inheritance cannot explain the full complexity of human diversity and should not be used to essentialize race.
Applications of Mendelian genetics	Avoid examples or case illustrations that reproduce racial stereotypes or biased assumptions about "typical" traits of certain groups.
Chromosomes and genes	Stress that genes are not exclusive to any "race"; genetic diversity is distributed across all human populations.
Human heredity	Explain that there is no robust biological basis for discrete human races and that within-population variation is often greater than between-population variation.

The subtopic mapping above makes the 'genetics focus' more pedagogically actionable. Rather than keeping anti-racism at the level of a general moral appeal, lecturers can anchor discussion in specific inheritance lessons, compare valid and invalid forms of genetic reasoning, and help preservice teachers distinguish biological evidence from racial mythologies. This point is especially important because recent scholarship shows that race-as-biology misconceptions remain common and can be reduced only when genetics is taught with explicit attention to human variation, social context, and the consequences of scientific misuse (Donovan et al., 2024; Lujan & DiCarlo, 2024; Subiantoro, 2021).

Educator conceptualization and implementation readiness

The interview evidence can also be presented more explicitly to show the local character of the needs profile. The academic report involved eight educators from three institutions in Bengkulu 3 lecturers from Universitas Bengkulu, 3 lecturers from Universitas Muhammadiyah Bengkulu, and 2 lecturers from UIN Fatmawati Sukarno Bengkulu who teach biology or biology-related courses relevant to preservice teacher education. Table 4 condenses the recurring themes that emerged from these interviews and shows how they directly informed the design recommendations in this article.

Table 4. Educator Interview Themes and Design Implications

Theme	Summary of local finding	Design implication for article
Conceptual understanding	All respondents reported basic understanding of race, racism, and anti-racism, including awareness that race has weak biological grounding but strong social consequences.	Use anti-racism as a legitimate SSI topic grounded in both science and social justice.
Current teaching practice	None of the interviewed lecturers had explicitly embedded anti-racism in biology course activities, examples, or assessments.	Move beyond advocacy and provide concrete entry points, lesson phases, and assessment guidance.
Perceived relevance	Educators judged genetics, evolution, biodiversity, ecology, health, and	Retain a broad curriculum map while prioritizing genetics and

Theme	Summary of local finding	Design implication for article
	bioethics as suitable contexts for discussing anti-racism.	evolution as the strongest initial entry points.
Main barriers	Lecturers cited limited references, absence of ready-to-use modules, uncertainty about facilitating sensitive dialogue, and lack of assessment tools.	Provide case repositories, facilitation scripts, CER worksheets, rubrics, and attitude measures.
Readiness and support	Respondents expressed high interest in trying this innovation and indicated willingness to collaborate if institutional and pedagogical support is available.	Frame SSI-PBL as a feasible and scalable design rather than an abstract recommendation.

Presenting the interview evidence in a compact table helps the discussion remain transparent about what comes from the local needs analysis. It also shows that the proposed framework is not merely speculative; it responds directly to lecturers' stated constraints and priorities.

The educator side findings strengthen the document analysis. The academic report involved eight biology educators from three universities in Bengkulu, Universitas Bengkulu, Universitas Muhammadiyah Bengkulu, and UIN Fatmawati Sukarno Bengkulu who were selected because they teach biology-related courses with integration potential. Interview results indicate that, at the level of personal and professional awareness, lecturers generally recognize the urgency of anti-racism and acknowledge that biology can contribute to this agenda through SSI-oriented learning. They identified genetics, heredity, human evolution, biodiversity, public health, and bioethics as relevant spaces for such integration. Similar patterns have been reported in recent university biology studies, where instructors considered race and racism relevant to biology teaching but still needed stronger curricular support for implementation.

At the same time, the educators also described a clear implementation gap. They had not yet embedded anti-racism explicitly in their courses because of limited references, the absence of ready-to-use teaching materials, uncertainty about how to facilitate sensitive classroom dialogue, and the lack of assessment tools for socio-scientific reasoning and dispositional outcomes. Importantly, these barriers were accompanied by positive readiness: lecturers expressed strong interest in trying this innovation and indicated that they would welcome collaboration, institutional support, and a practical framework that could translate the idea into teachable classroom procedures. These barriers are also visible in recent biology education studies, which report that race-related content is often adopted unevenly because instructors lack external incentives, curated materials, and clear support structures.

Table 5. Priority Instructional Resources for SSI-Based Anti-Racism in Biology

Resource component	Description	Primary function
SSI case-based module	A structured lesson sequence anchored on authentic dilemmas, scientific readings, and data sets	Ensure coherent integration of biology concepts and socio-ethical reasoning
Student worksheets (inquiry + CER)	Tasks for evaluating evidence and constructing claim–evidence–reasoning arguments	Scaffold scientific reasoning and argumentation quality
Facilitation guide and discourse norms	Discussion scripts, questioning prompts, and conflict-management strategies	Maintain safe, respectful dialogue and minimize harm

Case repository (local/national/global)	Curated cases of stereotyping, discrimination, and misuse of scientific claims	Provide contextual relevance and multiple perspectives
Argumentation rubric (SSI)	Rubric for claims, evidence relevance, reasoning quality, rebuttals, and ethical justification	Support fair, transparent assessment and formative feedback
Attitude scale (diversity & anti-racism)	Items targeting acceptance of diversity, empathy, fairness orientation, anti-discrimination intention	Monitor changes in dispositions alongside cognitive learning

Priority resource needs and design recommendation: from findings to SSI-PBL implementation

Taken together, the bibliometric scan, document analysis, and educator interviews point to three interrelated priority needs. First, educators need coherent learning materials that explicitly connect biology concepts with anti-racist socio-scientific dilemmas. Second, they need facilitation supports that help them manage disagreement, prevent stereotyping, and maintain psychologically safe classroom discussion. Third, they need multidimensional assessment tools capable of capturing not only conceptual understanding but also argumentation quality, socio-scientific reasoning, and changes in students' diversity-related dispositions. Table 5 organizes these needs into concrete resource components, such as case-based modules, inquiry worksheets, discourse norms, case repositories, argumentation rubrics, and attitude measures. These needs are highly consistent with recent anti-racist and SSI-oriented biology education literature (Nardi, 2021; Scheuermann et al., 2024; Tran et al., 2024).

Based on this needs profile, the SSI problem-based learning (SSI-PBL) becomes especially relevant. The six phases issue orientation, problem formulation, investigation, argumentation, decision making, and reflection offer a practical flow for translating anti-racism from an abstract educational value into a structured biology learning experience. For preservice teacher education, this design is particularly valuable because students are not only learning biology content; they are also rehearsing how to teach controversial, evidence-based, and ethically sensitive topics in future school settings. This recommendation is supported by recent reviews showing that SSI and problem-based approaches are effective for strengthening scientific literacy, inquiry, and reasoning in science learning, including in preservice teacher contexts (Haviz et al., 2024; Hernández-Ramos, 2021; Hmelo-Silver, 2016).

Tables 6 and 7 therefore function as more than supplementary design tools. They operationalize the main empirical implication of this study: anti-racism in biology cannot be sustained through declarative statements alone, but requires alignment among issue framing, evidence use, dialogic argumentation, ethical reflection, and assessment. In this sense, the proposed lesson flow and assessment framework are direct responses to the gaps identified in curriculum documents and educator testimony, and they are consistent with recent SSI and PBL scholarship that emphasizes structured scaffolding for inquiry, argumentation, and decision making (Haviz et al., 2024; Hernández-Ramos, 2021).

Table 6. SSI-PBL Phases and Example Activities for Anti-Racism Integration

Phase	Instructor role	Student activity/output
1. Issue orientation	Present dilemma, establish respectful discourse norms	State initial claims; identify assumptions and questions
2. Problem formulation	Guide inquiry questions and resource planning	Formulate inquiry problems; plan evidence search
3. Investigation	Provide data sources; coach evidence evaluation	Analyze genetics/evolution evidence; produce summaries

4. Argumentation	Moderate structured debate and rebuttals	Develop CER arguments; respond to counterclaims
5. Decision making	Support ethical reasoning and consequence evaluation	Propose decisions; justify with evidence and values
6. Reflection & assessment	Provide feedback; administer rubrics/scales	Reflect on learning and attitudes; revise arguments

Table 7. Suggested Assessment Framework for SSI Anti-Racism Biology Learning

Outcome domain	**Assessment method**	**Example evidence**
Conceptual understanding	Short-answer and applied problems	Accurate explanation of genetic variation and adaptation
Socio-scientific reasoning	Written CER task + rubric scoring	Claims supported by relevant evidence and coherent reasoning
Argumentation discourse	Observation protocol or peer assessment	Quality of rebuttals and perspective-taking
Dispositional change	Attitude scale + reflection prompts	Increased acceptance of diversity and anti-discrimination intentions
Civic action planning	Project proposal or action plan	Feasible actions for inclusive classroom/school culture

The integrated findings highlight a critical design gap between what biology can explain scientifically and what biology teaching currently asks students to do with that knowledge. Contemporary genetics and evolutionary biology provide robust evidence that human biological variation is continuous, that most variation occurs within populations, and that visible traits such as skin pigmentation reflect adaptation rather than discrete racial hierarchy. Yet, unless this evidence is deliberately framed within SSI-based learning, students may complete biology courses without confronting the public misuse of biological concepts in racist discourse. This confirms a central point in recent literature: biology education can challenge racial essentialism only when scientific evidence is explicitly connected to social interpretation and classroom discussion (Fuentes et al., 2019; Donovan et al., 2024).

Among all biology topics, human genetics and heredity emerge as the strongest entry points. The academic report consistently positions genetics as the most strategic focus because it directly addresses variation among individuals, inheritance, human relatedness, and the misconception that race is a biologically fixed category. Evolution complements this focus by explaining migration, common ancestry, and clinal adaptation, particularly in relation to skin color. When these two areas are taught together, they provide a powerful scientific basis for dismantling biological essentialism while preserving disciplinary rigor. Recent evidence from humane genomics education strongly supports this (Donovan et al., 2024; Fuentes et al., 2019)

Nevertheless, the broader curriculum mapping suggests that a comprehensive anti-racist biology approach should not be restricted to genetics alone. Biodiversity and classification can help students question how scientific classification differs from social ranking; biotechnology and bioethics can open discussion about bias, justice, and access in genomic innovation; and ecology, health, and stigma can show how stereotypes shape social and health outcomes. This wider mapping is important because it moves anti-racism from a single-topic intervention toward a curriculum orientation distributed across multiple learning contexts, which is increasingly recommended in recent work on race, genomics, and inclusive science education (Lujan & DiCarlo, 2024).

Another important implication concerns the nature of curricular invisibility. The findings do not show an absence of relevant biology content; rather, they show an absence of explicit alignment among learning outcomes, activities, and assessments. In other words, the curriculum currently contains scientific concepts that could support anti-racist reasoning, but it does not yet

convert those concepts into explicit pedagogical intentions. This implicit-opportunity profile explains why educators may feel the topic is relevant yet still struggle to teach it in concrete and assessable ways. Recent studies of university biology teaching similarly report that students often receive limited exposure to social issues in biology courses and that instructors who do include race-related content often work without strong institutional incentives or curricular guidance (Bencze et al., 2020; Lee et al., 2013; Scheuermann et al., 2024; Tran et al., 2024).

The educator interviews also underline that anti-racism as an SSI theme must be facilitated with conceptual nuance and relational care. Biology instruction can demonstrate that race is not a robust biological taxonomy, but this should not be simplified into the message that racism is unreal or unimportant. Instead, the more educationally productive position is to help students distinguish between biological variation, which is real and complex, and racial hierarchy, which is socially constructed and historically sustained. Such an approach requires facilitation scripts, respectful discussion norms, and assessment practices that encourage evidence-based dialogue without reproducing harm or stigma (Donovan et al., 2024; Hancock et al., 2019a, 2019b; Subiantoro, 2023; Zeidler et al., 2019a).

Overall, the merged evidence suggests that embedding anti-racism in higher-education biology is both necessary and feasible, but only when curriculum design, lecturer readiness, instructional resources, and assessment are aligned. The study therefore extends the original discussion by showing not only where anti-racism can be inserted conceptually, but also why implementation has remained limited and what concrete supports are needed for change. In this sense, the proposed SSI-PBL pathway is not merely a design preference; it is a response to an empirically identified need for inclusive, scientifically grounded, and socially responsible biology teacher education (Donovan et al., 2024; Nardi, 2021; Scheuermann et al., 2024).

An additional contribution of bringing the report tables into the article is methodological transparency. Readers can now see more clearly how the needs analysis moved from a broad literature gap, to topic-level and subtopic-level curriculum opportunities, and finally to lecturer-identified implementation supports. This layered structure is especially useful for future design-based or development studies because it identifies not only what should be taught, but also where, why, and with what pedagogical scaffolds.

CONCLUSION

This study provides evidence that anti-racism can be meaningfully positioned as a socio-scientific issue within higher-education biology, particularly in preservice biology teacher education. *First*, the findings indicate that biology educators conceptualize anti-racism as a relevant instructional concern when it is grounded in core biological concepts, including human genetic variation, heredity, evolution, adaptation, common ancestry, biodiversity, and the social misuse of biological explanations. This suggests that anti-racism should not be treated merely as an external moral agenda added to biology learning, but as a socio-scientific context through which students can examine the relationship between scientific evidence, ethical judgment, social interpretation, and inclusive civic responsibility. *Second*, the document analysis reveals that the integration of anti-racism in biology course planning and instructional materials remains largely implicit. Several biology topics already provide strong conceptual entry points for anti-racist learning, especially genetics, human evolution, biodiversity, biotechnology, and health-related issues. However, these opportunities are rarely translated into explicit learning outcomes, structured inquiry activities, discussion prompts, assignments, or assessment indicators. Thus, the central challenge is not the absence of relevant biological content, but the lack of deliberate pedagogical framing that connects biological knowledge with socio-scientific reasoning about race, racism, and social justice. *Third*, the study identifies the need for systematic instructional and assessment support to enable meaningful implementation. Educators require SSI-based modules,

contextual case repositories, inquiry worksheets, facilitation guides for sensitive classroom dialogue, argumentation rubrics, and instruments for assessing diversity-related and anti-racist dispositions. In response to these needs, the proposed SSI-PBL framework offers a feasible instructional pathway by integrating issue orientation, problem formulation, evidence investigation, argumentation, decision making, and reflection into biology learning. Overall, this study contributes to biology education by clarifying how anti-racism can be transformed from an implicit curricular possibility into an explicit, structured, and assessable learning orientation. Human genetics and evolution appear to be the most strategic initial entry points because they directly address misconceptions about biological race, human variation, adaptation, and common ancestry. Nevertheless, anti-racist biology education should not be limited to these topics alone; it should be developed as a broader curriculum orientation that connects multiple areas of biology with ethical, social, and civic dimensions of science learning. Future research should move beyond needs analysis by developing, implementing, and empirically evaluating SSI-PBL-based anti-racism biology modules. Design-based research, quasi-experimental studies, and longitudinal mixed-methods inquiry are recommended to examine the effects of such modules on students' conceptual understanding, socio-scientific reasoning, argumentation quality, classroom discourse, and anti-racist dispositions. Further studies should also investigate how institutional support, lecturer professional development, and culturally responsive assessment practices influence the sustainability of anti-racist SSI learning in higher-education biology.

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