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Critical Engaged Pedagogy to Confront Racism and Colonialism in (Geo) Science Education Through a Historical Lens

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The geosciences continue to grapple with the exclusion of Black, Indigenous, Latinx, and other students of Color. These patterns can be understood in the discipline's roots in colonialism and extractivism. Furthermore, training of the scientific process as objective and race-neutral results in scientists who do not recognize how science can perpetuate inequities in society. Using a U.S. university biogeography course as a case study, we describe an innovative framework for teaching equity through a critical historical lens that interrogates: 1) biases in the processes and forms of knowledge production, legitimization, and exclusion; 2) the source of inequities in representation in the discipline; and 3) how societal benefits and harms of scientific practices are felt disproportionately demographically and geographically. Students were encouraged to critically analyze the historical context of scientific theories and their proponents and challenge assumptions about the representativeness of data supporting those theories into the present day. Engaging with these questions broadened students' understanding of changing paradigms in the field and of links between colonialism and modern science. We provide recommendations for instructors seeking to use similar approaches to enhance student learning.

Keywords: science teaching, history, colonialism, imperialism, decoloniality

INTRODUCTION

The earth sciences and other science, technology, engineering, mathematics, and medicine (STEMM) fields in North America and Europe are grappling with the persistent exclusion of Black, Indigenous, and Latinx students (Bernard and Cooperdock, 2018; Raji and Ali, 2021). Students of Color, as well as gender and sexual minorities and disabled students express feeling tokenized, unwelcome, and isolated (Rainey et al., 2018; McGee et al., 2021; Marin-Spiotta et al., 2023; Rowan, 2023). They do not see their backgrounds and aspirations reflected in the curriculum and frequently face discrimination, microaggressions, and other hostile behaviors (Wilkins-Yel et al., 2019; Miles et al., 2020; Schusler et al., 2021). Dominant STEMM pedagogies uphold research agendas that center the White experience as universal, delegitimize other ways of producing knowledge, and sustain current power relations and resource inequities (Battey and Leyva, 2016; Afolabi, 2020; Prescod-Weinstein, 2020; Fúnez-Flores, 2023).

One challenge to overcoming racism and other forms of identity-based exclusion in STEMM is that most students are not exposed to how science and universities both replicate and contribute to societal inequities. Science and engineering students in the U.S. rarely learn about the problematic history of many of the key figures and ideas in their discipline (Prescod-Weinstein, 2021; Forsythe, 2023). Rigid degree program structures limit students' opportunities to explore outside their majors and into the humanities and social sciences to better understand the role of science in society. One approach to overcome this barrier is to bring these themes into science curricula. In particular, providing a historical context has the potential to increase understanding of modern racial inequities in science and in society (Fang and White, 2022).

Efforts interrogating histories of exclusion in the geosciences have highlighted its origins in extractivism, settler colonialism, and imperialism (Pico, 2021; Monarrez et al., 2022; Rogers et al., 2022; Pico, 2023). Extractivism can be understood to encompasses both the removal of natural resources from the earth for capital gain and the exploitation of labor and land related to colonialism and capitalism. For example, geology as a discipline came to be in the late 18th century, with many of its key Western figures also proponents of scientific racism—and of eugenics (Cartier, 2021). Scientific racism was used to justify the exploitation of labor through slavery and the disposession of land from peoples deemed to be racially inferior. Scientific expeditions to map terrain and identify mineral resources globally were inextricably linked to capitalist and empire-building projects, leading the way for violent settler colonialism and expansion of borders through the taming of "primitive" land and people (Nyblade and McDonald, 2021; Monarrez et al., 2022).

These imaginations continue to shape language, norms, and stereotypes in the geosciences and in STEMM more broadly (Chakrabarti, 2019; Pico, 2021). Universities have been both instruments of colonialism and imperialism as agents of "civilization" and vehicles for the accumulation of capital and labor from chattel slavery and indentured labor (Wilder, 2014; Ball, 2022). Racialized exclusions and exploitation of labor are replicated in higher education and STEMM (Malone and Barabino, 2009; Dupree and Boykin, 2021; McGee et al., 2021; Morton, 2023). As geographer Max Liboiron reflects: "Colonialism is not a historical event, but an ongoing set of relations that still characterize the common sense of professional science" (Liboiron, 2021).

We present an innovative curricular intervention drawing from critical engaged pedagogy and antiracist scholarship to reveal the historical roots of racism and exclusion in the earth sciences and related fields. We start with a brief summary of scholarship on pedagogical practices that interrogate science paradigms. We then introduce a framework for teaching about equity in STEMM courses through a critical historical lens and apply it to a U.S. university-level geography course. Our paper concludes with recommendations for instructors seeking to integrate similar approaches into their courses, emphasizing the importance of creating an inclusive and reflective learning environment.

TRANSFORMATIVE PEDAGOGICAL PRACTICES

Dominant pedagogies do little to disturb persistent inequities in student outcomes, retention, and sense of belonging in higher education (McGee, 2016; Fiorini et al., 2023). One way to overcome this in the classroom is to value diversity in epistemology, introduce disciplinary concepts through the work of researchers from excluded groups, and make course material relevant to student life experiences and to creating a more equitable and just society (Camacho and Echelbarger, 2021). Examples of critical pedagogical frameworks and interventions have been described for chemistry (Babb and Austin, 2022) and environmental science (Bratman and DeLince, 2022).

We draw lessons from critical, feminist and antiracist scholarship to disrupt exclusionary models of learning in primarily White institutions. In *Teaching to Transgress*, feminist theorist and educator bell hooks identifies engaged pedagogy as a liberating practice for "interrogating biases in curricula that reinscribe systems of domination (such as racism and sexism) while simultaneously providing new ways to teach diverse groups of students (hooks, 1994; p. 10)." Culturally-relevant pedagogy, in addition to prioritizing student academic success, provides students with skills to develop critical consciousness to question cultural norms, values, and institutions that produce and sustain societal inequities (Ladson-Billings, 2021). Anti-racist approaches further make visible systemic oppression and integrate discussions of race, racism, and social justice throughout the curriculum (Lynch et al., 2017).

In the geosciences, education has been recognized as a vehicle for increasing inclusion of a diverse student body (Gates et al., 2019; Mattheis et al., 2019). Culturally-relevant approaches have addressed place-based learning for Native and Indigenous students (Lemus et al., 2014; Semken, 2018; Eitel et al., 2023), multicultural outreach (Medina Luna et al., 2019; Zuluaga et al., 2020) and inclusion of environmental justice (McDaris et al., 2019; Reinen and Kortz, 2019). Increasingly, curricular interventions to address racism and racial disparities in the geosciences underscore the importance of acknowledging the discipline's history (Hall et al., 2022; Rogers et al., 2022; Pico, 2023). Two important open access educational resources in this area are Geocontext (Cartier, 2021; Pico et al., 2021)[1] and the Decolonising UK Earth Science curriculum[2].

Calls to "decolonize the curriculum" have raised awareness of the hegemony of White European and U.S. scholars as experts and the problematic legacies of colonialism in Westernized science. Fernandes (2021) traces this movement back to the 2015 "Rhodes Must Fall" protests at the University of Cape Town, South Africa. Curricular decolonization has been described in many ways: from

[1]https://serc.carleton.edu/teachearth/geocontext/index.html
[2]https://www.decolearthsci.com/resources/

diversifying author lists, to bringing global perspectives to a course, to "identifying colonial systems, structures, and relationships, and working to challenge them" with the goal of developing a more complete scientific understanding (Dessent et al., 2022).

As widely used, the term "decolonization" itself has limitations outlined by Indigenous and other scholars. In "Decolonization is not a metaphor," Indigenous Studies scholar Eve Tuck and ethnic studies scholar Wayne Yang warn that decolonization must be an unsettling endeavor and that conflating it with other social justice efforts can contribute to assuaging settler feelings of guilt and responsibility (Tuck and Yang, 2012). They also stress that decolonization is explicitly about the repatriation of Indigenous life and land, which the decolonizing syllabi movement does not address. Yet anti-colonial education remains crucial. If colonialism is the replacement and erasure of Indigenous lives and expertise, expropriation of Indigenous land, and the disruption of Indigenous peoples' relationship with land, water, air, and other life, geographer Max Liboiron (2021) challenges us, how do we enact the opposite in our disciplines?

In this way, we understand our pedagogy as a step toward decoloniality, a concept born from South American critiques of the power structures and knowledge formations that grew out of European colonialism (Quijano, 2007; Mignolo and Walsh, 2018). "Decoloniality reveals "the dark side of modernity" and how it is built "on the backs" of "others," others that modernity racializes, erases, and/or objectifies" (William and Mary Decolonizing Humanities Project, 2023). It is a praxis that seeks to undo ongoing colonial injustices. In the words of philosopher Maldonado Torres (2017), decoloniality is "undoing and unlearning the coloniality of power, knowledge, and being and [. . .] creating a new sense of humanity and forms of interrelationality." Learning about the violent histories of settler colonialism and imperialism and their roles in both the erasure of Indigenous expertise and the production of Westernized knowledge in our disciplines, institutions, and nations is a critical step – but only a first step – in a process of anticolonial pedagogy. A decolonial approach also requires identifying how colonial violence continues to shape extractivist practices in science and society (Cupples, 2024).

CASE STUDY: MAKING VISIBLE COLONIALISM AND SCIENTIFIC RACISM IN A SCIENCE COURSE

Our case study is an intermediate-level university biogeography course. Biogeography involves the interdisciplinary study of how life is distributed over the Earth and through geological time and of the mechanisms responsible for these patterns, including geological events, such as plate tectonics, temporal and spatial variation in climate, and processes of evolution and extinction. The course, open to undergraduate and graduate students, is listed as a degree elective for physical geography and environmental science majors and fulfills a general education breadth requirement for undergraduate students. Thus, it provides an opportunity for STEMM students to engage with a critical historical analysis of a field that integrates the physical and natural sciences and for non-STEMM students to encounter this content while learning science.

The course was developed in 2010 and has undergone significant revisions to incorporate content about equity since 2020. The first iterations started with discussions of common barriers to representation in the discipline, including racism, heterosexism, and ableism, and of geographic biases in journal publications, affecting whose voice and expertise is recognized. These readings were tested in a smaller course before biogeography, which enrolls 50–60 students. The next iteration included content on how current societal inequities affect interpretations of some of the physical and natural processes shaping biogeographic patterns. The three most recent versions of the course increasingly embedded a critical historical analysis into the teaching of major scientific concepts and aimed to make connections between past centuries' histories of colonialism, imperialism and scientific racism and their modern manifestations in science.

ENGAGING STUDENTS IN CRITICAL ANALYSIS

We briefly describe various pedagogical tools to promote meaningful learning and critical perspectives. We facilitate regular in-class discussions to create a dynamic, interactive learning environment, allowing students to communicate their thoughts, participate in meaningful debates, and gain from diverse perspectives. These are complemented by regular online assignments, providing a more individualized and comfortable platform for those students less inclined to public participation. Class assignments are designed to go beyond the traditional teaching of disciplinary content to re-evaluating classical views of the subject.

We work intentionally to create a respectful environment. From the start, we explain the purpose of integrating social, geopolitical, and historical contexts into our study of scientific concepts and include the following learning objective in the syllabus: "to learn how legacies of colonialism affect historical and current biases in the representation, methods, and applications of the discipline." We lay out norms for conversations and engagement with the course material and with each other.

From the beginning, students are introduced to the major paradigm shifts of biogeography, highlighting how the field has changed in response to emerging knowledge, such as plate tectonics, and novel technological advances, such as radiocarbon dating, phylogenetics, and ancient DNA analysis. Students learn that science is not immutable and instead is strongly shaped by sociocultural context and processes in which data are collected, analyzed, and interpreted. This approach sets the stage for students to cultivate a critical perspective. Researchers have found that

BOX 1 | A Humanities Education for Anti-Racism Literacy (HEAL) Framework for Integrating Equity into a STEMM Course.

1. What comprises scientific knowledge in the discipline?
    a. What inequities exist in the processes of knowledge production and legitimization in the history of the discipline and how do they manifest today?
    b. How may these biases affect our interpretation of the science?
    c. What and whose knowledge is privileged and excluded?
2. Who is represented in the discipline today?
    a. What are the demographics of students, scholars, and practitioners?
    b. What are identified barriers to participation and retention?
    c. Who feels represented in the discipline and who is excluded?
3. Who benefits from the production of knowledge and its applications?
    a. How do inequities in the history and current practice of the discipline perpetuate inequities in society?
    b. What biases exist in the interpretation and application of disciplinary knowledge and technological products?
    c. Who is harmed by these?

incorporating historical narratives and storytelling into teaching geology and biology can enhance student's understanding of the dynamic nature of the scientific knowledge and of the influence of culture and society on science (Williams and Rudge, 2016; Dolphin et al., 2018; Nyarko and Rudge, 2022).

Within class time, we create a space for discussion to promote students' ability to critically question and analyze scientific narratives in the literature. These exercises encourage students to analyze the historical context of research practices. Student responses to discussion questions and online assignments reveal that the critical perspectives we aim to incorporate in the course resonate with students across various disciplines, indicating the broader applicability of these practices.

The course culminates with a final paper assignment detailing the biogeography of a particular species or group of species selected by each student. One of the prompts asks whether colonialism and/or scientific biases affected either aspects of their species' biogeography or scientific understanding of species' histories and current distributions. This exercise challenges students to synthesize their accumulated knowledge and insights and to effectively integrate the critical perspectives they have engaged with throughout the course into their essays.

AN ANTI-RACIST FRAMEWORK FOR TEACHING ABOUT (IN)EQUITY

We provide a generalized framework for incorporating a critical historical anti-racist analysis into the content of geoscience and other STEMM courses that exposes: 1) the origin and consequences of inequities in representation; 2) biases in the processes and forms of knowledge production, legitimization, and exclusion; 3) and how societal benefits and harms of the application of scientific knowledge and methods are felt disproportionately geographically and demographically (**Box 1**). This framework was informed by our (Hennessy, Marin-Spiotta) interdisciplinary work to generate models of transformative higher education as part of the Mellon-funded Humanities Education for Anti-Racism Literacy (HEAL) in the Sciences and Medicine project at the University of Wisconsin-Madison (Caldwell et al., In press). History can provide a powerful lens for understanding disparities and inequities in the participation and experiences of Black, Indigenous, and other people of Color and the distribution of resources in higher education (Monarrez et al., 2022). Institutions of higher education and research organizations in the U.S., Europe, and many other parts of the world operate within a culture that systematically privileges Whiteness and dictates accepted and replicated norms and practices to the exclusion of others (Afolabi, 2020; Callwood et al., 2022; Lawrence and Escobedo, 2023).

Inequities in the Formation of the Discipline

Colonialism, imperialism, and scientific racism in biogeography and related fields (geology, ecology, evolution) are closely embedded in the history of key figures, such as Charles Darwin, Alfred R. Wallace, Alexander von Humboldt, Charles Lyell, John Wesley Powell, Louis Agassiz, and their ideas (Cartier, 2021; Pico, 2023). Early Western contributors to the foundation of the STEMM disciplines as we know them today built their knowledge and influence along imperialistic projects, financed by military and capitalist enterprises. In turn, their ideas directly or indirectly contributed to ideologies that drove settler colonialism and other practices of dispossession, exploitation, and erasure of Indigenous and local peoples. However, these topics are typically not explicitly addressed in U.S. science textbooks (Pico, 2023).

Prominent natural historians, and geologists frequently ventured beyond cataloging diverse life forms and landforms into describing the sociocultural dynamics of the people they encountered on their journeys far from home. Lyell, a pivotal advocate of the geological principle of uniformity, extended his stratigraphic classification to human races during his travels in North America, referring to Black people as "a different species in time" (Yusoff, 2019). This intersection of geology and societal views was not unique to Lyell. Powell and Agassiz believed in the biological inferiority of people of different races and contributed to state-sanctioned projects of eugenics and Indigenous land dispossession, providing direct links between U.S. geology, White supremacy, scientific racism, and settler colonialism (Pico, 2023). Powell, for example, who, in addition to leading the U.S. Geological Survey, also directed the Smithsonian's Bureau of Ethnology, believed in scientific racism, advocating the existence of a racial continuum "From Barbarism to Civilization" based on geographically determinist interpretations of the environments in which different cultures lived—an argument that legitimized settler colonialism in the U.S. West.

As successive iterations of the course integrated a more critical lens of the “father figures” of the field, the students in the course became more willing to identify mistreatment and erasure of local and Indigenous expertise as scientific racism. Students were able to identify racial prejudices embedded into narratives recounting scientific travels from the Victorian era. Readings about Darwin’s and Wallace’s expeditions that shaped the theory of evolution are paired with critical analyses of natural history museums’ colonial roots. Museums played an important role in establishing scientific racism by functioning as repositories of specimens from around the globe, legitimizing extractivist collection methods (Das and Lowe, 2018).

Students gained insights into how 19th century colonialism and scientific racism shaped scientific interpretations and how science could be used as a tool for geopolitics. Here we provide an example of how we scaffolded this content throughout the course. Typically, students uncritically learn about factors shaping the contemporary distribution of terrestrial biomes and the role of physical (e.g., fire) and biological disturbance (e.g., herbivory) in influencing transitions between forest and savanna at the local scale. With the multiple goals of exposing students to studies outside of North America and to African scientists, we discussed research on a new approach for distinguishing ecosystem states in Madagascar (Solofondranohatra et al., 2018). This study revealed Eurocentric biases that misclassified native savanna as anthropogenic degraded forest, ignoring thousands of years of Malagasy pastoralist management of grasses and resulting in erroneous vegetation maps for the country (Bond et al., 2008). This provided the opportunity to discuss how the imposition of colonial science in Madagascar identified local peoples as destructive to the environment and thus necessitating European control; this perspective continued to inform research in the late 1990s (Gade, 1996). Later in the course, students read how a key figure in biogeography, Alexander von Humboldt, exported Western European biases, influencing forest conservation policy globally at the expense of native grasslands (Pausas and Bond, 2019). In the unit on paleoclimate, students learn how new knowledge of Madagascar’s unique mountain geology and climatic patterns during the Pleistocene resulted in a diversity of savannas (Wilmé et al., 2006). Through these interconnected examples, students learn how paradigm shifts transform disciplinary understanding and how contemporary scientific knowledge can be deeply rooted in historical political projects.

Inequities in Representation in the Geosciences

Current demographic trends in the geosciences can be better understood in the context of inequities in the discipline since its inception, shaped by practices of extractivism, scientific racism, and maintenance of colonial powers. In North America, for example, the overrepresentation of White people at all levels of the academic hierarchy and in the profession reflect centuries of exclusions and the positioning of Western universities as the centers of scientific learning. In the course, students are exposed to data describing patterns in under- and overrepresentation by race and ethnicity, gender, and other important identities, such as sexuality, ability status, and first-generation status. These are accompanied by articles on the barriers to equitable participation (Anadu et al., 2020; Marin-Spiotta et al., 2020; Pickrell, 2020). Exposing demographic inequities in geoscience journal editorial boards (Pourret et al., 2021) provides students with the opportunity to learn about why publications matter in science and for scientists. Geographic biases, such as the gross underrepresentation of African authors in the geoscience literature today (North et al., 2020), for example, can launch discussions about how the dominance of Western perspectives shapes understanding of scientific concepts and has implications for the professional advancement of global scientists.

The historical foundations of biogeography, geology, paleontology, and other natural history fields lay the groundwork for modern extractivism in research methods. An analysis of the authorship networks for publications on amber inclusions reveals how current research practices have excluded Myanmar researchers (Dunne et al., 2022). Helicopter research (and the related parachute research) describes the common practice of foreign researchers or researchers from a more affluent region landing in an area, extracting specimens or data for analysis elsewhere, and publishing their findings with little to no recognition of local scientists and other experts (Minasny et al., 2020). Colonial research refers to this practice when there is a contemporary or historical colonial relationship between the place of data extraction and the home of the outside researchers (Goodenough and Mills, 2021). Students in the course draw direct lines between modern examples of data collection and the way Darwin, Wallace, Humboldt, and others extracted the information from which they developed theories that continue to shape our disciplines today. Students learn how inequities in access create geographic gaps in data that can bias scientific understanding in the geosciences (Carter, 2021; Golembiewski, 2022; Raja et al., 2022).

Inequities in the Application of Scientific Knowledge

The third component of the HEAL framework relates to how inequities in historical and current practices bias interpretation and application of disciplinary knowledge and how these contribute to societal inequities. One example is how technological advancements in molecular biology, including the ability to sequence ancient DNA, have revolutionized science in multiple fields. The use of molecular clocks to estimate phylogenetic divergence times has rewritten many classic studies of evolutionary trees and has also been used to provide support or reject hypothesis about the timing of tectonic and other geologic events. While groundbreaking, these technological revolutions also raise ethical concerns, particularly regarding their application to human populations, as discussed by Indigenous scholar Kim TallBear (2013) in the book *Native American DNA*. TallBear raises important questions about how traditional concepts of ancestry can or cannot be reconciled with the search of genetic markers of identity, as well as by whom and why are these types of studies conducted, who holds power and ownership over the data, and how benefits of the research are distributed. These questions become especially critical given the historical context of violence enacted through settler colonialism and the extractivist nature of most research to date on Indigenous people and their lands.

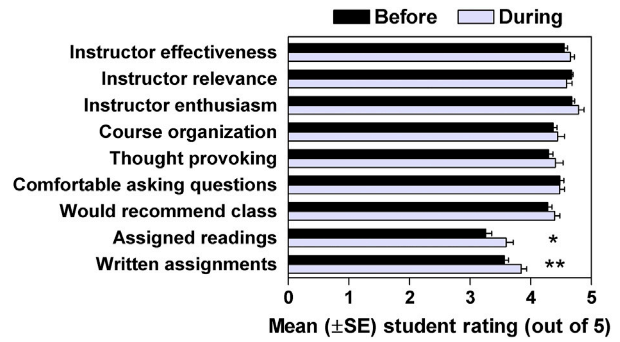

FIGURE 1 | Student's t-tests for fourteen semesters of student evaluation ratings for the biogeography course, comparing before (10 semesters) and during (4 semesters) the incorporation of de-colonial material. 0.07>*>0.05, 0.05>**>0.01. See **Supplementary Material** for full prompt text, raw data (**Supplementary Table S1**), and statistical results (**Supplementary Table S2**).

TEACHING ABOUT RACISM IN A SCIENCE COURSE

Teaching about racism and histories of oppression raises a number of vulnerabilities for the instructor and students. We briefly review some of these here and refer the reader to relevant scholarship from the teacher-education field (Joseph et al., 2016).

A challenge in antiracist pedagogy, especially in primarily White institutions, is the marginalization of students of Color by centering the race-consciousness building and learning of White students (or instructors) (Blackwell, 2010). One way to address this is to include guidelines for expected norms in the classroom, including making sure no person is asked to be a spokesperson of a group. By reading the primary literature, students learn about the experiences of historically excluded scholars, rather than as a lecture from an instructor who may not hold those identities. We found that by naming the importance of intersectionality in shaping people's experiences in the classroom and in the readings, conversations about identity become more than one-dimensional, with potential for broader learning by students in the course. Furthermore, bringing an interdisciplinary approach to recognizing the historical roots of inequities in a discipline today into a science classroom also increases the likelihood that everyone will learn something new, regardless of their background, and thus can avoid the pitfall of teaching to educate only one section of the students.

Discipline-specific examples make the content more relevant to students. Students are asked to engage with personal narratives of scientists in the field and think about how these challenges could manifest in their own disciplines. When reading about current demographic trends and barriers to equitable participation in the geosciences, students are exposed to present initiatives led by scientific societies nationally to advance diversity, equity, inclusion, accessibility, and social justice. After hearing about national initiatives in response to racial disparities in the geosciences, students wanted to hear about what was being done locally at their university to improve conditions for students who continue to be underserved and minoritized. Local examples also helped the students relate to the content. One student shared that the article on helicopter research made them think of scientists from the urban campus coming to rural counties to extract data for their studies without interacting with or respecting local expertise. With that reference point, the students could explore the additional layers involved when two regions have centuries-long histories of colonialism, violence, and racial inequities.

Students used the final paper to deepen their engagement with the topics of colonialism and scientific racism, connecting them to broader themes in biogeography, such as how systematic racism affects the biological and physical nature of urban landscapes, European versus Indigenous fire management practices, and the impact of colonial policies on Tribal lands sovereignty. In a mid-term evaluation, a student identified a strength of the course: "topics like research ethics, colonial biases were fascinating. Being able to balance the knowledge we learned in lecture with insights from other research papers was really informative and I thought that those outside source perspectives deepened my knowledge and understanding of the material."

Instructors face a number of internal and external barriers to incorporating antiracist teaching practices, including fear of resistance and losing control in the classroom (Akamine Phillips et al., 2019). We have experienced little pushback during the course or in written student evaluations, which we primarily attribute to the identity and positionality of the lead faculty and, hopefully, to attempts to scaffold this content into the course. Recognizing that students entering a traditional STEMM course do not expect to critically engage with concepts like scientific racism and colonialism, on the first day we review the course learning goals in the syllabus and establish why these topics are so important for our training as scientists or as science-literate professionals.

We compared the results of student course evaluations between semesters of the biogeography course before and during intervention of the addition of anti-racist and de-colonial material (**Supplementary Table S1**). Students were asked to complete an anonymous and voluntary course evaluation near

BOX 2 | Summary of teaching practices to support the integration of the Humanities Education for Anti-Racism Literacy (HEAL) Framework in a STEMM course.

How students incorporated concepts into their work.

- Students actively engaged with selected readings that exposed biases within biogeography. They critically analyzed how historical perspectives influenced scientific thinking.
- Students connected the concepts of scientific racism and colonialism to their own majors and career goals.
- Students examined research methods, such as helicopter and parachute research, and assessed their implications in the context of extractivism and scientific biases.
- In their final papers, students synthesized their understanding of the course material with a critical analysis of human impacts, colonialist influences, and historical biases in the study of species' biogeographic histories.
- Online assignments requested students to express their thoughts and share insights on the course material, demonstrating their understanding and application of the key concepts.

Tools used to help students engage with concepts.

- We provided a selection of literature that offered historical and contemporary insights into how scientific racism and colonialism have influenced scientific thinking and practices in the field.
- Assignments were created to encourage critical thinking, analysis, and personal reflection, prompting students to question classical views of the field and to apply these concepts in their work.
- In-class discussions (pair-share, small groups, large groups) cultivated a dynamic learning environment, encouraging students to share their thoughts and engage with different viewpoints.
- Online assignments offered a space for more reflective and in-depth exploration of the concepts, which was particularly beneficial for students who were less comfortable participating in group discussions.
- The final paper assignment required students to integrate their understanding of biogeography with a critical perspective on the discussed concepts, allowing them to demonstrate their comprehensive understanding of the material.

the end of each semester, consisting of the nine prompts which remained consistent for the course. We then used Student's *t*-tests to individually test differences for each prompt before and during the intervention (**Figure 1**; **Supplementary Table S2**). Overall, ratings are consistently high, with little to no change after modification of the course, revealing that addition of material on scientific racism, colonialism, and barriers to participation in the field did not decrease student satisfaction. Student ratings for the assigned readings and written assignments significantly increased with the intervention.

Effective teaching requires self-reflection and awareness of how instructor and student identities and lived experiences influence our relations in the classroom. This is especially true for White educators in institutions where Whiteness is normalized (Haynes and Patton, 2019). The fear of making mistakes attenuates with more practice and time invested into learning but probably never goes away. Regardless of identity, the majority of STEMM instructors are not trained to address these topics in the classroom, given traditional scientific training that upholds the view of science as objective and race-neutral. STEMM faculty of Color face additional vulnerabilities in speaking out about historical and modern racism in the classroom, as documented by research on ethnic studies courses.

Critical engaged pedagogy invites instructors to affirm our students as whole persons, with experiential knowledge from their lives outside the classroom that bring value to the learning happening in the classroom. In order to do this, instructors need to see ourselves as whole persons, too. As hooks urges us: "I do not expect students to take any risks that I would not take, to share in any way that I would not share. When professors bring narratives of their experiences into classroom discussions it eliminates the possibility that we can function as all-knowing, silent interrogators" (hooks, 1994; p. 21). As instructors, we acknowledge to our students that our own scientific training did not include learning about current inequities in our disciplines and their historical origins, or the interrelations between science and colonialism. We can reflect on ways that our research practices sustain these inequities and share with the students how our scholarship, both our understanding of the discipline and our own approach to research, are being transformed through this work, in and outside of the classroom. Similary, students demonstrated the ability to identify how what they were learning applied beyond the specific discipline and content of the course. A student reflected on how they could use knowledge gained in the course "as a basis to look for biases and inequities in what I learn going forward."

CONCLUSION

Overall, students demonstrated critical thinking about how historical and geopolitical events affect how and what type of empirical data, collected by whom and where, is used to build scientific knowledge. This course was not only an academic exercise in learning biogeography, but also represented an exploration of the broader implications of science in society, emphasizing the need to question and challenge long-standing paradigms. Because we discussed relationships between society and science, students readily shared knowledge from their own majors and other courses, including environmental studies, economics, computer science, international relations, human geography, sociology, etc. These connections made the science more accessible and relevant to current events.

Based on experience with this course, we provide recommendations for instructors seeking to bring an equity perspective into their curricula (**Box 2**). First, one does not have to completely overhaul a course in one sitting. The literature we cite proposes a broad suite of strategies how and what to teach. One does not have to be an expert in the history of science and society to adopt a critical lens to historical narratives of key figures and concepts in the geosciences and other STEMM disciplines. We have deliberately cited the literature generously to serve as a resource. The HEAL framework interrogating how knowledge is produced, who is represented in a discipline, and how inequities and biases in the practice of science affect its societal impact proved useful for thinking about how to weave critical concepts and literature into an existing curriculum and tie them to the science. The framework also provides a number of places from which to start an intervention.

Lastly, hooks' (1994) critical engaged pedagogy persuades us to center student learning, through fostering critical thinking, personal reflection, and valuing their lived experiences. Bringing a critical historical lens to our teaching deepened student discussions and participation with the course material and enriched our own engagement with the course and the students. Understanding the violent histories of exclusion, extractivism, and erasure in the geosciences is an important step towards reimagining ethical, respectful, and more caring ways of mutual interaction with people and knowledge.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The UW-Madison Institutional Review Board determined that the use of data from standard teaching evaluations in this manuscript did not constitute research involving human subjects.

AUTHOR CONTRIBUTIONS

EM-S, ED-V, and KK-R were involved in iterations of the course redesign and delivery. EH and EM-S were involved in the conceptualization of the HEAL equity framework. All authors contributed to writing and editing the paper and provided critical review for intellectual content. KK-R conducted the data analysis. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.escubed.org/articles/10.3389/esss.2024.10114/full#supplementary-material

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