Addressing Racisms and Anti-Racisms in Science and Teacher Education Research: A scoping review

Patrick Phillips, University of Ottawa
Rieley M. O'Leary, University of Ottawa
Marcus G. Parley, University of Ottawa
Patrick R. Labelle, University of Ottawa
Nicholas Ng-A-Fook, Ph.D., University of Ottawa

A Canadian Curriculum Theory Project Research Team
Faculty of Education, University of Ottawa

Table of Contents

1.0 Acknowledgements

We wish to thank the Social Sciences and Humanities Research Council, Genome Canada, and Ontario Genomics for funding this scoping review. We further thank our committee of expert advisors at the University of Ottawa, who reviewed this report: Dr. Lerona Dana Lewis, Dr. Giuliano Reis, and Dr. Tasha Ausman. We acknowledge the contribution of Alain El Hofi, Research Librarian at the University of Ottawa Library, who peer-reviewed the MEDLINE search strategy using the Peer Review of Electronic Search Strategies (PRESS) guideline for systematic reviews (McGowan et al., 2016).

Social Sciences and Humanities Research Council of Canada
Conseil de recherches en sciences humaines du Canada

2.0 Introduction

Amidst the present moment of strategic thought on macro global and micro local challenges to a just and equitable future, the authors of UNESCO's *Futures of Education: A New Social Contract* report make a critical observation: "All exploration of possible and alternative futures raises profound questions of ethics, equity, and justice – what futures are desirable and for whom?" (UNESCO, 2022, p. 8). UNESCO places at the heart of any strategic foresight planning the past, present, and future of teacher education and spaces teachers will create in their classrooms. Such shared future spaces seek to create educational opportunities that enable "individuals and communities to flourish together" (p. 2). Despite technological innovations and reforming policies here in Canada or abroad, educational research, including on science and genomics education, still does not adequately address equity and inclusion. Today "gaps in access, participation and outcomes [continue to be] based on yesterday's exclusions and oppressions" (UNESCO, 2022, p. 20). Indeed, there remain "significant gaps and distortions in humanity's accumulated knowledge that need to be addressed and corrected. Indigenous perspectives, languages, and knowledges have long been marginalized. Women and girls, minorities and low-income groups are also severely underrepresented" (UNESCO, 2022, p. 12). In response, how have educational researchers and policymakers sought to address such ongoing individual, systemic, and societal opportunity gaps in relation to teacher education research? In our study, we scope the emerging tensions or gaps in relation to how Diversity, Equity, and Inclusion (DEI) and anti-racisms are being taken up (or not) within the broader field of genomics education, educational research, and implications for teacher education.

In terms of the understanding and curricula of studying human genetics, these gaps have persisted for over a century. Over 100 years ago, American sociologist W.E.B. Du Bois (1897/1970) was concerned that race was being used as a biological explanation for social and cultural differences between different populations of people. He argued against the idea of racial categories as discrete groups of people, suggesting that these categories served to misrepresent the true diversity of humanity (Du Bois, 1897/1970). Today, although the mainstream conceptual understanding of "race" among scientists and science educators is that race is a social construct, studies in major research journals continue to claim, "categories like 'white' and 'black' [as] biological variables" (Gannon, 2016, para. 2). By some measures, the use of "race" as a biological category has increased in the so-called postgenomic age (Chow-White and Green, 2013). Even today in Canada, marital, and so reproductive, relations between Indigenous and non-Indigenous peoples are still mediated by race-based policies such as *The Indian Act* (Coulthard, 2014; Thompson, 2009). Such historical settler colonial macro and micro context here in Canada are also problematic for both the advancement of genomics and teacher education as a body of knowledge that has, and continues, to be harmful for Black, Indigenous, and other (non-white) racialized communities (Brothers, Bennett, & Cho, 2021).

In turn "race," understood as an immutable biological category, leads to diseases being misdiagnosed (for example that sickle-cell anemia is a "Black" disease), while reproducing

racist social constructions of others and their respective segregated exclusionary hierarchies (Yudell et al., 2016, p. 565). Genomics and in turn the broader field of science education is thus caught up in a paradox: "both believing race to be a tool to elucidate human diversity and believing that race is a poorly defined marker for that diversity" (Yudell et al., 2016, p. 565). As Yudell et al. (2016) argue, this paradox cannot be solved with more technological innovations. Instead, to "cultivate and adopt an anti-racist environment [in the learning and practice of genomics], we must be intentional and self-aware of our character, culture and climate" (Green, 2021, para. 12). Yet curricular and pedagogical opportunities for teachers and students to (un)learn the social and cultural dimensions of genomics remain limited (Gouvea, 2022). Worse, there is evidence that typical teaching of provincial science education curricula may foster problematic beliefs by omitting critical attention to how the science of genomics intersects with reproducing certain settler colonial ideological conceptions of race and racism (e.g., Morning, 2008; Donovan, 2014; Ng-A-Fook et al., 2023).

Meanwhile, teacher education, as a profession and body of knowledge, is charged with deepening our understanding in relation to such curricular and pedagogical paradoxes (Moore, 2021; Wiggan et al., 2020). How might teachers then (un)learn to support and work with "different population groups who are ethnically, culturally, and linguistically diverse, to include and adequately support students" (UNESCO, 2022, p. 86)? How might they ensure that "learners from historically excluded and marginalized groups are adequately supported" (ibid.)? In response, teacher educators and teachers are called upon to turn schools into sites of "inclusion, equity and individual and collective well-being" (UNESCO, 2022, p. 94). Globally and locally, then, teacher education "needs to be rethought to align with educational priorities and orient better towards future challenges and prospects" (UNESCO, 2022, p. 85). And yet, what does existing educational research have to say about such challenging calls to action? Here in Canada, the challenges, and prospective themes of SSHRC's *Shifting Dynamics of Privilege and Marginalization Knowledge Synthesis* implicate this same need. Canada is directly impacted as the "world continues to experience massive displacement of people and an increase in the divide between the privileged and marginalized … [while] some marginalized or underrepresented groups continue to be perceived as outsiders in their own country of origin" (SSHRC, 2022, n.p.). Meanwhile, SSHRC's (2021) *Guide to Addressing Equity, Diversity and Inclusion Considerations in Partnership Grant Applications* calls on researchers to "learn about the current state of diversity in [our] discipline(s)" (n.p.). For teacher education, this is a critical research goal in and of itself. While there have been several policy initiatives designed to address diversity, equity, and inclusive excellence in teacher education and schools (Ng-A-Fook et. al. 2022), we do not know the current state of their effects in relation to science education and its discursive trends here in Ontario, let alone how it is taken up in relation to genomics (Reardon, 2011).

In 2017, the Association of Canadian Deans of Education published their *Accord on Teacher Education*, with the broad aim of "[fostering] an inclusive and equitable society" (p. 1). The Accord's guiding principles include a vision of teacher education in which "educators

are responsive and responsible to learners, schools, colleagues, and communities" while being committed to promoting DEI and "[challenging] all forms of social oppression" (p. 3). In the summer of 2020, nearly 50 Canadian universities signed the *Scarborough Charter on Anti-Black Racism and Black Inclusion in Canadian Higher Education: Principles, Actions, and Accountabilities*, affirming that the responsibility of institutions, including teacher education programs, is to "build practices of ongoing dialogue and action yielding inclusion, substantive equality and societal transformation" (Preamble section, para. 1). Black flourishing and inclusion are predicated on "the ability of universities and colleges to educate and to innovate; to be alive to complexity and proactive in the face of crisis; to foster fundamental questioning through rigorous, respectful engagements across difference; and to enable societal transformation" (Principles section, para. 4). At the University of Ottawa's Faculty of Education, our 2022-27 Action Plan is committed toward increasing the "capacity of teaching staff, administrative staff, and students to create and sustain inclusive, accessible, and anti-racist student experiences and learning environments" (University of Ottawa, 2022, n.p.). As part of such capacity building, our study sought to conduct a scoping review of Canadian teacher education and in relation to the anti-racist education debates taking place both inside and outside the fields of genomics and educational research.

3.0 Executive Summary

Today, although the mainstream understanding "race" among scientists and science educators continues to be that it is a sociocultural construction, studies in major research journals continue to claim "race" as a valid biological category of human difference (Hubbard & Monnig, 2020). By some measures, the use of "race" as a biological category has increased in the so-called postgenomic age (Fitzgerald, 2014). Genomics and in turn science education is thus caught up in a paradox: ostensibly understanding race to be a poor proxy for human difference while still teaching it as a biological variable (Donovan, 2014, 2017, 2022). And yet, opportunities for teachers and students to (un)learn the social, cultural, and historical dimensions and contexts of genomics remain limited. Worse, typical teaching of science education curricula may foster problematic beliefs in certain racialized biological reductionism and/or its respective essentialisms (Sabatello, 2019; Willinsky, 2020). Meanwhile, teacher education, as a profession and body of knowledge, is charged with deepening our understanding in relation to such curricular and pedagogical paradoxes (Donovan, 2015, 2016; Gillborn, 2018; Ng-A-Fook, et al., 2023). In response, our scoping review sought to address the following lines of inquiry:

1. What research exists within the broader field of North American genomics education in relation to addressing racisms, diversity, equity, inclusion, and anti-racisms?
2. If such research exists, what are the promising practices for teacher educators and/or science educators here in Ontario?

3. Is such research on genomics in relation to anti-racist education taken up within the broader field of educational research and more specifically teacher education research?
4. How might existing research on anti-racist education support the translation of such curricular and pedagogical opportunities and/or gaps for current practicing science teachers and/or future teacher candidates here in Canada and/or elsewhere?

3.1 Executive Summary of Key Findings

- **Genetic essentialisms remain a core challenge and gap in teacher education, science education, and curriculum policy.** All students come to science education with implicit understandings of "race" and genetics learned from popular media and their introductions to basic genetic concepts in the K-12 schooling systems (Bates, 2005; Donovan, 2022; Martschenko 2020; Willinsky 2020). Most students taking introductory science courses at university are only taught basic genetic literacy, which, even in the case of purportedly progressive science curricula, can serve to reinforce or instill the belief in a biological essence of "race." This inattention to reductive essentialist thinking in turn has the danger of justifying and/or reproducing existing racist beliefs within past, present, and future policy and practice.

- **Domain-specific disciplinary siloing limits the teaching and learning of contextualized--social, cultural, historical--genetics/genomics literacy.** In the K-12 science curricula the sociocultural and/or historical contexts of "race" are often relegated (if present at all) to the social sciences and history curricula. However, biological categorizations of "race" are still used to teach basic genetic concepts and/or as a proxy for human difference. Learners are often left with the implicit lesson that "race" is still defined biologically. There is often no room in science curricula to explore socio-cultural and historical perspectives outside of the government mandated curriculum policy K-12 content, allowing dangerous myths among the public to persist.

- **Absence of proactive purposeful anti-racist and/or decolonizing curricular and pedagogical frameworks for teaching and understanding genomics education and its respective literacies within the K-12 public school curriculum, teacher education, and/or science education.** There is an absence of studies and/or research programs in Canada that analyze and synthesize how settler colonial logics, its respective exclusions, have framed historical and/or contemporary conceptions or debates of genetic essentialisms, reductionisms, and respective racisms in relation to the field of genomic education and its respective literacies.

- **Predominantly White K-12 and Higher Education Institutions reproduce a science education and respective curriculum that often limits the educational opportunities for different non-white racialized equity-seeking communities**. Most science majors arrive at post-secondary institutions without having learned about racisms and anti-racisms in relation to genomics literacies, serving as a barrier to diversity, equity, inclusion, and representation in science fields broadly, teacher education, and science education. Students in these fields experience forms of racism in their training in the classroom and in professional apprenticeship, often feeling as if they are being othered by their peers, mentors, and/or professors. In the case of genomics-focused fields, disciplines are often dominated by a white settler colonial logic such as, but not limited to, genetic counseling, biomedical sciences, engineering, and medicine. Meanwhile, the reproduction of genetic determinisms framed as a biological category of "race" reinforces beliefs that different, non-white racialized people share DNA that is unique from the rest of humankind.

- **Creating, supporting, and enacting science education curricula and pedagogies that introduce students to a humane genomics literacy reduces the dangers of reproducing genetic essentialisms.** Genomics and genetics, as in previous paradigms of eugenics, assume the current order and cultural values, risking the understanding of race as ahistorical rather than seeing it as an historically contingent form of understanding human difference and thus foreclosing critical consciousness of how present and future technosciences might be misused.

3.2 Executive Summary of Key Policy Implications

- **There remains a core need for an anti-racist and anti-essentialist humane genomics literacy curriculum for science education. Science teachers must be prepared to teach the racist past and future potential of their disciplines, as well as the present inequalities that scientific racisms maintain.** Throughout students' K-12 educational journeys, science educators are pivotal leaders in disrupting and challenging racisms and taking up anti-racist understandings of genomics science and its respective technologies. All students should have the opportunity to learn about different racialized groups that have been and continue to be affected by genetic essentialisms that reproduce different kinds of racisms and exclusions.

- **An anti-racism and anti-essentializing humane genomics education curriculum should be taught from a cross-disciplinary perspective**. Teacher education and methods courses must take up the different concepts put forth within a genomics literacy. Such a curriculum would ensure teacher education programs and candidates are introduced to the differences between and among basic, standard, and humane genomic

literacies. Use of race/ethnicity as a biological marker must be taken up and problematized across science curricula, and both sociocultural/humanities and science-based perspectives must be brought into dialogue across curricula. A humane genetic literacy has the explicit purpose of refuting genetic essentialism and instead strives to create a society that is more equitable. This requires scaffolding the necessary knowledge and understanding of key genomics concepts across the K-12 science curriculum.

- **Create national, provincial, and territorial K-12 professional learning opportunities for teacher educators and science educators to develop and implement curriculum and pedagogies that proactively takes up the differences between basic, standard, and humane genomics literacies**. Such professional learning would seek to disrupt and challenge genetic essentialisms, racisms, and exclusions as well as anti-racist strategic curricular and pedagogical responses.

4.0 Background

As educational historian Ann Gibson Winfield (2007) notes, for the "first six decades of the twentieth century, political and social discourse in [North America] was dominated by an ideology that relegated the vast majority of the human race to imbecility, declaring that only those of Nordic ancestry were worthy of survival" (p. xvii). This formative ideology is eugenics: a set of beliefs and practices that emerged in the late 19th and early 20th centuries, through which its advocates aimed to enhance and improve the genetic quality of certain human populations. It is based on discriminatory notions that certain heritable traits, such as intelligence, physical attributes, or moral characteristics, can be selectively promoted or suppressed through controlled breeding and social interventions. Eugenic thinking would go on to influence the development of genetics, and later genomics, as a basis for understanding human difference (Roll-Hansen, 2010; Chatters 2021, Liscum and Garcia, 2022). During this period, curriculum thought across North America would be infused by seemingly "naturalistic" notions of human difference to the point that eugenics might be called one of the foundational paradigms of curriculum as a practice and field of study (Selden, 1978), informing common sense notions of intelligence, assessment, and reform. This study thus works from the premise that eugenics thinking has been perennially embedded in our curricula as a "master narrative" of human-beingness (Kelly et al., 2021; Phillips & Ng-A-Fook, 2024).

Indeed, as Donovan et al., (2021) stress, "genetics knowledge is regularly invoked in sociopolitical debates in order to maintain and mitigate structural inequality between races," and if they continue, "we take it to be true that genetics knowledge affects the content of these debates, then educators need to think about the kind of impact they want to have on their students' genomics literacy in the 21st century (p. 545). Despite this need, genetic deterministic thinking (see section 7.1)—or notions that reduce human difference and potential to one

predetermined genetic code—remains embedded in contemporary genomic research, practice, and teaching. For example, "using the large datasets available with new gene sequencing and biobank projects, behavioral geneticists are developing tools that attempt to predict individual intelligence based on genetics. These predictive tools are meant to enable a 'precision education' that will transform society" but in fact threaten deepened racial bias across society (Scherz, 2022, p. 59; see also Nisbett, 2013). In medical research and practice, Otlowski et al. (2012) warn of a global rise in genetic discrimination, or the "differential treatment of asymptomatic individuals or their relatives on the basis of their real or assumed genetic characteristics … that requires multilevel responses to ensure social justice and equitable outcomes for all citizens (p. 433). Meanwhile, science education students and their educators, from K-12 to post-secondary and health professional education programs (Carmichael et al, 2020, 2021; Fofana, 2013; Green et al., 2022), are routinely exposed to both popular and ostensibly expert understandings of "race" and genetics that perpetuate false beliefs that "race" has a biological core (e.g. Bates, 2005; Braun & Saunders, 2017; Tsai et al., 2016; Tsai, 2021; Martschenko, 2020; Willinsky, 2020; Hubbard & Monnig, 2020; Donovan, 2022). "While it has been uncommon for genetics instruction to address issues of race explicitly, researchers suggest that a more humane, anti-racist approach to genetics and genomics education is needed and have begun to describe what it might look like" (Gouvea, 2022, p. 1). In our qualitative findings (sections 7.1 to 7.5), this is best demonstrated by a small but growing literature on genetics education that centers anti-racist approaches in the teaching and learning of genetics/genomics.

5.0 Objectives

Our scoping review sought to: (a) identify the types of available research on genomics education and anti-racist education approaches for addressing its different concepts in teacher education and K-12 science education; (b) identify promising anti-racist education strategies; (c) identify gaps in the existing teacher education research literature to propose future research directions; (d) create an educational resource for teacher educators and/or teachers to use in the classroom to address existing curricular and/or pedagogical gaps. Our proposed objectives respond to the following themes as set by SSHRC: 1) Uncertain, divided world; 2) Identities, privileges, and opportunities, and 3) Sense making.

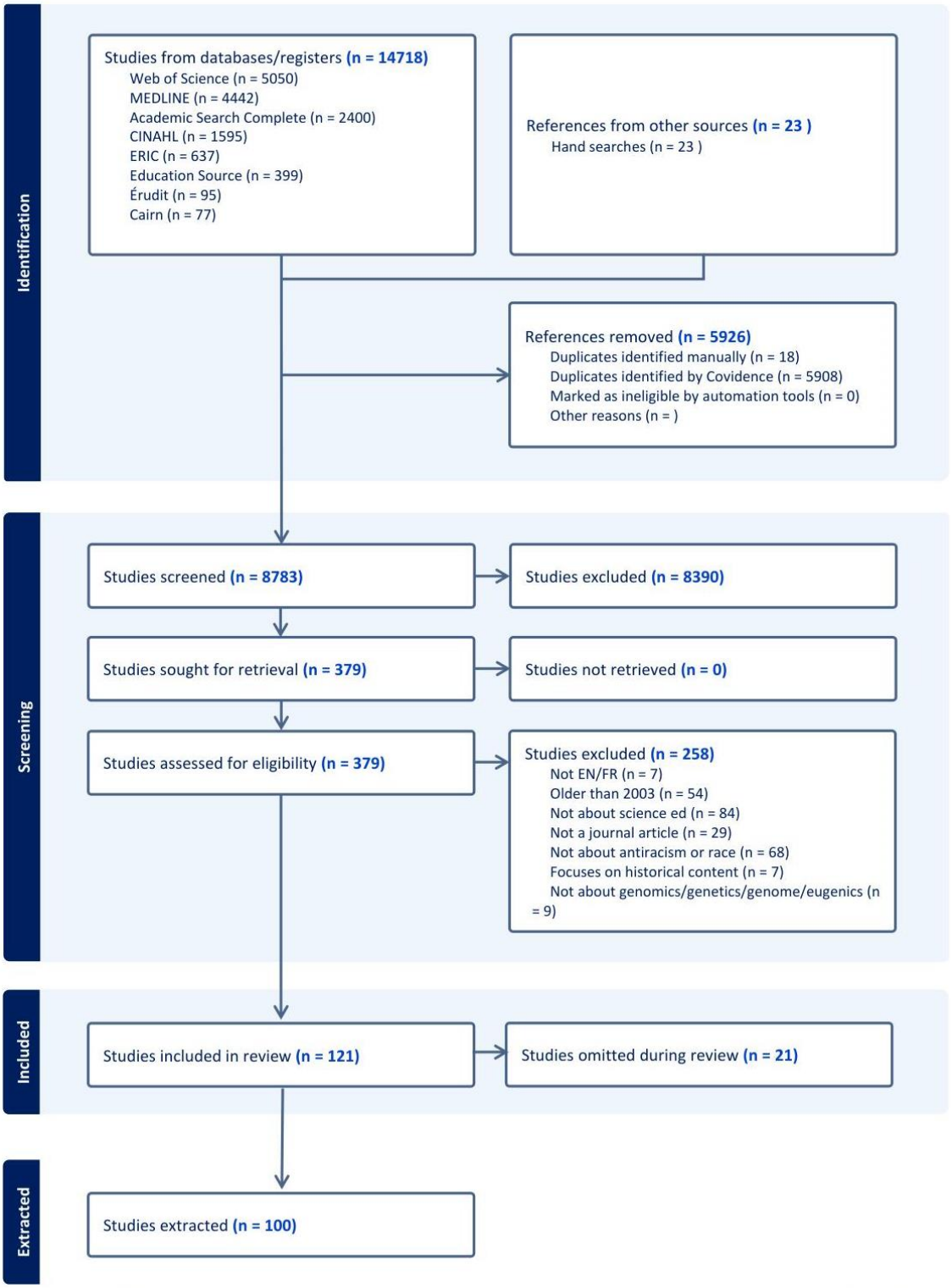
6.0 Methods

We conducted a collaborative scoping review to examine the extent, range, and nature of Anglophone and Francophone research activity and practice on anti-racisms and science education, with a focus on genomics and genetics education/literacy. As is typical of a scoping review, our study sought to summarize the breadth and depth of this topic, and identify gaps, possibilities, and limitations of the way racisms and anti-racisms are (or not) taken up in science education.

Our scoping review followed the steps outlined by Arksey and O'Malley (2005) and adhered to the reporting standards outlined in the PRISMA-ScR guidelines. Once our questions were finalized, test searches were developed by our team's educational research librarian. To capture relevant test articles (see Appendix A for all search strategies). Our finalized search strategy was peer reviewed by a research librarian (see subsection 6.2 below for more detail), and suggested changes polled from the team were tested and incorporated. Our final search protocol was conducted across eight relevant bibliographic databases (see Fig. 1 below). A small number (23) of studies from hand searches were also included.

Our team used Covidence, a web-based collaboration platform, to manage study screening and selection and enable tracking amidst distributed work. The team met virtually and/or in person eleven times between April and November 2023. As described in the following subsections, these meetings facilitated internal validation and consistency in screening and data extraction.

Figure 1
PRISMA diagram of our scoping study screening process



6.1 Search strategy and sources

This current review focused on finding studies that address racism and anti-racism training in the context of science education, specifically genomics education. A research librarian with experience in planning various knowledge synthesis projects drafted, developed, and implemented a search strategy to find pertinent published articles in eight electronic databases: Academic Search Complete (EBSCOhost), Cairn, CINAHL (EBSCOhost), Education Source (EBSCOhost), ERIC (Ovid), Érudit, MEDLINE (Ovid) and Web of Science (Clarivate). The strategy was informed, in part, by others found in previous reviews on anti-racism or diversity training (Benuto et al., 2018; Hassen et al., 2021; Wang et al., 2022) as well as those found in reviews focused on genomics or genetics education (Gasteiger et al., 2023; Puddester et al., 2022; Rahimzadeh et al., 2020; Wright, 2014). A draft strategy, which included subject headings and keywords, was developed for MEDLINE (Ovid) by the research librarian and feedback was obtained from other review team members. The strategy was also peer-reviewed by another librarian following the Peer-Review of Electronic Search Strategy guideline (McGowan et al., 2016). The final strategy was executed on June 26, 2023, in English-language databases and on July 12, 2023 in French-language ones. The complete search strategy is available in Appendix A. For some databases, results were limited by publication type to identify only those references from academic journals (details are provided in the full search strategy). Once searches were completed, citations were imported into Covidence, an online tool used to manage various steps of a review's screening phases. Duplicate references were identified and removed once imported into Covidence. Additional duplicates were identified and excluded while screening references.

6.2 Internal Validation and Team Collaboration

Once our database searches were complete and our corpus uploaded to Covidence, the team progressed through three stages, as facilitated by Covidence: 1) title and abstract screening, 2) full-text screening, and 3) data extraction. At the beginning of each of these phases, the team research librarian and project manager prepared and facilitated pilot tests. These tests consisted of a sample, scoring template, and team validation meetings and debriefings. For example, for our first phase, our team research librarian created a template scoring spreadsheet for the team to fill out individually. The team then met to debrief and gauge its internal consistency in categorization of inclusion and exclusion. The team manager then continued this practice through each phase, which are each described in the following two subsections.

6.3 Study selection

Phase 1 of our study followed the standard abstract screening process as facilitated by Covidence. Of the 14,718 articles initially obtained from database searches, 8,783 journal articles were actually included for screening after duplicates were removed. Abstract screening thus consisted of the abstracts being read and evaluated in Covidence for inclusion by two (2) team members out of a team of six (6) active reviewers, randomly assigned by Covidence. Team members voted to either include or exclude articles according to the following exclusion criteria:

- Date/older than 2003
- Language/not FR or EN
- Type/not a journal article
- Content/is historical content
- Not about science education
- Not about genetics/genomics
- Not about anti-racism or race

The criteria and the date were chosen by the team because 2003 marked the conclusion of the Human Genome Project. The team thought it prudent to assess how concepts, trends, and debates—how racisms and anti-racisms are addressed in science and genomics education—have or have not developed since this important milestone. During the pilot of this phase, team members noticed several articles that, while falling within our date range (2003-23), dealt with historical content, such as the history of eugenics, genetics, or genomics thinking (e.g. Gericke et al., 2017; Martschenko, 2020; Otlowski et al., 2012). These were flagged for relevance to the background and different section contexts of the report using the Notes function of Covidence. However, they were excluded from the main study corpus. Screening conflicts were resolved by the Principal Investigator and/or team member who did not participate in the initial voting on the article. Abstract screening resulted in 379 articles for full-text screening.

Phase 2 of our study likewise followed full-text screening as facilitated by Covidence and bound by our research questions. In addition to verifying those articles passed our **Phase 1** exclusion criteria, our team (now comprised of four (4) reviewers) scanned and reviewed the 379 included articles towards inclusion based on whether or not the articles addressed one or more of the following:

- The conceptualization and/or teaching of anti-racism or “race” as a sociocultural and/or biological construction in science education or a related field;
- What might count as/be included in genomics/genetics literacy in science education or a related field or context;

- The experiences of racialized persons in science education or a related field; and
- The application of a genetics/genomics education pedagogy, social action research interventions, other forms of knowledge transfer methods, and/or implications for teacher education.

All articles were assessed and voted on by two (2) team members as randomly assigned by Covidence. Any conflicts were resolved by a PI who was not involved in the initial voting of an article. The full-text screening phase resulted in a total of 121 articles being included for data extraction, which we describe in the following subsection.

6.4 Data extraction

Phase 3 of our project involved close and critical reading of our remaining 121 articles. To facilitate this, the team met to collaborate on a data extraction protocol. The result of this discussion was a two-step process: initial extraction of key qualitative and quantitative data through a master qualitative and quantitative spreadsheet and a shared extraction summary document. The master spreadsheet tracked data such as journal names, study aims and findings, methodologies, and paraphrases and quotations that aligned with our study questions in the context of genomics/genetics literacy:

- Implications for racisms;
- Implications for anti-racisms;
- Implications for equity, diversity, and inclusion;
- Implications for science education; and
- Implications for teacher education.

Team members each extracted data from approximately ten to thirty articles each. The team met three times to each report on and discuss emerging concepts, tensions, and themes across the extraction phase. The project manager then used these findings to identify key themes and implications emerging from the study. Based on these key points, the project manager created a master data extraction summary document with respective data categories. All team members then contributed qualitative data to this document, which then informed our knowledge brief and this report. Finally, the project manager transformed some of the quantitative and qualitative data into quantitative analyses, through counting and visualization. As indicated in **Figure 1**, a further 21 items were excluded during data extraction, based on a closer reading of texts and through determination that they did not meet this review's inclusion criteria, resulting in a final total of 100 included articles. The resulting findings are discussed in the next section.

7.0 Findings

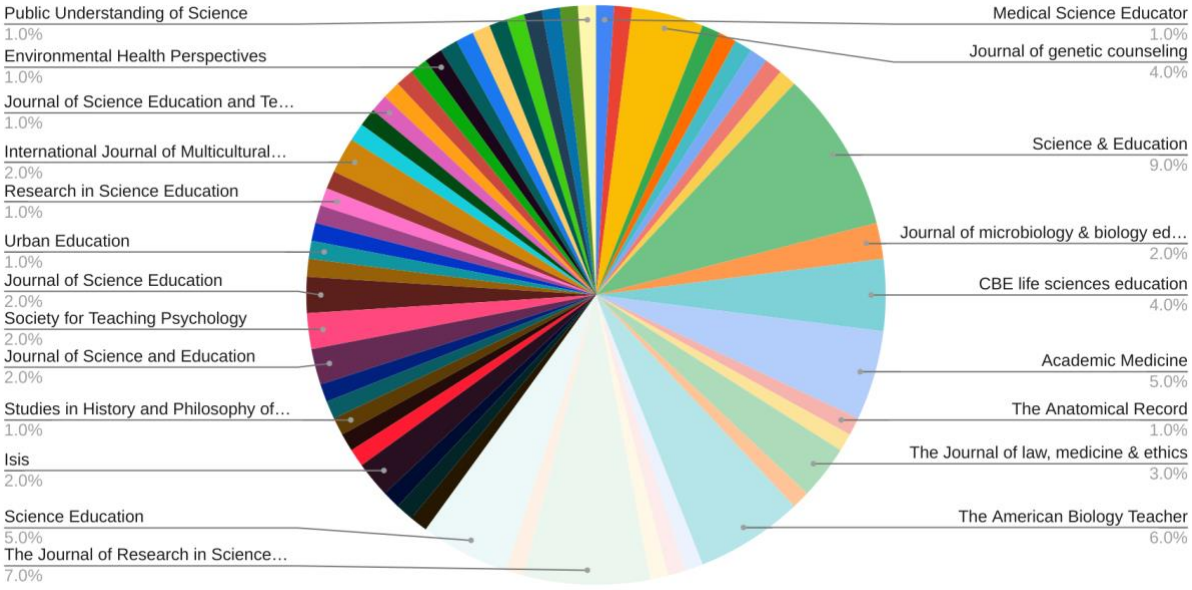
Through close reading and basic descriptive statistical recording, the team arrived at several key empirical and qualitative, analytical findings. The statistical data are discussed here first, followed by subsections on each qualitative theme or issue.

To scope the macro status of genomics/genetics in relation to anti-racisms in science education as discussed in the literature, the team tracked several quantitative indicators, including:

- Which journals articles were appearing in, and at what count per journal;
- Language and country of origin of relevant articles;
- Domain/disciplinary context of publications;
- Type of study —i.e. empirical or theoretical; and
- Dates of publication.

We posit that these statistics suggest important characteristics of the ways anti-racisms are taken up (or not) by researchers in relevant fields.

Figure 2
Included article counts by journal



As illustrated by the many slices of **Figure 2** above, our included articles originated in many disparate disciplinary professional peer-reviewed journals. This suggests a wide yet simultaneously limited —in terms of individual journals —take up of racisms or anti-racisms in relation to genomics/genetics education. This may also suggest a lack of editorial or general

disciplinary priority (at least until recently; see **Figure 6** below). Although **Figure 2** also suggests that much has been published around genomics across different fields, we focused on discussions happening within science education, genomics/genetic education, and teacher education.

Figure 3

Disciplinary domain contexts of included disciplinary journals/articles

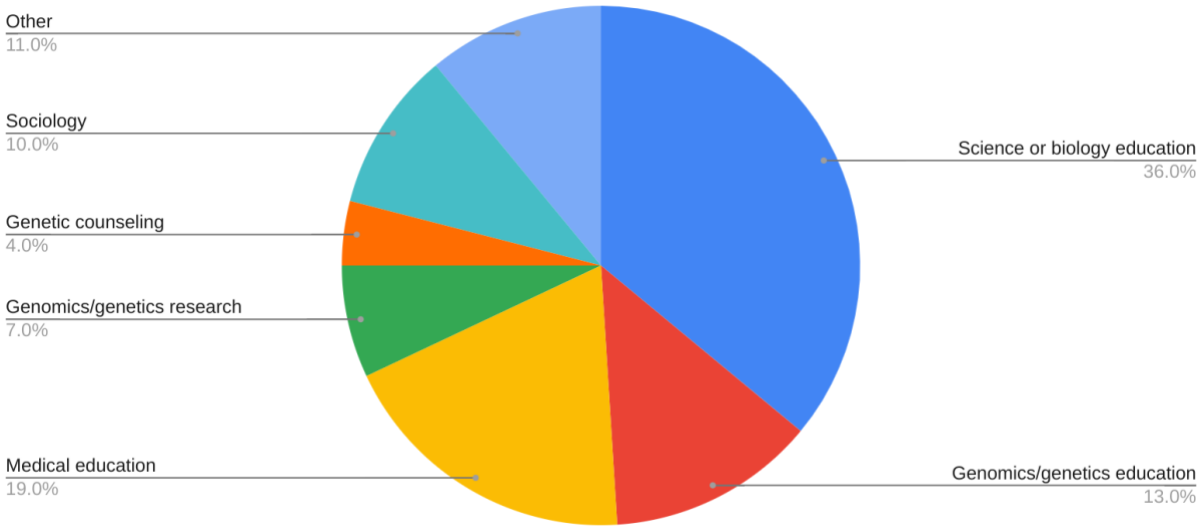
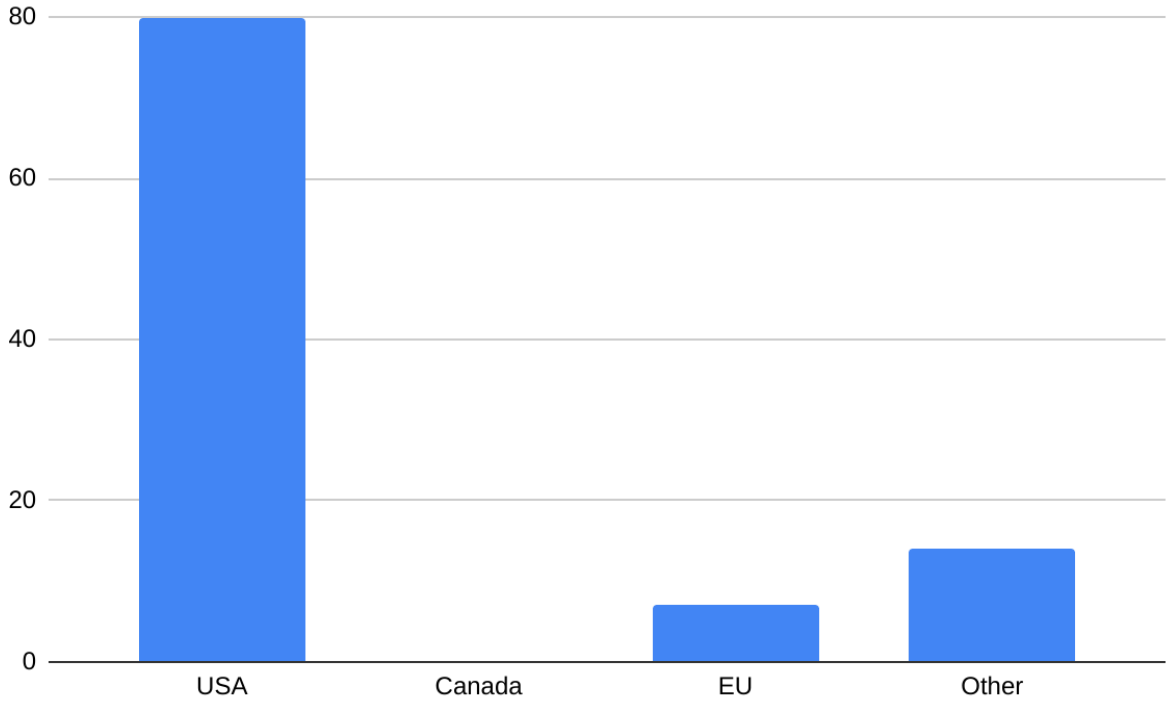


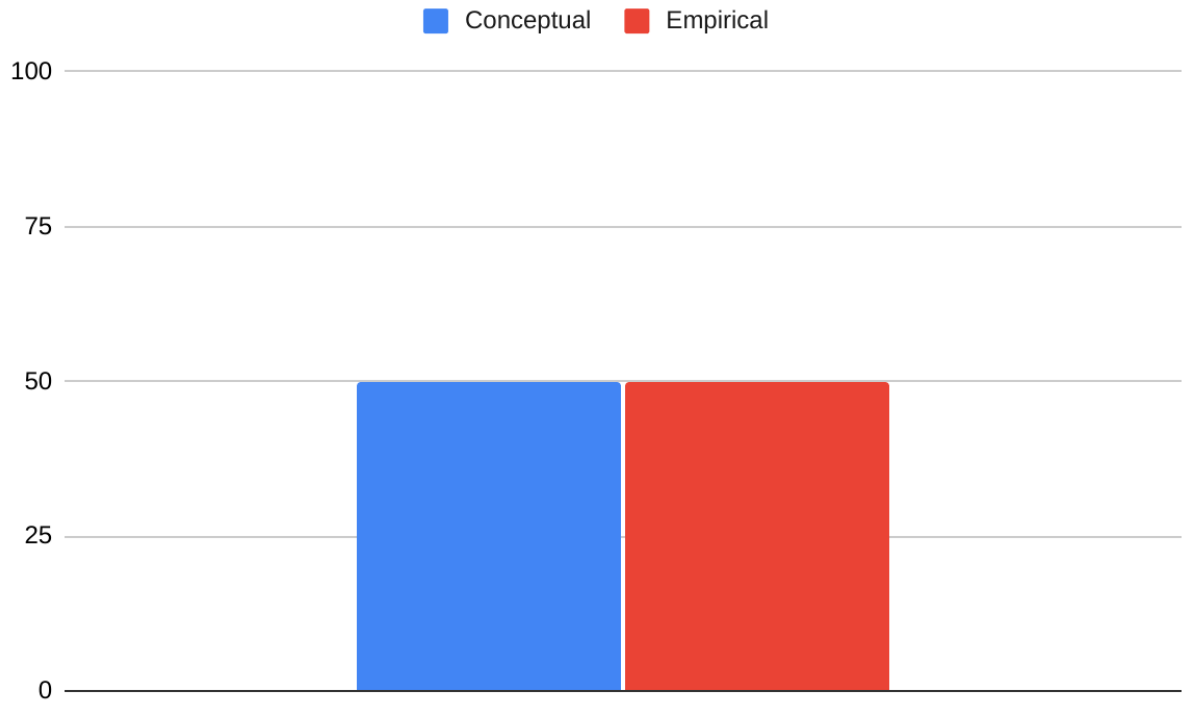
Figure 3 above provides a more clarified view compared to **Figure 2**, aggregating the disciplinary/domain contexts of our study's included articles. While these data show a primary concentration within science education more broadly, a relative scarcity of take-up within genomics/genetics research and literacy is made visible. Within the 13% (n=13) of studies focused on genomics/genetics education, nine (9) of these were led by the same author, Brian Donovan (2014, 2015a; 2015b; 2016; 2017; 2022; Donovan et al., 2019; Donovan et al., 2020; Donovan et al., 2021) whose work we discuss further below. Medical education appears to be a domain in which racisms and anti-racisms in relation to genomics/genetics are emerging as important concerns for both health profession education researchers and practitioners (e.g. clinical practice/instruction; see for example Tsai, 2021; Lujan and DiCarlo, 2021). Here, "Other" aggregates outlier disciplinary domains such as anthropology and philosophy.

Figure 4
Country of research/origin of included articles



The overwhelming majority (80%) of included articles stemmed from studies in the United States. One of these studies included data from Canada, but was counted as a US study. These data suggest a lack of a relevant research agenda in Canadian science education, genomics/genetics research, or genomics/genetics education.

Figure 5
Types of included articles



According to Donovan and Nehm (2020), "very little empirical work has addressed the interplay between genetics education and social identities" (p. 1452). **Figure 5** above demonstrates a 50-50 split between conceptual/theoretical and empirical studies in our sample. Given that most of these articles are from the past six years (see **Figure 6** below), these data suggest that addressing racisms/anti-racisms within genomics education —or genomics/genetics *literacy* —is presently an emerging area of inquiry. Qualitatively, Brian Donovan has emerged as a leader in this area, based on our study's close readings. Donovan advances an explicitly anti-racist, anti-essentialist *humane* genetics literacy. As Donovan (2022) explains, "Humane genetics education differs from the basic genetics education offered to most students and also most standard views about how to reform genetics education because it has an anti-essentialist purpose derived from anti-racist educational approaches that value humanitarianism" (p. 2). Donovan is currently a senior researcher at BSCS Science Learning, a US non-profit focused on socially just science and teacher education research. **Figures 6** and **7** below offers a quantitative sense of Donovan's work, providing citation network visualizations based on two papers: *From Basic to Humane Genomics Literacy: How Different Types of Genetics Curricula Could Influence Anti-Essentialist Understandings of Race* (Donovan et al., 2020; **Figure 6**) and *Toward a more humane genetics education: Learning about the social and quantitative complexities of human genetic variation research could reduce racial bias in adolescent and adult populations* (Donovan et al., 2019; **Figure 7**). Several other scholars within our corpus are connected to Donovan's work (e.g. Jennifer Tsai, John Willinsky, Amelia Hubbard, Robyn Tornabene) and

together represent a relatively small but core group of scholars advancing literature based on teaching and learning about human difference —or genomics literacy —from an explicitly anti-racist and anti-essentialist curricular and pedagogical foundation.

Figure 6

Citational network of Donovan et al. (2020), "From Basic to Humane Genomics Literacy: How Different Types of Genetics Curricula Could Influence Anti-Essentialist Understandings of Race" generated with the Connected Papers web app. Larger circles indicate more citations, while darker shading indicates more recent publication.

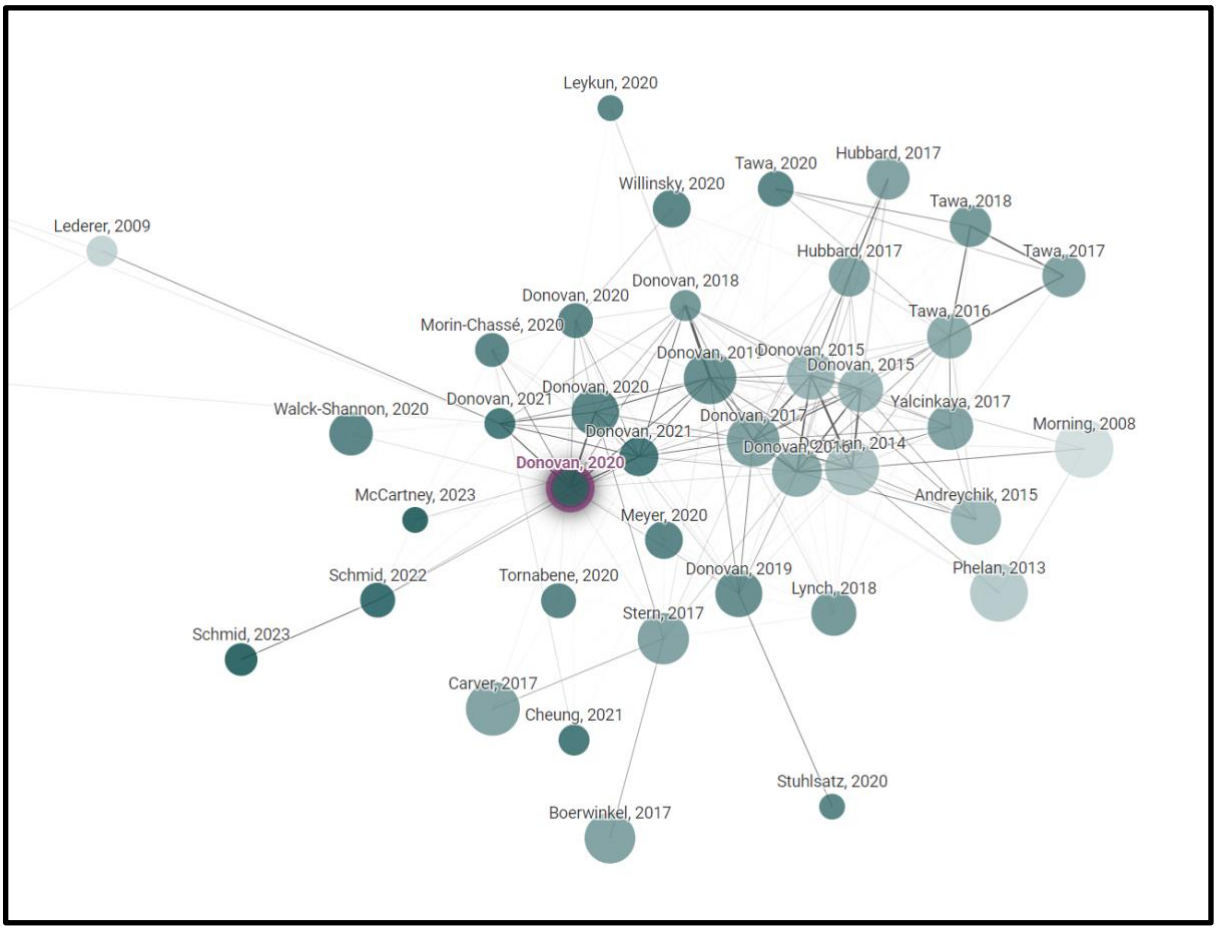


Figure 7

Citational network of Donovan et al. (2019), "Toward a more humane genetics education: Learning about the social and quantitative complexities of human genetic variation research could reduce racial bias in adolescent and adult populations" generated with the Connected Papers web app. Larger circles indicate more citations, while darker shading indicates more recent publication.

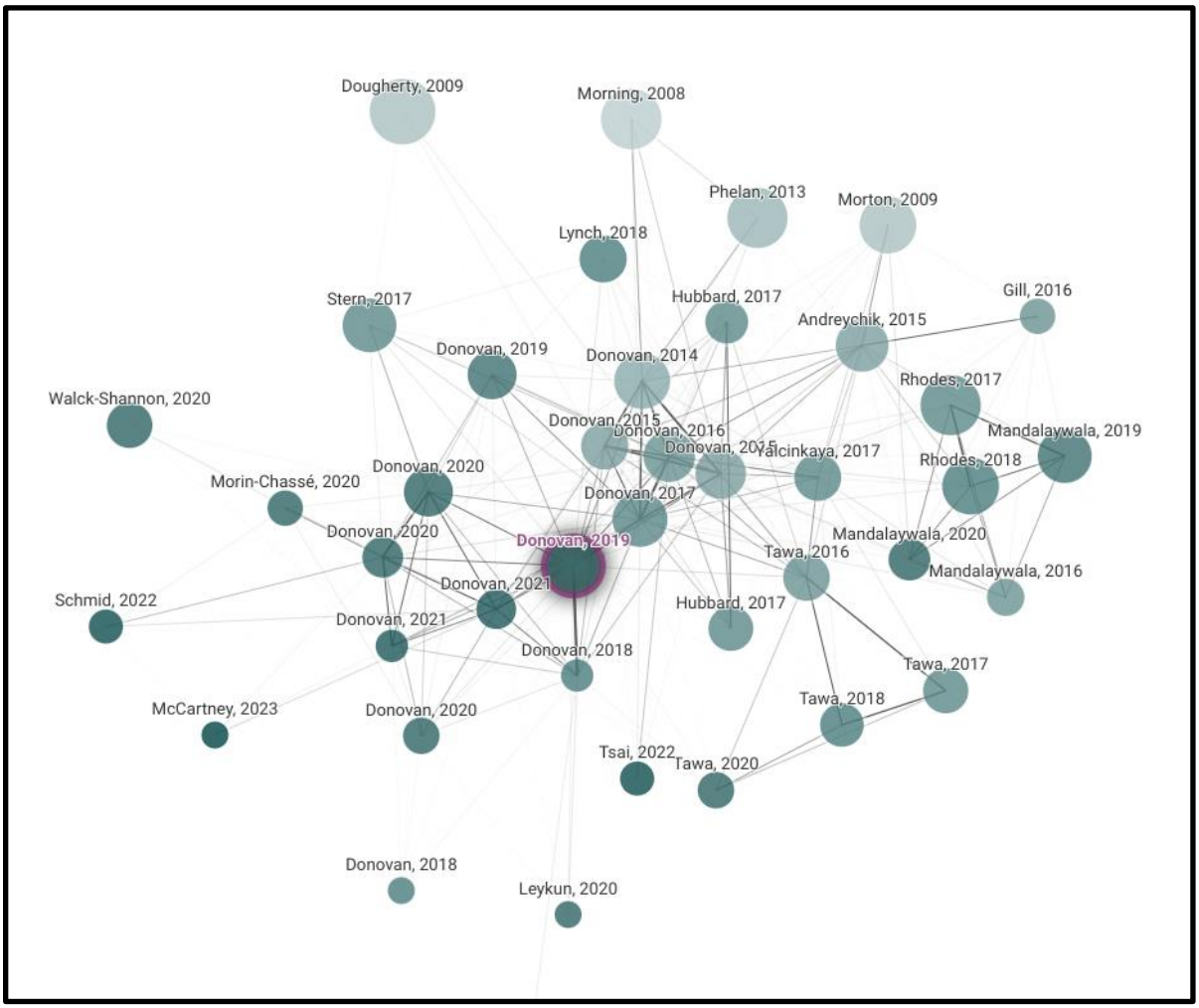


Figure 8
Publication dates of included articles

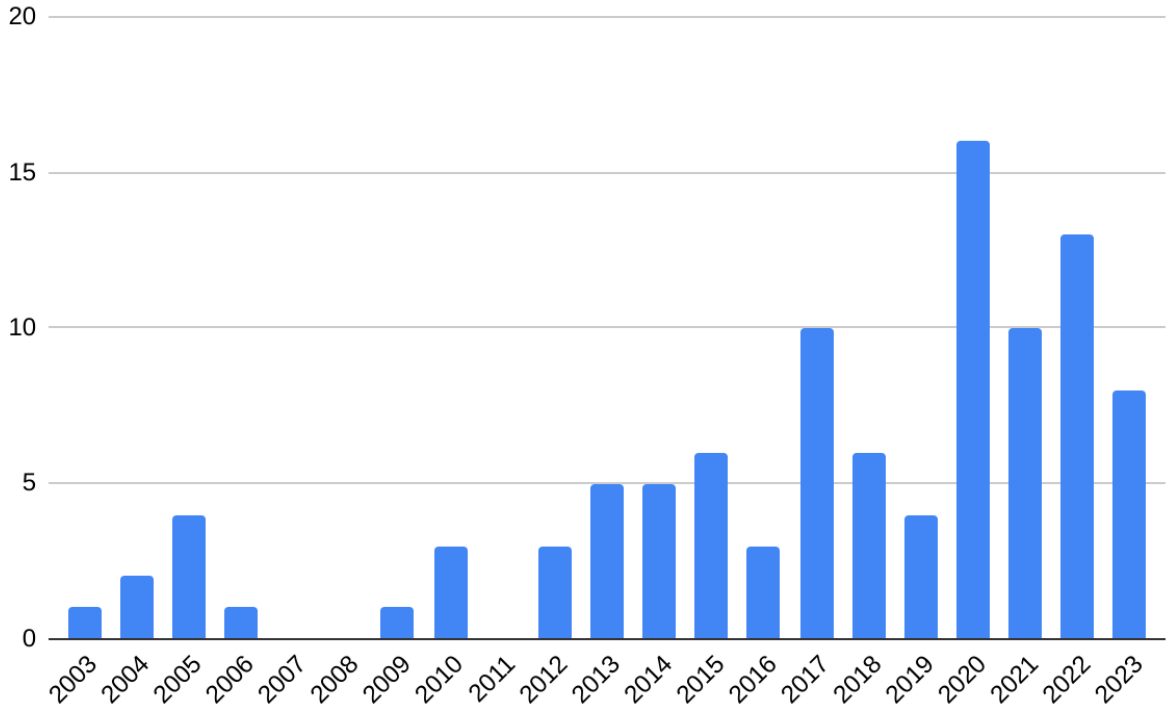


Figure 8 above shows the frequency of relevant studies across time, starting from the conclusion of the Human Genome Project in 2003. These data suggest a relatively recent inclusion of our study's foci within genomics/genetics research, practice, and education. Indeed, while the initial conclusion of the Human Genome Project "did not uniformly trigger a reevaluation of the use of 'race' in genetic studies," it is encouraging to see an upward trend in recent years (Duello et al., 2021, p. 238). The notable spike in publications on genomics/genetics in relation to social identity in 2020 coincides with a heightened disparity in public and K-12 messaging on the complexity of human difference. Hubbard and Monnig (2020) explain the context of this spike most succinctly: "Exposure to information about genetics is at an all-time high, while a full understanding of the biocultural complexity of human difference is low" (p. 1541). Based on our sample, this disparity appears to have prompted increased attention to how the teaching and learning of human difference, if not carefully and more comprehensively addressed through accurate scientific, sociological, and historical lenses, can in fact lead to dangerous, essentializing beliefs about human difference (e.g. Donovan et al., 2020; Tawa, 2020; Willinsky, 2020; Martschenko, 2020; Lee et al., 2020; Morin-Chasse, 2020; Reese, 2020). We discuss this issue in the first subsection below. At the same time, our data suggests a recent interest in how the teaching of science, including human genetic difference can lead to the under-representation (e.g. Visintainer, 2020) and alienation (e.g. Hales, 2020; Carmichael et al., 2020) of racialized or otherwise marginalized students in science education.

In the following subsections, we detail the main thematic findings of our study.

7.1 Genetic essentialisms remain a core challenge and gap in teacher education, science education, and curriculum policy.

> But if all genetics educators taught genetics to refute genetic essentialism, then it is hard to imagine how genetic essentialism could live on in our culture. Humans created genetic essentialism, and humane genomics educators can help to end it.
>
> (Donovan, 2022, p. 9)

All students come to science education with implicit understandings of "race" and genetics learned from popular media and their introductions to basic genetic concepts in the K-12 schooling systems (Donovan et al., 2020; Lee et al., 2021). Most students taking introductory science courses at university are only taught basic genetic literacy, which, even in the case of purportedly progressive science curricula, can serve to reinforce or instill the belief in a biological essence of "race." This inattention to reductive essentialist thinking in turn has the dangers of justifying and/or reproducing existing racist beliefs within past, present, and future policy and practice (Acquaviva & Mintz, 2010; Gillborn, 2016; Gouvea, 2022; Kaszycka & Strzalko, 2013; Tornabene et al., 2020).

Psychologist and behavioral geneticist Harden (2023) provides definition and semantic clarity on this phenomenon. As Harden explains, "essentialism is the belief that things have essences—one or more deep, underlying characteristics, without which the thing or person would not be what it is—and that these essences explain why certain individual things or people are appropriately considered members of the same category" (p. 199). Genetic essentialism is thus a belief that what makes a person fall into a particular category, such as racialized categories, is rooted in an immutable genetic essence. Harden uses the example of skin color: a genetic essentialist "will believe that people who have a similarly dark skin tone share an underlying essence, such that their superficial similarity reflects a deeper property that explains what they are all 'really' like" (p. 200). Genetic essentialism is an important curricular concern; research has shown that genetic essentialist beliefs about social groups might engender discrimination towards essentialized groups (Braun & Saunders, 2017; Donovan et al., 2021; Donovan, 2022; Stern et al., 2023). Studies have found that holding essentialist beliefs about race (as well as gender, religious groups or sexual orientation) is correlated with greater stereotyping, prejudice, dehumanization and support for discriminatory policies (Herd et al., 2021; Morin-Chassé, 2020; Roth et al. 2023; Sabatello, & Juengst, 2019). Sparks et al. (2020) make a causal connection between genetic essentialisms and educational attainment—in that perceived essential predispositions to certain topics and professions can foreclose future opportunities for certain racialized students.

Harden (2023) notes that research in psychology has shown that essentialist thinking begins early in a learner's development, emerging as a kind of cognitive bias as early as preschool. In North American K-12 education systems and their respective curricula, culturally pervasive essentialism is rarely challenged by genetics education, which tends to in fact reinforce these deeply embedded assumptions (Donovan, 2022). The completion of "the Human Genome Project did not uniformly trigger a reevaluation of the use of 'race' in genetic studies," nor in genetics education (Duello et al., 2021, p. 238). Hubbard and Monnig (2020) charge that the vast majority of post-secondary learners, or non-genomics focused students, encounter ideas of genetics and human difference in lessons that superficially address this complex topic and may in fact reinforce essentialist assumptions. Indeed, as Gingell and Bergemann (2022) stress, "many learners will have cemented views around the genetic origins of race long before they enter professional education" (p. 258). In STEM fields like medical education, ideas of bio-essentialism often remain unchallenged or even inadvertently promoted (Tsai, 2021, p. 218; see also Lujan and DiCarlo, 2021; Meier, 2012). Meanwhile, in biomedical research, race as a biological construct continues to be used as a genetic category, due to a lack of understanding of the continuous nature of human genetic variation (Duello et al., 2021). Kampourakis and Peterson (2023) argue that racist assumptions may still exist within the terminology used in the practice and teaching around genetics and ancestry, such as "admixture," which perpetuate erroneous assumptions that there are genetically "pure" and stable populations of people.

Li et al. (2022) argue that to effectively dismantle the systems of oppression that harm racialized individuals, STEM fields such as medical education must address how racial categories are regularly misused. As these authors caution, "many current medical education resources treat socially defined race as a biological marker or as an epidemiological variable to distinguish one patient population from another, without discussion of the underlying causes of health disparities" (pp. 1526-27). In their experience using dialogues to teach about race and biology, Beckwith et al. (2017) noted that individuals who participated in their lessons often displayed evidence of genetic determinist assumptions throughout their discussions. Furthermore, as Hales (2020) remarks, genetics is often taught in undergraduate science classrooms by focusing on monogenic traits which in turn "can increase students' misperceptions of racial biological differences" (p. 6). These misunderstandings are demonstrated in other topics related to genomics education and its respective literacies. Kalinowski et al., (2012) describe a similar issue in learning evolution as it relates to race. These authors emphasize that students generally have misconceptions and lack an understanding of the role of DNA in inheritance and therefore how genetic variation within populations contributes to biological traits. To be clear, this does not mean denial of genetic predispositions towards some traits or disease, but that race and population are often erroneously conflated.

Donovan (2015a) discusses how educators must be careful and aware in how they address these misconceptions. Science educators "ought to know that essentialist beliefs are predictive of racial bias and misunderstanding of intraspecific diversity if one wishes to educate students about human genetic variation without increasing prejudice" (p. 67). Despite the

scientific and educational consensus for proactively teaching against genetic essentialisms, several students and educators continue to consciously and/or unconsciously uphold these beliefs and concomitantly are unaware of their potential exclusionary impacts for different individuals and/or communities (Donovan, 2014). This is partly because science education often focuses solely on "fundamental" basic genetic concepts like Mendelian inheritance, neglecting situated, contextual, social, cultural and/or ethical dimensions of genetic variation (Donovan et al., 2020; Donovan et al., 2021; Kampourakis & Peterson, 2014; Sze & Swati, 2004; Schulz et al., 2003). Additionally, science education tends to be influenced by the prevailing culture, ideology, and politics, which can either reinforce or challenge genetic essentialisms (Kung, 2018; Roth et al., 2023). Hence, there is a crucial need for a transformative approach in teaching genetics and race within science education (Donovan, 2016a; Donovan et al. 2020). This approach must acknowledge and confront the historical and present-day contexts of racism and anti-racism, empowering both students and teachers to become not only scientifically literate but also socially responsible citizens (Boutte et al., 2010; Reis et al., 2015). As Phelan et al. (2017) state succinctly, "If we are indeed living in an increasingly genetic-essentialist world, then our reading of the human genome with regard to racial differences should have a critical impact on beliefs about essential racial differences that are key to the perpetuation of racism and racial inequality" (p. 170). How might we then address such potential essentializing racism(s) as part of a broader science education and more specifically genomics literacy?

7.2 Domain-specific disciplinary siloing limits the teaching and learning of contextualized—social, cultural, historical—genomics literacy.

> In the first decade of the new millennium, social scientists across the disciplines of [political science and economics] began to actively grapple with whether and how they might want to engage with molecular genetics. In each discipline, "genetics entrepreneurs" promulgated specific visions of what such an engagement might bring. These visions endeavored to link the core questions and/or contributions of each discipline to genetic techniques and information.
>
> (Shostak & Beckfield, 2015, pp. 99-100)

In the K-12 science curricula the sociocultural and/or historical contexts of "race" are often relegated (if present at all) to the social sciences and history curricula. However, biological categorizations of "race" are still used to teach basic genetic concepts and/or as a proxy for human difference. Learners are often left with the implicit lesson that "race" is still defined biologically. There is often no room in science curricula to explore socio-cultural and historical perspectives outside of the government mandated curriculum policy K-12 content, allowing dangerous myths among the public to persist (Bolnick, 2015; Braun & Saunders, 2017).

In medical school curricula literature, this is a concern that different researchers have been seeking to address. Several authors emphasize that there is not much room or time to explore socio-cultural and historical perspectives outside of the mandated core curriculum (Bolnick, 2015; Braun & Saunders, 2017). This is likely due to medical schools having a centralized and standardized curriculum and often being geared towards medical licensing examinations that will grant their students competency for practice (Braun & Saunders, 2017; Ripp & Braun, 2017). Bolnick (2015) describes such compressed standardization as leading to a "disconnect between the training provided in medical school and what physicians need to know about race, human genetic and epigenetic variation and the causes of racial health disparities" (p. 362). In turn, many medical school institutions lack expertise in addressing genomics educational challenges with their students (Bolnick, 2015). Furthermore, common methods of testing in these institutes and licensing exams also narrow the possibilities for a thorough understanding of "race" in terms of its sociocultural and historical contexts. Multiple-choice questions do not afford curricular and/or pedagogical opportunities for a full discourse on a student's understanding of the relationship between race, biology and health (Braun & Saunders, 2017). Additionally, as previously discussed, these exams often present material that supports racialized essentializing stereotypes (Nieblas-Bedolla et. al., 2020; Ripp & Braun, 2017).

Meanwhile, in the K-12 science education curricula, discussions about the social or historical aspects of "race" usually find a place only in social sciences or history classes (Stitzlein, 2009). Nonetheless, biological classifications of "race" persistently serve as tools to impart basic genetic concepts as a substitute for human diversity (Donovan, 2017). Consequently, students often infer that "race" is still biologically defined, despite scientific evidence stating otherwise—race is a social construct varying across time and place (Hubbard, 2017). Science curricula typically lack room to explore socio-cultural and historical viewpoints beyond mandated content, allowing prevalent misconceptions to persist among the public (Gillborn, 2016; Stitzlein, 2009). Hales (2020) makes the point that most undergraduate textbooks that have content that support less essentialist views of race and genetics (i.e. emphasizing within population differences) are often kept as stand-alone chapters at the end of the book, including quantitative genetics and evolutionary genetics.

Donovan (2015a) touches on this lack of addressing race in the science of genetics curriculum. He notes:

> Even the curriculum that science teachers inherit appears to discuss race in an inappropriate manner by failing to address scientific controversies surrounding race (Donovan, 2015b; Morning, 2008). Early in the 20th century biology textbooks directly taught students that races were biological subdivisions of the human species and some texts also taught students about a racial hierarchy (Morning, 2008). Today, textbooks address race indirectly by referring to 'race' or racial categories in passing but not as an explicit focus of learning (Morning, 2008).

> Usually these subtle references occur in chapters discussing forensics, genetic diseases, and human evolution (Morning, 2008). Furthermore, evidence from a field experiment carried out in eighth grade science classrooms demonstrated that when students encounter these subtle references to race in the modern biology curriculum it can lead students to agree more strongly that races differ in complex human traits (e.g. academic ability & artistic ability) because of genetics (Donovan, 2014). Put differently, there appears to be a hidden racial curriculum in biology textbooks that is learned by students but never purposefully taught by teachers. And arguably, this curriculum reinforces potentially prejudiced beliefs about race that are not supported by biological theory or research (Donovan, 2015b). (p. 65)

Thus, "until courses in human biology and genetics include cultural contributions and assumptions about our ways of 'knowing,'" Hubbard and Monnig (2020) warn, "students and the general public will continue to stumble through ideas about human difference from an ideologically biological core" (p. 1550; see also Stetsenko, 2018). At the same time, a purely abiological (e.g. sociological) conceptualization of race can lead to problematic assumptions of "colourblindness" (Bynum, 2021; Tawa, 2020). According to Hubbard and Monnig (2020), this implicates the need for a "biocultural approach" toward teaching human biological variation across the curricula that leverages both genetics and sociological perspectives in all contexts in which concepts of "race" might be invoked in learners' education. We discuss this further in our Implications section. In fields like medical education, Tsai (2021) emphasizes that science educators, such as in medical education, need "not only the knowledge required to understand injustice, but the empathy needed to commit to health justice, as well as the skills and community relationships to push back against inequity firmly and effectively. All three are important" (p. 219). More broadly, Sparks et al. (2020) argue that tightly controlled and Mendelian-focused genetics exercises across non-major curricula can produce or reinforce erroneous beliefs about genetics, typically highlighting only White male contributions to science, while a lack of examination of genetics/genomics's problematic history forecloses development of critical thinking. These knowledges are not situated within a specific discipline and therefore require the interdisciplinary collaboration of expertise across curricula.

Hughey and Byrd (2015) propose that such interdisciplinary curricula can address issues of contemporary, cultural DNA mystique, enduring antagonism against the "soft" sciences, and feedback loops in which racial essentialisms cause real disparities that are then understood as proof of such essentialisms. These complex issues are difficult to address through the lenses of singular disciplines; for example, medical curricula often omit discussions of the inequitable social intersections that lead to real health disparities, and instead present race as a hard biological variable. There remain notions that there are "hard" and "soft" sciences, which are often brought forth by some learners to professional learning contexts and in turn reproduce disciplinary siloing. Archila et al. (2022) suggest that such siloing leads to science students' inability to identify, evaluate, and critique genetics claims as arguments. Reese (2020) further argues that without strong interdisciplinary connections across curricula (e.g. sociology and science perspectives together), equity, diversity, and inclusion cannot be solely realized in science education.

Such interdisciplinary approaches would facilitate the development of a contextualized genetics/genomics literacy, including:

- Understanding genetic concepts and their relation to human diversity and ancestry (Venville et al., 2005; Fowler & Noel, 2022; Zimmerman et al., 2022).
- Recognizing the social and ethical implications of genetic research and technologies on individuals and groups (Gericke et al., 2017).
- Analyzing socioscientific issues involving genetics and race and developing critical examination skills (Lee et al., 2020).
- Appreciating the various dimensions of human diversity and their interaction with genetics and race (Mayfield, 2017).
- Reflecting on personal beliefs and biases related to genetics and race (Sheldon, 2018).
- Engaging in dialogues and actions promoting diversity, equity, and justice, challenging genetic essentialisms and racism (Saunders & Rennie, 2013).

Numerous studies have highlighted the advantages and obstacles of implementing such an approach in science education, offering suggestions for curriculum design, teaching methods, evaluation, and professional growth (e.g., Donovan, 2016; Pang & Valle, 2004; Raveendran & Chunawala, 2015; Raven & Jurkiewicz, 2014; Uchenna, 2023; Young et al., 2022). However, there remains a dearth of systematic and comprehensive research on effectively and sustainably addressing genetic essentialisms and racisms in science education, and evaluating the outcomes and impacts of such endeavors for teacher education (Lazarowitz & Bloch, 2005; Martschenko, 2023; Shotwell, 2019; Stitzlein, 2009).

7.3 Absence of proactive purposeful anti-racist and/or decolonizing curricular and pedagogical frameworks for teaching and understanding genomics education and its respective literacies within the K-12 public school curriculum, teacher education, and/or science education.

> The controversies surrounding the continuing role of race in genetics only adds to the need for science educators to attend to the place of race in their biology textbooks, as a means of introducing students to its implications for continuing advances in genetics, from precision medicine to genetic engineering. At issue, then, is not the purging of race from biology textbooks, for while many biologists support dropping the concept, almost as many continue to find "race" useful to the study of biology. Rather, my assumption is that having biology students learn about the changing and contested place of race in this science can make a valuable contribution to their understanding of the world.
>
> (Willinsky, 2020, p. 1460)

There is an absence of studies and/or research programs in Canada that analyze and synthesize how settler colonial logics (Wolfe, 2006; Donald, 2019) and their exclusions have framed historical and/or contemporary conceptions or debates of genetic essentialism and respective racisms in relation to the field of genomic education and its respective literacies.

"Despite widespread recognition that genetic essentialism is a scientifically inaccurate and prejudiced view of human difference," Donovan and Nehm (2020) observe, "essentialist thinking has not received sufficient attention from genetics educators" (p. 1452). Across K-12 curricula, "students are rarely taught how biologists and anthropologists discredited genetic essentialist beliefs about race in the mid-twentieth century by challenging the epistemology and ontology of race science" (p. 1452). Further, "students are rarely taught how gender biases influence scientific discourse about biological sex, thereby exacerbating the public's belief in gender essentialism," while "standards for genetics education rarely address human inheritance and variation in an anti-essentialist manner (e.g., addressing the complex ways in which genes, the social environment, and social identity interact to create continuous variation in human traits" (Donovan and Nehm, 2020, p. 1452).

Consequently, "the genetics educator will not overcome longheld views by simply announcing in a slide presentation that race is a social construct" (Gingell and Bergemann, 2022, p. 258). In the macro, global context, "many countries throughout the world are struggling to address longstanding inequalities stemming from deeply ingrained societal prejudices about race, ethnicity, sex, gender, disability, and sexual orientation" founded and perpetuated in significant part by basic genetics education and popular messaging around genomics (Donovan and Nehm, 2020, p. 1451).

However, the "problematic interplay between genetic essentialism and genetics education is not simply a product of teachers' own beliefs about social groups, nor is it a result of their unwillingness to change their teaching practices" (Donovan and Nehm, 2020, p. 1452). Donovan and Nehm (2020) note that, although "it is true that a minority of biology teachers in several countries believe that some ethnic groups are genetically superior to others, many more biology teachers do not endorse genetic essentialism," and that there appears to be a growing interest amongst biology teachers in challenging racist essentialist thinking around genetics (p. 1452). Yet, "using genetics education to reduce belief in genetic essentialism among adolescent students requires much more than an educator's interest and commitment" and few "have designed and executed empirical studies capable of establishing best practices for achieving this goal;" moreover, very little empirical work "has addressed the interplay between genetics education and social identities" over the past 20 years (Donovan and Nehm, 2020, p. 1452).

7.4 Predominantly White Settler Colonial K-12 and Higher Education Institutions reproduce a science education and respective curriculum that often limits the educational opportunities for different non-white racialized equity-seeking communities.

> Coursework that reinforces stereotypes about particular racial or ethnic groups should be critically assessed for educational value. Rather than just teaching students how to provide care to specific non-majority groups, students should be encouraged to examine and address their own implicit biases and be educated about historic and structural factors that lead to healthcare disparities and social inequities.
>
> (Carmichael et al., 2020, p. 312)

Most science majors arrive at post-secondary institutions without having learned about racisms and anti-racisms in relation to genomics. As a barrier to diversity, equity, inclusion, and representation in science fields broadly, including in teacher and science education, students experience forms of racism in their training in the classroom and in professional apprenticeship (Arteaga & El-Hani, 2012). In the case of genomics-focused fields, disciplines are often dominated by settler colonial logics (Wispelwey et al., 2023) such as, but not limited to, genetic counseling, biomedical sciences, engineering, and medicine. Meanwhile, the reproduction of genetic determinisms framed as a biological category of race reinforces erroneous beliefs that different, non-white racialized people share DNA that is unique from the rest of humankind.

Science education and its respective literacies encompasses the instruction and learning of scientific concepts, methodologies, and practical uses across disciplines such as but not limited to biology, chemistry, physics, and mathematics. It aims to cultivate the knowledge, abilities, and perspectives of both students and educators in comprehending and applying scientific information in various contexts, such as health, the environment, technology, and society. Science and science education is not a neutral enterprise, however. Most K-12 and higher education institutions perpetuate a view of science and corresponding curriculum that frequently restricts educational opportunities for non-white racialized equity-seeking communities, while simultaneously perpetuating essentialist misconceptions about human genetic variation that likewise reinforce racist assumptions.

In Carmichael et al.'s (2020) qualitative analysis of minority students in a genetics counseling program, they noted that none of their participants described a curriculum that addressed "systemic racism, structural patterns of inequality in healthcare access, or legacies of historic discrimination in depth" (p. 307). Instead, the students shared experiences where they felt programs relied on their minority students to supplement race and cultural content that the institute should be responsible for teaching (Carmichael et al., 2020). The authors describe their results as the "conscripted curriculum," as described by Olsen (2019) for medical schools, where minority students bear a burden of educating their classmates about the social basis of race (Carmichael et al., 2020). The students in their study felt pressured by their classmates and

faculty to contribute more when engaging in discussions related to racial disparities in health (Carmichael et al., 2020). These minority genetic counseling students also experienced multiple forms of racism in their training, both in the classroom and in clinical rotations, often feeling as if they are being "othered" by their peers, mentors, professors and institutions (Carmichael et al., 2021). In these situations, minority genetic counseling students would seek support from many sources, searching for guidance and understanding from other racial or minority students and faculty (Carmichael et al., 2021). They only felt comfortable in reaching out to white program leadership when they needed someone to listen or take action in relation to an issue (Carmichael et al., 2021). However, they did not perceive that these individuals could provide them with empathy or guidance. Elsewhere, Pollock et al. (2023) reveal the "prevalence of implicit racial bias among genetic counselor graduates, lack of exposure to diverse populations within and outside of graduate training, and concerns regarding racial insensitivity and effectiveness of didactic and clinical genetic counseling training" (p. 792).

The issue of representation in faculty and staff among K-12 and higher education institutions can be burdening in addition to the essentialist views imposed by the curriculum, be it hidden or direct. Higher education institutions especially have a long history of eugenics thinking and systemic racism. Nelson (2018) describes the historical evolution of higher education institutions and their intertwining with systemic racism and slavery. She argues that many issues with race and genetics fall at the institutional level, indicating a level of responsibility across educators and higher administration to make systemic changes that address these racist histories (Nelson, 2018). Developing structural competency regarding "race" and health is also argued by Bolnick (2015) who stresses that medical schools must develop their structural competency, shifting "the focus from individuals to institutions, communities and policies that shape clinical interactions and health outcomes" (p. 366). These views of responsibility at the institutional level are shared among scholars from our literature review including those who research K-12 environments (Donovan, 2014; 2015a; 2016), undergraduate science education (Hamilton & Stoebel, 2020) and medical education (Braun & Saunders, 2017).

"Ideas of bio-essentialism run rampant in medical education, and they work to reduce and dehumanize people of color in a healthcare system that already produces unequal treatment," warns Tsai (2021, p. 218). In turn, medical school educators "are insufficiently knowledgeable about the concept of race in relation to healthcare and insufficiently aware of their own bias and the potential harmful consequences of passing this bias on to the next generation of health professionals" (Bakkum et al., 2023, p. 601). In their critique of racial essentialism in medical school curricula, Braun and Saunders (2017) provide another insight. They suggest that more recently, medical education institutions have struggled to keep up with incoming students who likely have pre-existing knowledge of race-based genetics misconceptions from their previous experiences in higher education: "current medical students are sometimes more aware than their professors of how racism manifests in medicine and medical education—including the intensifying scientific controversies regarding human genetic

variation" (Braun and Saunders, 2017, p. 518). Overall, the role of educational institutions in "propagating race-based bias in curricula has also been highlighted in the USA and in Europe leading to calls for a 'seismic paradigm shift . . . in which an anti-racist perspective informs all healthcare education, research, and practice'" (Lynn et al., 2023, p. 2). Yet, some expert members of the medical community "still dispute the meaning of race and subsequent use of race in medicine and this shift away from race-based-medicine has, thus far, been quite limited in medical curricula" (Lynn et al., 2023, p. 2).

Institutional whiteness is further embedded in the data and concepts often used to teach human variation. Kampourakis et al. (2023) argue that racist assumptions may still exist within the terminology used in typical teaching around genetics, particularly when using ancestry as a way of teaching about human difference. "Admixture," for example, has racist origins. It is still used in many teaching contexts, but problematically suggests that there are "pure" populations and so "pure" races. Further, most genetic data sets are overrepresented by White/European ancestry, or otherwise misrepresent populations as "pure" (Duello et al., 2021).

7.5 Creating, supporting, and enacting science education curricula and pedagogies that introduce students to a humane genomics literacy reduces the dangers of reproducing genetic essentialisms.

> At best, genetics education does little to prevent genetic essentialism, and at worst it indirectly contributes to it through the kind of instruction it offers to students. While it is defensible to argue that some genetic essentialists will persist in their beliefs regardless of the genetics education that is provided to them, it is indefensible to claim that genetics education is irrelevant to genetic essentialism.
>
> (Donavan, 2022, p. 8)

Genomics and genetics, as in previous eugenics historical movements, assume the current order and cultural values, risking the understanding of race as ahistorical rather than seeing it as an historically contingent form of understanding human difference and thus foreclosing critical consciousness of how present and future technosciences might be misused.

Genomics or genetics literacy refers to the capacity to comprehend and apply genomic knowledge across diverse domains like health, environment, agriculture, and society (Gericke et al., 2017). A humane genomics literacy integrates the social, cultural, and historical aspects of genomic knowledge, advocating for diversity, fairness, and justice in both scientific and societal realms (Saunders & Rennie, 2013). Genomics or genetics literacy should directly address and refute genetic essentialism, which engenders the belief that human characteristics, behaviors, and identities are dictated by genes, inherited along racial lines (Gillborn, 2016; see Section 7.1 above). This notion often serves as a rationale for upholding racism, discrimination, and societal disparities (Castéra & Clément, 2014). However, scientific evidence contradicts

genetic essentialism, revealing human genetic diversity as intricate, continuous, and influenced by numerous factors such as environment, culture, and history (McChesney, 2015).

The historical association between genetic essentialism and racism is stark, having been utilized to validate and execute various forms of oppression and violence against marginalized communities, including colonization, genocide, slavery, segregation, sterilization, and experimentation (Donovan, 2017). These injustices often align with the paradigm of eugenics, focused on enhancing the human population through controlled breeding (Donovan, 2016). Eugenics operates under existing cultural values and assumptions, potentially obscuring the understanding of race as a product of history, hindering critical awareness of how current and future scientific technologies might be misused (Stitzlein, 2009).

In our study's sample, several studies made use of guided inquiry labs to explore genetic diversity and "race." Kalinowski et al. (2012) describe an activity where students engaged with DNA sequences from individuals of varying races. In their study, they aimed to develop introductory biology college students' scientific reasoning skills by addressing potential existing biases. This lab was designed to improve students' learning of concepts related to natural selection as opposed to molecular genetics (Kalinowski, 2012). Their study suggests that student's pre-existing typological thinking related to "race" and genetics can be combated in the classroom through engaging in activities and discourse that dispel these ideas. Other studies used similar methods; using PCR and sequencing to have students compare their own genetic make-ups and applying the results to compare any existing biases they have on the topic (Marquez-Magana et al., 2013; Yang et al., 2017). Marquez-Magana et al.'s (2013) study suggests that students' existing beliefs of genetics are the main contributor for racial disparities and were found to be mostly dispelled after the hands-on activity. These examples suggest that students' existing biases towards race and genetics may be reduced by engaging them in concrete and direct experience with genome sequencing related to "race." However, it is interesting to note that both studies utilized racial differences as a secondary topic and not the focus of the student's learning outcomes, indicating the need for more direct research on addressing students' misconceptions and beliefs of race and biology.

"Put simply," Donovan et al. (2021) summarize, "these proposals contend that school genetics should teach students multifactorial genetics" instead of basic or Mendelian genetics (p. 523). They explain:

> Knowing how population thinking and multifactorial genetics refute genetic essentialism is what we call humane genomics literacy. Humane genomics literacy is related to, yet distinct from, standard genomics literacy. As argued earlier, standard genomics literacy is the kind of knowledge that scholars have argued is missing or underemphasized in standards and curricula. It is a story about how trait variation is more complicated than the Mendelian explanation for it. The story is more complicated because it requires students to integrate molecular concepts, multifactorial concepts, and population thinking. Humane genomics literacy complicates this story further, by asking

> the learner to explore how these concepts refute the genetic essentialist assumptions used by White supremacists. (p. 526)

Donovan et al. (2021) hypothesize that a humane genomics literacy will reduce genetic essentialist thinking; to date, their data suggests support for this hypothesis. Hence, there is an urgent call to craft, bolster, and implement science education curricula and teaching methodologies that introduce students to a humane framing and understanding of genomics literacies.

8.0 Discussion & Implications

In the following subsections, we discuss the main implications for science and teacher education that emerged from our scoping review: 1) a core need for an anti-racist and anti-essentialist humane genomics; 2) that an anti-racism and anti-essentializing humane genomics education curriculum should be taught from a cross-disciplinary perspective; and 3) the importance of creating national, provincial, and territorial K-12 professional learning opportunities for teacher educators and science educators to develop and implement curricula and pedagogies that proactively take up the differences between basic, standard, and humane genomics literacies.

8.1 There remains a core need for an anti-racist and anti-essentialist humane genomics literacy curriculum for science education.

Science teachers must be prepared to teach the racist past and future potential of their disciplines, as well as the present inequalities that scientific racisms maintain. Throughout students' K-12 educational journeys, science educators are pivotal leaders in disrupting and challenging racisms and taking up anti-racist understandings of genomics science and its respective technologies. All students should have the opportunity to learn about different racialized groups that have been and continue to be affected by genetic essentialisms that reproduce different kinds of racisms and exclusions.

Across our scoping review of different studies, there exists a lack of consensus or consistency in curriculum that focuses strictly on developing anti-racist humane genomics literacy. However, this lack of consistency is recognized in the literature, with several authors describing the need for increased anti-racist initiatives among educational institutions. Hales (2020) cogently explains this need:

> … Genetics instructors' choices have significant social impact. Although some instructors may feel discomfort including topics perceived as political, doing so is an important step toward inclusivity and retention of students from underrepresented groups. Refraining from addressing such topics is itself a political choice that reinforces the status quo. Genetics instructors are encouraged to build

> historical and cultural background knowledge and a language framework for discussing pseudoscientific racism. (p. 6)

In her critique on "race" and genetics in education, Brewer (2006) suggests the need for training for all stakeholders involved with medical education communities, including educators, public health practitioners and curriculum. Brewer argues that medical curriculum, for example, should be revised:

> This revision should be more than just a course in the ethics of science – a full curriculum on the meaning and history of race should be integrated into training, preferably involving a series of courses. We need to incorporate into the curriculum more complicated understandings of race and racism, and their implications for medical and scientific practice (p. 517).

More recently, Tsai and her colleagues (2016, 2021) have advanced a similar call for explicitly anti-racist, anti-essentialist curriculum in medical and pre-medical science education, for both students and educators.

As previously discussed, students may already have presumptions about "race" and biology/genetics through their experiences and engagement with the world before exploring this content in a classroom environment (Kalinowski et al., 2012; Marquez-Magana, 2013). Further, typical approaches to teaching genomics or genetics in K-12 and introductory higher education courses can in fact instill or reinforce genetic essentialist thinking and associated biases. Sparks et al. (2020) argue that tightly controlled and Mendelian-focused genetics exercises across non-major curricula can produce or reinforce erroneous beliefs about genetics, typically highlighting only White male contributions to science, and lack examination of the discipline's problematic history, and so foreclose development of critical thinking around the future of genomic technosciences. Critically, most post-secondary students encounter genetic concepts through non-specialized courses (Hubbard & Monnig, 2020). Such curricular experiences can thus reinforce previously founded essentialist thinking and biases students might already have, and contribute to maintaining systemic racisms across disciplines, professions, and individual life trajectories.

The glaring implication, then, is that anti-essentialist, anti-racist curricula are needed across learners' educational experiences, from K-12 to higher and professional education. Donovan et al.'s (2020) research has shown that belief in genetic essentialism can be maintained or challenged by what concepts and pedagogies are leveraged in genetics education. Donovan et al. (2020) have called for a *humane* genetics literacy. Such a curricular and pedagogical project moves beyond a "basic' and/or 'standard' genetic literacy curriculum:

- **Basic genomics literacy (BGL)** is a form of derived genomics literacy that includes only Mendelian and molecular genetics concepts—the basis of most genetics

curricula and standards. It is the easiest form of genomics literacy to use for essentialist arguments.

- **Standard genomics literacy (SGL)** is what most scholars have proposed, emphasizing more in genetics standards and curricula, which includes ideas such as multifactorial genetics and population thinking. It is not structured for the purpose of refuting belief in genetic essentialism.
- **Humane genomics literacy (HGL)** takes standard genomics literacy and structures it to refute essentialist thinking. It is the knowledge of how multifactorial genetics and population thinking refute the assumptions of genetic essentialism. This knowledge is humane because it is oriented toward reducing racism. (p. 1481)

To be clear, a shift from BGL to HGL does not mean bypassing basic concepts. Standard genomics literacy is inclusive of BGL while HGL is inclusive of SGL, but each goes beyond the former by incorporating population thinking and multifactorial models of inheritance (SGL) and centering how the latter refutes genetic essentialism (HGL). HGL thus has the explicit aim of refuting genetic essentialism and recognizing and leveraging the value of science education and educators in creating a more equitable society. Donovan et al.'s (2020) "hypotheses predict that students learning from a curriculum oriented only toward BGL will increase in belief in genetic essentialism. Conversely, students learning from a curriculum oriented toward SGL and/or HGL will decrease in belief in genetic essentialism" (p. 1487). Further, a humane genomic curriculum and respective science education literacy seeks to proactively disrupt students' pre-existing knowledge and address any conscious and/or unconscious "racist" (mis)understandings they may have.

The voices of communities affected directly by certain racialized essentialist reductive views should be heard and utilized more when considering curriculum and institutional changes that address biases in how genetics literacy is taken up by science and/or health profession educators (Brewer, 2006). Teacher educators and in-service science teachers should discuss different racisms and anti-racism as part of the science curriculum to proactively introduce students to past and potential future dangers of genetic essentialisms, including how they have been historically embedded into our society and how they linger today. As Donovan et. al. (2020), reminds us,

> …genomics literacy matters not only because it is required to make sense of socioscientific issues related to genetics. It also matters because of its relationship to genetic essentialism—a cognitive form of prejudice. By helping students to develop and understanding of the complex relationship between genetic variation and trait variation through genetics education, it might be possible to reduce student belief in genetic essentialism. (p. 524)

Discussions around social and historical racialized genetic essentialisms have been found to be a helpful tool to approach the teaching of science and genomics education (Beckwith et. al., 2017; Hamilton & Stoebel, 2020). Consequently, teacher education and/or health profession programs should strive to ensure that future science educators and/or health professionals have the necessary knowledge, genomics literacies, and competencies to proactively challenge different forms of racisms that stem from historical, contemporary, and/or future sociocultural and/or biocultural conceptions of "race" in relation to our situated, specific, and wider understanding of human and more-than-human genomes (Beckwith et al., 2017; Donovan, 2015a). For a more detailed overview of the differences between BGL, SGL, and HGL, it would be worthwhile for science teacher educators to review Donovan's (2022) most recent publication. In turn, how might science educators become more aware of the controversial nature of this content and prepare accordingly before engaging in lessons on this topic? As we discuss in the next subsection (8.2), such curricular inquiries should be cross-disciplinary.

8.2 An anti-racism and anti-essentializing humane genomics education curriculum should be taught from a cross-disciplinary perspective.

> "…genomics literacy is needed to make sense of many issues about race and genetics in modern society."
>
> (Donovan, et al., 2020, p. 522)

Teacher education and methods courses must take up the different concepts put forth within a genomics literacy. Such a curriculum would ensure teacher education programs and candidates are introduced to the differences between and among basic, standard, and humane genomic literacies. Use of race/ethnicity as a biological marker must be taken up and problematized across science curricula, and both sociocultural/humanities and science-based perspectives must be brought into dialogue across curricula. This requires scaffolding the necessary knowledge and understanding of key genomics concepts and their complexities across the K-12 science curriculum.

As discussed in the previous subsection (8.1), a humane genetic literacy aims to combat genetic essentialism, striving for a more equitable society (see also Saunders & Rennie, 2013). Achieving this goal involves laying the groundwork for comprehensive understanding of crucial genomics concepts throughout the K-12 science curriculum (Sheldon, 2018). Genomics should not be taught as just content knowledge; it implies a moral and political stance on the ethical use of genomic knowledge and technologies. It should advocate engagement in socioscientific issues to foster diversity, equity, and justice in science and society (Lee et al., 2018; 2021; 2020). To instill this literacy, students should grasp key genomics concepts alongside the social, cultural, and historical aspects of genomics and race (Gericke et al., 2017). Moreover, it should provide students with ample opportunities and support to hone critical thinking,

communication, collaboration, and citizenship skills, enabling them to apply humane genomics literacy across diverse contexts (Saunders & Rennie, 2013).

Adopting an interdisciplinary focus when teaching "race" and genetics was a common call to action in our extracted articles, emerging from various disciplines such as biology, anthropology, genetics/genomics, psychology, philosophy, and sociology. Overall, an interdisciplinary approach supports the teaching of a social perspective on race as opposed to one driven solely by genetics or biology, which students are typically presented in current curricula. An interdisciplinary approach to teach about the concept of "race" in science education (including medical education) includes gathering teaching perspectives from broader fields such as sociology, anthropology, evolutionary genetics, public health and history (Bolnick, 2015; Braun & Saunders, 2017; Brewer, 2006; Hales, 2020; Hamilton & Stoebel, 2020; Nieblas-Bedolla et al., 2020). The interdisciplinary approach is suggested to be developed either within core curriculum or supplemented in addition to the core curriculum (Bolnick, 2015; Braun & Saunders, 2017). Among these suggestions are an emphasis on teaching the history of genetic essentialism and addressing racial disparities in health as socially influenced: "By learning from the past, today's physicians will be better armed to discern—and correct—the ways in which contemporary medicine perpetuates historical injustices" (Fofana, 2013, p. 137). Elsewhere, Visintainer (2020) foregrounds the need to consider science classrooms as "powered social contexts" and thus spaces in which students and teachers construct certain identities in relation to science (p. 398). While Stern (2023) suggests that a core goal of science education should be challenging societal misconceptions of genetics concepts. Similarly, Reese (2020) suggests science educators need to be prepared to teach about "how racist, sexist, and classist mindsets and policies have led to science incidents and scenarios, such as the Tuskegee Study, the eugenics movement, few women and minorities at the top of science and medicine, and health disparities in the population" (p. 1).

Several promising teaching interventions emerged from our study and could inform the content and pedagogy of teacher education methods courses. Hamilton and Stoebel (2020), an historian and a biologist, reflected on their experience co-teaching a history course about race and genetics. They developed their course to explore historical texts while engaging in learning scientific elements about race and genetics (Hamilton & Stoebel, 2020). They concluded that having perspectives from a biologist and a historian allowed for rich discussion with students about the topic and opened the students' interdisciplinary understanding of the subject. Tsai et al. (2016) discuss the preliminary development of a longitudinal curriculum on race and medicine throughout the programming of their university's medical school. In addition to Donovan et al.'s (2020) work on humane genetics literacy interventions (as discussed in section 8.1), Hubbard's (2017a; 2017b) "biocultural approach" or interdisciplinary curricular approach to bio-technoscientific education, offers a promising starting point. Hubbard and Monnig's (2020) research has shown that while many educators might avoid addressing issues of race and racism in introductory contexts, even a simple mythbusting quiz at the beginning the term might significantly disrupt previously held assumptions about race and biology. Herd (2021)

advocates for the inclusion of sociological expertise in science curricula, noting that sociologists can and are engaging in "sociogenomics research [and] are making, and can continue to make, substantive and critical contributions. Sociology … can ultimately help to better understand the interplay between the social and biological and reduce the risk for reductionist understandings of genetic influence" (p. 431; see also Seiter & Fuselier, 2021). Li et al. (2022) and Gouvea (2022) have experimented with critically examining race as deployed in existing genomic/genetic educational resources as a fruitful exercise alongside their students.

It is thus the recommendation of our team that an interdisciplinary framework for science teacher education curricula be advanced; the literature suggests that this would be best accomplished through methods courses (Gericke et al., 2017) and have the most impact if focused on K-12 education (Donovan, 2022). Reese (2020) proposes an EDI-focused course in science education, arguing that interdisciplinarity (e.g. sociology and science perspectives together) is a necessity for EDI to be realized in science education writ large. Finally, while the literature does not name it as a future research direction, our study's analysis suggests that exploring the oral histories of Indigenous (see Jacobs, 2010), Black and other racialized youth who have and/or are not part of the settler colonial narratives that continue to inform certain biological concepts of "race;" its curriculum, pedagogy and respective (humane) literacies would help teacher educators to further understand how to disrupt essentialist conceptions of genomics education within the broader field of science and science education.

8.3 Create national, provincial, and territorial K-12 professional learning opportunities for teacher educators and science educators to develop and implement curriculum and pedagogies that proactively takes up the differences between basic, standard, and humane genomics literacies.

> On the basis of experimental results consistent with this hypothesis, we argue that supporting the development of genomics literacy through genetics education could reduce the prevalence of belief in genetic essentialism during adolescence.
>
> (Donovan, et al., 2020, p. 522)

Postdigital education scholar Jandrić (2021) asserts that we "are now witnessing a rapid convergence between physics and biology," in which 'biology' "practices, such as genome mapping and editing, cannot be thought of without computers, and 'physics' developments, such as new energy sources, cannot be thought of without consideration of their implications" for biology, from human to the wider biosphere (p. 261). "The convergence between biology and information and the convergence between science and technology are closely followed by numerous lower-order convergences such as the emergence of bioeconomy … through to the Covid-19 pandemic, [and] cut across traditional borders of biology, information, and society" (Jandrić, 2021, p. 262). For example, Scherz (2022) warns that the convergence of genomics

and AI technologies threaten a new and as yet unexamined 'precision education' in which a student's genetic information is filtered through biased, proprietary algorithms, reviving the "demons of eugenics" (p. 65; see also Fullwiley, 2014). The biases encoded in such bio-technological unions suggest a future in which "Whiteness, other hegemonic social identities (e.g., marriage, traditional gender roles), and mental and physical attributes (e.g., being ablebodied) are synonymous with the ideal family and population health" (Chatters et al., 2021, p. 448; see also Paranhos & Cardoso, 2020). We would further add that these algorithmic developments encode and perpetuate settler colonial logics into a future of what it means to be human (Phillips & Ng-A-Fook, 2024). Our research here and elsewhere suggests that educational research and professional learning are needed to inform and support teachers and teacher educators to respond to both the opportunities and dangers of emerging technosciences in relation to the contexts of a postdigital turn (Jandrić & Knox, 2022). Such professional learning would seek to disrupt and challenge genetic essentialisms, racisms, and exclusions as well as advance anti-racist strategic curricular and pedagogical responses.

Here in Canada, a will to realize such humane genomic futurities ostensibly needs to exist from a policy perspective. In 2017, the Association of Canadian Deans of Education (ACDE) published their Accord on Teacher Education, with the broad aim of "[fostering] an inclusive and equitable society" (p. 1). In the summer of 2020, nearly 50 Canadian universities signed the Scarborough Charter on Anti-Black Racism and Black Inclusion in Canadian Higher Education: Principles, Actions, and Accountabilities, affirming that the responsibility of institutions, including teacher education programs, is to "build practices of ongoing dialogue and action yielding inclusion, substantive equality and societal transformation" (Preamble section, para. 1). At the University of Ottawa's Faculty of Education, our 2022-27 Action Plan is committed toward increasing the "capacity of teaching staff, administrative staff, and students to create and sustain inclusive, accessible, and anti-racist student experiences and learning environments" (University of Ottawa, 2022, n.p.).

In the context of our study, such commitments imply the question: How might we seek to address and engender a humane genomics literacy nationally via ACDE and teacher education programming across Canada? Other than some studies of biology textbooks (e.g. Willinsky, 2020), there has not been a comprehensive study of science curriculum and its relationship to racisms and anti-racisms here in Canada. We argue that future studies are needed in terms of an analysis of provincial curriculum policy documents. Such analyses could be done in partnership with different national, provincial, and territorial professional science educators networks, such as Genome Ontario, Genome Quebec, and Science Teachers Association of Ontario (STAO). These analyses should then inform the creation and dissemination of practical teacher education resources; for example, STAO maintains an index on anti-racist science education resources, but none address racisms and anti-racisms in genomics literacy. Meanwhile, Genome Canada, Ontario and Quebec do not appear to include resources or research on racisms and anti-racisms in genomics education or related research.

Such further research and resource development would support the establishment of national, provincial, and territorial professional learning opportunities in K-12 education, providing teacher educators and science educators with the requisite expertise, skills, and resources to effectively integrate these distinct genomic literacies into curricula. These professional development opportunities should aim to disrupt and challenge genetic essentialisms, racisms, and exclusionary practices, fostering anti-racist strategic responses in curriculum and pedagogy. These professional (un)learning opportunities would encompass:

- Equipping teacher educators and science educators with a comprehensive understanding of genomics and its far-reaching implications across diverse domains like health, environment, and wider society (Gericke et al., 2017).
- Offering critical insights to teacher educators and science educators regarding the societal, cultural, and historical contexts shaping the creation and interpretation of genomic knowledge, along with their connections to white settler colonial logic, genetic essentialism, and racism (Kung, 2018).
- Providing a structured framework and instances of humane genomics literacy, distinguishing it from basic and standard genomic literacies in terms of concepts, methodologies, values, and ethical considerations (Donovan et al. 2020; Saunders & Rennie, 2013).
- Empowering teacher educators and science educators with methodologies and tools to create and implement curricula and pedagogies that actively address the distinctions among basic, standard, and humane genomics literacies. These strategies aim to nurture students' understanding and application of genomic knowledge within its social, cultural, and historical contexts, while further advocating for diversity, equity, and justice in science and society (Sheldon, 2018).
- Providing teacher educators and science educators with collaborative spaces and support to engage in reflective practices, facilitating the exchange of experiences and insights while addressing challenges encountered in developing and implementing curricula and pedagogies that address the disparities among basic, standard, and humane genomics literacies (Lee et al., 2018; 2021; 2020).

What continues to emerge from our scoping review is a prescient call for science educators to become more aware of, equipped to, and supported in teaching the nuanced histories of their fields, the biological and sociological complexity of human variation, and the promises as well as dangers of emerging bio-technosciences while promoting anti-racism as a core competency of science education. Moreover, what becomes clear from our research is that part of such future work could involve collaboration between and among genome research organizations, professional science education associations, and teacher education programs, studies on what the baseline of genomics literacy is in Canada, and inquiry into how we might leverage existing and emerging promising literature to foster new social action education and research projects.

9.0 Limitations and Opportunities for Future Research

This scoping review was limited by a relatively short (under one year) funding and reporting timeline. In response, our study focused on peer-reviewed journal articles. The team also lost its Francophone team members early in the screening phases of the project due to unforeseen circumstances and other research commitments. As a result, future Canadian research initiatives into Francophone research literature as well as Anglophone and Francophone professional organizations, programs and initiatives are warranted.

The search strategy developed for this review was comprehensive and exhaustive. Despite this, our search strategy did not return any significant Francophone literature on racisms and anti-racisms in relation to science and/or teacher education. We ran a sensitive search across eight databases to identify pertinent studies. However, we acknowledge that a search strategy may be prone to subjectivity and may have been designed differently, which means that some studies could have been missed. Nevertheless, we do feel confident that the approaches used were rigorous and comprehensive. The team did locate possible Francophone resources such as Genome Quebec and France Génomique. However, the team lacked the financial and human resources to expand the project's scope beyond journal articles. Moreover, searching Genome Quebec and France Génomique's English language websites did not return any results for projects or resources focused on addressing racisms, anti-racisms, or the interplay between biology and social identity. What resources exist and what and how institutions are addressing racisms and anti-racisms in science education should be explored further.

Finally, due to the summative nature of scoping reviews, this report does not critique the literature as it currently stands. Critical inquiry into the curricular possibilities and limitations of this body of literature remains a future research priority for our team. For example, an interdisciplinary curriculum on its own may not address the intersectionality of race (Dr. Lerona Lewis, personal communication, March 6, 2024). Further, how and to what extent "race" is addressed in Canadian provincial science curricula policy documents should be investigated, including what a humane genomics literacy would look like on the ground (Dr. Tasha Ausman, personal communication, February 11, 2024).

10.0 References

Acquaviva, K. D., & Mintz, M. (2010). Perspective: Are we teaching racial profiling? The dangers of subjective determinations of race and ethnicity in case presentations. *Academic Medicine*, 85(4), 702–705. https://doi.org/10.1097/ACM.0b013e3181d296c7

Archila, P. A., Molina, J., Danies, G., Truscott De Mejía, A.-M., & Restrepo, S. (2022). Using the controversy over human race to introduce students to the identification and the evaluation of arguments. *Science & Education*, 31(4), 861–892. https://doi.org/10.1007/s11191-021-00299-8

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. International journal of social research methodology, 8(1), 19-32. https://doi.org/10.1080/1364557032000119616

Arteaga, J. M. S., & El-Hani, C. N. (2012). Othering processes and STS curricula: From nineteenth century scientific discourse on interracial competition and racial extinction to othering in biomedical technosciences. *Science & Education*, 21(5), 607–629. https://doi.org/10.1007/s11191-011-9384-x

Bakkum, M. J., Verdonk, P., Thomas, E. G., Van Rosse, F., Okorie, M., Papaioannidou, P., Likic, R., Sanz, E. J., Christiaens, T., Costa, J. N., Dima, L., De Ponti, F., Van Smeden, J., Van Agtmael, M. A., Richir, M. C., Tichelaar, J., & for the EurOPE consortium. (2023). A clinical pharmacology and therapeutics teacher's guide to race-based medicine, inclusivity, and diversity. *Clinical Pharmacology & Therapeutics*, 113(3), 600–606. https://doi.org/10.1002/cpt.2786

Bates, B. R. (2005). Public culture and public understanding of genetics: A focus group study. Public *Understanding of Science*, 14(1), 47–65. https://doi.org/10.1177/0963662505048409

Beckwith, J., Bergman, K., Carson, M., Doerr, T., Geller, L., Pierce, R., Krimsky, S., Martin, C., Santiago, M., Murray, A. V., Warren, C., & Zichterman, C. (2017). Using dialogues to explore genetics, ancestry, and race. *The American Biology Teacher*, 79(7), 525–537. https://doi.org/10.1525/abt.2017.79.7.525

Benuto, L. T., Casas, J., & O'Donohue, W. T. (2018). Training culturally competent psychologists: A systematic review of the training outcome literature. *Training and Education in Professional Psychology*, 12(3), 125–134. https://doi.org/10.1037/tep0000190

Bolnick. (2015). Combating racial health disparities through medical education: The need for anthropological and genetic perspectives in medical training. *Human Biology*, 87(4), 361. https://doi.org/10.13110/humanbiology.87.4.0361

Boutte, G., Kelly-Jackson, C., & Johnson, G. L. (2010). Culturally Relevant Teaching in Science Classrooms: Addressing Academic Achievement, Cultural Competence, and Critical Consciousness. *International Journal of Multicultural Education*, *12*(2), 1-20. https://doi.org/10.18251/ijme.v12i2.343

Braun, L., & Saunders, B. (2017). Avoiding racial essentialism in medical science curricula. AMA Journal of Ethics, 19(6), 518–527. https://doi.org/10.1001/journalofethics.2017.19.6.peer1-1706

Brewer, R. M. (2006). Thinking critically about race and genetics. *Journal of Law, Medicine & Ethics*, 34(3), 513–519. https://doi.org/10.1111/j.1748-720X.2006.00064.x

Bynum, G. (2021). "Race is a fiction; racism is not"? Understandings of race in anti-racist education. *Educational Theory*, 71(2), 223–245. https://doi.org/10.1111/edth.12479

Carmichael, N., Redlinger-Grosse, K., & Birnbaum, S. (2020). Conscripted curriculum: The experiences of minority genetic counseling students. *Journal of Genetic Counseling*, 29(2), 303–314. https://doi.org/10.1002/jgc4.1260

Carmichael, N., Redlinger-Grosse, K., & Birnbaum, S. (2021). Supporting a sense of inclusion and belonging for genetic counseling students who identify as racial or ethnic minorities. Journal of Genetic Counseling, 30(3), 813–827. https://doi.org/10.1002/jgc4.1381

Castéra, J., & Clément, P. (2014). Teachers' conceptions about the genetic determinism of human behaviour: A survey in 23 countries. Science & Education, 23(2), 417–443. https://doi.org/10.1007/s11191-012-9494-0

Chatters, L. M., Taylor, R. J., & Schulz, A. J. (2022). The return of race science and why it matters for family science. *Journal of Family Theory & Review*, 14(3), 442–462. https://doi.org/10.1111/jftr.12472

Cilli, El., Delaini, P., & Costazza, B. (2010). Ethno-anthropological and genetic study of the Yaghnobis; an isolated community in Central Asia. *A preliminary study. Journal of Anthropological Sciences*, 89, 1–6. https://doi.org/10.4436/jass.89003

Donald, D. (2019). Homo economicus and forgetful curriculum. In H. Tomlins-Jahnke, S. Styres, S. Lilley, & D. Zinga (Eds.), *Indigenous education: New directions in theory and practice* (pp. 103–125). University of Alberta Press.

Donovan, B. M. (2014). Playing with fire? The impact of the hidden curriculum in school genetics on essentialist conceptions of race. *Journal of Research in Science Teaching*, 51(4), 462–496. https://doi.org/10.1002/tea.21138

Donovan, B. M. (2015a). Putting humanity back into the teaching of human biology. S*tudies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 52, 65–75. https://doi.org/10.1016/j.shpsc.2015.01.011

Donovan, B. M. (2015b). Reclaiming race as a topic of the U.S. biology textbook curriculum. *Science Education*, 99(6), 1092–1117. https://doi.org/10.1002/sce.21173

Donovan, B. M. (2016a). Framing the genetics curriculum for social justice: An experimental exploration of how the biology curriculum influences beliefs about racial difference. *Science Education*, 100(3), 586–616. https://doi.org/10.1002/sce.21221

Donovan, B. M. (2017). Learned inequality: Racial labels in the biology curriculum can affect the development of racial prejudice. *Journal of Research in Science Teaching*, 54(3), 379–411. https://doi.org/10.1002/tea.21370

Donovan, B. M. (2022). Ending genetic essentialism through genetics education. *Human Genetics and Genomics Advances*, 3(1), 1-13. https://doi.org/10.1016/j.xhgg.2021.100058

Donovan, B. M., Semmens, R., Keck, P., Brimhall, E., Busch, K. C., Weindling, M., Duncan, A., Stuhlsatz, M., Bracey, Z. B., Bloom, M., Kowalski, S., & Salazar, B. (2019). Toward a more humane genetics education: Learning about the social and quantitative complexities of human genetic variation research could reduce racial bias in adolescent and adult populations. *Science Education*, 103(3), 529–560. https://doi.org/10.1002/sce.21506

Donovan, B. M., Weindling, M., & Lee, D. M. (2020). From basic to humane genomics literacy: How different types of genetics curricula could influence anti-essentialist understandings of race. *Science & Education*, 29(6), 1479–1511. https://doi.org/10.1007/s11191-020-00171-1

Donovan, B. M., Weindling, M., Salazar, B., Duncan, A., Stuhlsatz, M., & Keck, P. (2021). Genomics literacy matters: Supporting the development of genomics literacy through genetics education could reduce the prevalence of genetic essentialism. Journal of Research in Science Teaching, 58(4), 520–550. https://doi.org/10.1002/tea.21670

Donovan, B., & Nehm, R. H. (2020). Genetics and identity: Introduction to the special issue. *Science & Education*, 29(6), 1451–1458. https://doi.org/10.1007/s11191-020-00180-0

Du Bois, W.E.B. (1897/1970). The conservation of races. In Foner, P. S. (Ed.). (1970). W. E. B. Du Bois speaks: Speeches and addresses, 1890-1919 (pp. 73-75). Pathfinder Press.

Duello, T. M., Rivedal, S., Wickland, C., & Weller, A. (2021). Race and genetics versus 'race' in genetics. Evolution, Medicine, and Public Health, 9(1), 232–245. https://doi.org/10.1093/emph/eoab018

Fitzgerald, K. J. (2014). The Continuing Significance of Race: Racial Genomics in a Postracial Era. *Humanity & Society*, 38(1), 49-66. https://doi.org/10.1177/0160597613519231

Fofana, M. O. (2013). The spectre of race in American medicine. *Medical Humanities*, 39(2), 137–141. https://doi.org/10.1136/medhum-2013-010374

Fowler, K., & Noel, S. (2022). Culturally affirming assessments of an inheritance and traits unit through genetic raps. *Science Teacher*, 89(5), p.22-28. https://www.nsta.org/science-teacher/science-teacher-mayjune-2022/flow-my-dna

Fullwiley, D. (2014). The "contemporary synthesis": When politically inclusive genomic science relies on biological notions of race. *Isis*, 105(4), 803–814. https://doi.org/10.1086/679427

Gasteiger, N., Vercell, A., Khan, N., Dowding, D., Davies, A. C., & Davies, A. (2023). Digital interventions for genomics and genetics education, empowerment, and service engagement: A systematic review. *Journal of Community Genetics*, 14(3), 227–240. https://doi.org/10.1007/s12687-023-00648-w

Gericke, N., Carver, R., Castéra, J., Evangelista, N. A. M., Marre, C. C., & El-Hani, C. N. (2017). Exploring relationships among belief in genetic determinism, genetics knowledge, and social factors. *Science & Education*, 26(10), 1223–1259. https://doi.org/10.1007/s11191-017-9950-y

Gillborn, D. (2016). Softly, softly: Genetics, intelligence and the hidden racism of the new geneism. *Journal of Education Policy*, 31(4), 365–388. https://doi.org/10.1080/02680939.2016.1139189

Gillborn, D. (2018). Heads I win, tails you lose: Anti-Black racism as fluid, relentless, individual and systemic. *Peabody Journal of Education*, 93(1), 66–77. https://doi.org/10.1080/0161956X.2017.1403178

Gingell, G., & Bergemann, A. D. (2021). Disrupting essentialism in medical genetics education. *Medical Science Educator*, 32(1), 255–262. https://doi.org/10.1007/s40670-021-01458-w

Gouvea, J. S. (2022). Addressing racism in human genetics and genomics education. *CBE—Life Sciences Education*, 21(4), fe5. https://doi.org/10.1187/cbe.22-09-0188

Green, K.-A., Wolinsky, R., Parnell, S. J., Del Campo, D., Nathan, A. S., Garg, P. S., Kaplan, S. E., & Dasgupta, S. (2022). Deconstructing racism, hierarchy, and power in medical education: Guiding principles on inclusive curriculum design. *Academic Medicine*, 97(6), 804–811. https://doi.org/10.1097/ACM.0000000000004531

Hales, K. G. (2020). Signaling inclusivity in undergraduate biology courses through deliberate framing of genetics topics relevant to gender identity, disability, and race. *CBE—Life Sciences Education*, 19(2), es2. https://doi.org/10.1187/cbe.19-08-0156

Hamilton, V., & Stoebel, D. M. (2020). History in the education of scientists: Encouraging judgment and social action. *Isis*, 111(3), 623–630. https://doi.org/10.1086/711101

Harden, K. P. (2023). Genetic determinism, essentialism and reductionism: semantic clarity for contested science. *Nature Reviews Genetics*, *24*(3), 197-204. 10.1038/s41576-022-00537-x

Hassen, N., Lofters, A., Michael, S., Mall, A., Pinto, A. D., & Rackal, J. (2021). Implementing anti-racism interventions in healthcare settings: A scoping review. *International Journal of Environmental Research and Public Health*, 18(6), Article 6. https://doi.org/10.3390/ijerph18062993

Herd, P., Mills, M. C., & Dowd, J. B. (2021). Reconstructing sociogenomics research: Dismantling biological Race and genetic essentialism narratives. *Journal of Health and Social Behavior*, 62(3), 419–435. https://doi.org/10.1177/00221465211018682

Hubbard, A. R. (2017a). Testing common misconceptions about the nature of human racial variation. *The American Biology Teacher*, 79(7), 538–543. https://doi.org/10.1525/abt.2017.79.7.538

Hubbard, A. R. (2017b). Teaching Race (Bioculturally) Matters: A Visual Approach for College Biology Courses. *The American Biology Teacher*, 79(7), 516-524. https://doi.org/10.1525/abt.2017.79.7.516

Hubbard, A. R., & Monnig, L. A. (2020). Using anthropological principles to transform the teaching of human "difference" and genetic variation in college classrooms. *Science & Education*, 29(6), 1541–1565. https://doi.org/10.1007/s11191-020-00164-0

Hughey, M. W., & Byrd, W. C. (2015). Beautiful melodies telling me terrible things: The future of race and genetics for scholars and policy-makers. *The ANNALS of the American Academy of Political and Social Science*, 661(1), 238–258. https://doi.org/10.1177/0002716215591477

Jacobs, B., Roffenbender, J., Collmann, J., Cherry, K., Bitsói, L. L., Bassett, K., & Evans, C. H. (2010). Bridging the divide between genomic science and Indigenous Peoples. *Journal of Law, Medicine & Ethics*, 38(3), 684–696. https://doi.org/10.1111/j.1748-720X.2010.00521.x

Jandrić, P. (2021). Biology, information, society. *Postdigit Sci Educ* 3, 261–265. https://doi.org/10.1007/s42438-021-00220-0

Jandrić, P., & Knox, J. (2022). The postdigital turn: Philosophy, education, research. Policy Futures in Education, 20(7), 780-795. https://doi.org/10.1177/14782103211062713

Kalinowski, S. T., Andrews, T. M., Leonard, M. J., & Snodgrass, M. (2012). Are Africans, Europeans, and Asians different "races"? A guided-inquiry lab for introducing undergraduate students to genetic diversity and preparing them to study natural selection. *CBE—Life Sciences Education*, 11(2), 142–151. https://doi.org/10.1187/cbe.11-09-0087

Kampourakis, K., & Peterson, E. L. (2023). The racist origins, racialist connotations, and purity assumptions of the concept of "admixture" in human evolutionary genetics. *GENETICS*, 223(3), iyad002. https://doi.org/10.1093/genetics/iyad002

Kaszycka, K. A., & Strzałko, J. (2019). Race and perception of human diversity: Five European case studies. *Journal of Anthropological Sciences*: JASS, 96, 173-187.

Kung, S. (2018). The shifting space of ontology: Appeals to crisis and the reformulation of nation, race, and biology in educational reform. *Discourse: Studies in the Cultural Politics of Education*, 39(2), 196–218. https://doi.org/10.1080/01596306.2018.1404195

Lazarowitz, R., & Bloch, I. (2005). Awareness of societal issues among high school biology teachers teaching genetics. *Journal of Science Education and Technology*, 14(5–6), 437–457. https://doi.org/10.1007/s10956-005-0220-4

Lee, H., Lee, H., & Zeidler, D. L. (2020). Examining tensions in the socioscientific issues classroom: Students' border crossings into a new culture of science. *Journal of Research in Science Teaching*, 57(5), 672–694. https://doi.org/10.1002/tea.21600

Lee, J.-K., Aini, R. Q., Sya'bandari, Y., Rusmana, A. N., Ha, M., & Shin, S. (2021). Biological conceptualization of race: The unintended consequence of Korean college students' learning of biology. *Science & Education*, 30(2), 293–316. https://doi.org/10.1007/s11191-020-00178-8

Lee, J.-K., Shin, S., & Yoo, H. H. (2018). Exploring the ontological status of the race concept as perceived by Korean medical students. *EURASIA Journal of Mathematics, Science and Technology Education*, 14(10). https://doi.org/10.29333/ejmste/92288

Li, A., Deyrup, A. T., Graves, J. L., & Ross, L. F. (2022). Race in the reading: A study of problematic uses of race and ethnicity in a prominent pediatrics textbook. *Academic Medicine*, 97(10), 1521–1527. https://doi.org/10.1097/ACM.0000000000004666

Liscum, M., & Garcia, M. L. (2022). You can't keep a bad idea down: Dark history, death, and potential rebirth of eugenics. *The Anatomical Record*, 305(4), 902–937. https://doi.org/10.1002/ar.24849

Lujan, H. L., & DiCarlo, S. E. (2021). The racist "one drop rule" influencing science: It is time to stop teaching "race corrections" in medicine. *Advances in Physiology Education*, 45(3), 644–650. https://doi.org/10.1152/advan.00063.2021

Lynn, T. M., D'urzo, K. A., Vaughan-Ogunlusi, O., Wiesendanger, K., Colbert-Kaip, S., Capcara, A., Chen, S., Sreenan, S., & Brennan, M. P. (2023). The impact of a student-led anti-racism programme on medical students' perceptions and awareness of racial bias in medicine and confidence to advocate against racism. *Medical Education Online*, 28(1), 2176802. https://doi.org/10.1080/10872981.2023.2176802

Márquez-Magaña, L., Samayoa, C., & Umanzor, C. (2013). Debunking 'race' and asserting social determinants as primary causes of cancer health disparities: Outcomes of a science education activity for teens. *Journal of Cancer Education*, 28(2), 314–318. https://doi.org/10.1007/s13187-013-0474-0

Martschenko, D. (2020). DNA dreams: Teacher perspectives on the role and relevance of genetics for education. *Research in Education*, 107(1), 33–54. https://doi.org/10.1177/0034523719869956

Martschenko, D. O. (2023). Normalizing race in (gifted) education: Genomics and spaces of White exceptionalism. *Critical Studies in Education*, 64(1), 67–83. https://doi.org/10.1080/17508487.2021.1978517

Mayfield, K. K. (2017). Creating a critical genetics curriculum as a counternarrative to/in the urban imaginary. *Urban Education*, 52(1), 61–90. https://doi.org/10.1177/0042085914553672

McChesney, K. Y. (2015). Teaching diversity: The science you need to know to explain why race is not biological. *SAGE Open*, 5(4), 215824401561171. https://doi.org/10.1177/2158244015611712

McGowan, A. H. (2023). Genes and race in the classroom: Science in a social context. Journal of *College Science Teaching*, 34(6).

McGowan, J., Sampson, M., Salzwedel, D. M., Cogo, E., Foerster, V., & Lefebvre, C. (2016). PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. *Journal of Clinical Epidemiology*, 75, 40–46. https://doi.org/10.1016/j.jclinepi.2016.01.021

Meier, R. J. (2012). A critique of race-based and genomic medicine. *Coll. Antropol*, 36(5), 5-10.

Moore, A. E. (2021). “My job is to unsettle folks”: Perspectives on a praxis toward racial justice. *Teaching and Teacher Education*, 102, 1-11. https://doi.org/10.1016/j.tate.2021.103336

Morin-Chassé, A. (2020). Behavioral genetics, population genetics, and genetic essentialism: A survey experiment. *Science & Education*, 29(6), 1595–1619. https://doi.org/10.1007/s11191-020-00166-y

Morning, A. (2008). Reconstructing race in science and society: Biology text-books, 1952–2002. *American Journal of Sociology*, 114 (Suppl 1), S106–S137. https://doi.org/10.1086/592206

Nelson, A. (2018). The social life of DNA: Racial reconciliation and institutional morality after the genome. *The British Journal of Sociology*, 69(3), 522–537. https://doi.org/10.1111/1468-4446.12607

Nieblas-Bedolla, E., Christophers, B., Nkinsi, N. T., Schumann, P. D., & Stein, E. (2020). Changing how race is portrayed in medical education: Recommendations from medical students. *Academic Medicine*, 95(12), 1802–1806. https://doi.org/10.1097/ACM.0000000000003496

Nisbett, R. E. (2013). Schooling makes you smarter: What teachers need to know about IQ. *American Educator*, 37(1), 10–22.

Olsen, L. D. (2019). The Conscripted curriculum and the reproduction of racial inequalities in contemporary US medical education. J*ournal of Health and Social Behavior*, 60(1), 55–68. https://doi.org/10.1177/0022146518821388

Otlowski, M., Taylor, S., & Bombard, Y. (2012). Genetic discrimination: international perspectives. *Annual review of genomics and human genetics*, 13, 433-454. 10.1146/annurev-genom-090711-163800

Pang, V. O., & Valle, R. (2004). A change in paradigm: Applying contributions of genetic research to teaching about race and racism in social studies education. *Theory & Research in Social Education*, 32(4), 503–522. https://doi.org/10.1080/00933104.2004.10473267

Paranhos, M. L. R., & Cardoso, L. D. R. (2020). The right of life and death in a Biology curriculum. *Educar Em Revista*, 36, e75223. https://doi.org/10.1590/0104-4060.75223

Phelan, J. C., Link, B. G., & Feldman, N. M. (2013). The genomic revolution and beliefs about essential racial differences: A backdoor to eugenics? *American Sociological Review*, 78(2), 167–191. https://doi.org/10.1177/0003122413476034

Phillips, P. & Ng-A-Fook, N. (2024). An unsettling artificial intelligence: Algorithms, curriculum, and futurities. *Journal of the American Association for the Advancement of Curriculum Studies (JAAACS)*.

Pollock, B., Wetherill, L., Delk, P., Wesson, M., Rucker, S., Goodman, Z., Remeika, W., & Ivanovich, J. (2022). Diversity training experiences and factors associated with implicit racial bias among recent genetic counselor graduates of accredited programs in the United States and Canada. *Journal of Genetic Counseling*, 31(3), 792–802. https://doi.org/10.1002/jgc4.1547

Puddester, R., Pike, A., Maddigan, J., & Farrell, A. (2022). Nurses' knowledge, attitudes, confidence, and practices with genetics and genomics: A theory-informed integrative review protocol. *Journal of Personalized Medicine*, 12(9), Article 9. https://doi.org/10.3390/jpm12091358

Rahimzadeh, V., Knoppers, B. M., & Bartlett, G. (2020). Ethical, legal, and social issues (ELSI) of responsible data sharing involving children in genomics: A systematic literature review of reasons. *AJOB Empirical Bioethics*, 11(4), 233–245. https://doi.org/10.1080/23294515.2020.1818875

Raveendran, A. & Chunawala, S. (2015). Values in Science: Making Sense of Biology Doctoral Students' Critical Examination of a Deterministic Claim in a Media Article. *Science Education*, 99(4), 669-695. https://doi.org/10.1002/sce.21174

Raven, S., & Jurkiewicz, M. A. (2014). Preservice secondary science teachers' experiences and ideas about bullying in science classrooms. *Science Educator*, 23(1), 65-72.

Reese, A. J. (2020). An undergraduate elective course that introduces topics of diversity, equity, and inclusion into discussions of science. *Journal of Microbiology & Biology Education*, 21(1), 15. https://doi.org/10.1128/jmbe.v21i1.1947

Reis, G., & Ng-A-Fook, N., & Glithero, L. (2015). Provoking Ecojustice: Taking Citizen Science and Youth Activism Beyond the School Curriculum. In M. Mueller & D. Tippings (Eds.), *Ecojustice, citizen science and youth activism*, pp. 39-61. New York: Springer International Publishing Switzerland. 10.1007/978-3-319-11608-2

Ripp, K., & Braun, L. (2017). Race/ethnicity in medical education: An analysis of a question bank for step 1 of the United States Medical Licensing Examination. *Teaching and Learning in Medicine*, 29(2), 115–122. https://doi.org/10.1080/10401334.2016.1268056

Roll-Hansen, N. (2010). Eugenics and the Science of Genetics. In Bashford, A., & Levine, P. (Eds.). (2010). *The Oxford handbook of the history of eugenics* (pp. 80-97). Oxford University Press.

Roth, W. D., Van Stee, E. G., & Regla-Vargas, A. (2023). Conceptualizations of race: Essentialism and constructivism. *Annual Review of Sociology*, 49(1), 39–58. https://doi.org/10.1146/annurev-soc-031021-034017

Sabatello, M., & Juengst, E. (2019). Genomic essentialism: Its provenance and trajectory as an anticipatory ethical concern. *Hastings Center Report*, 49(S1). https://doi.org/10.1002/hast.1012

Saunders, K. J., & Rennie, L. J. (2013). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education*, 43(1), 253–274. https://doi.org/10.1007/s11165-011-9248-z

Scherz, P. (2022). Life as an intelligence test: Intelligence, education, and behavioral genetics. *Culture, Medicine, and Psychiatry*, 46(1), 59–75. https://doi.org/10.1007/s11013-021-09747-0

Shostak, S. & Beckfield, J. (2015). Making A Case For Genetics: Interdisciplinary Visions and Practices in the Contemporary Social Sciences. *Genetics, Health and Society Advances in Medical Sociology*, 6, 97-125. 1057-6290/doi:10.1108/S1057-629020150000016004

Schulz, A., Caldwell, C., & Foster, S. (2003). "What are they going to do with the information?" Latino/Latina and African American perspectives on the Human Genome Project. *Health Education & Behavior*, 30(2), 151–169. https://doi.org/10.1177/1090198102251026

Seiter, K. M., & Fuselier, L. (2021). Content knowledge and social factors influence student moral reasoning about CRISPR /Cas9 in humans. *Journal of Research in Science Teaching*, 58(6), 790–821. https://doi.org/10.1002/tea.21679

Sheldon, J. P. (2018). Incorporating a discussion of genetic attributions into psychology courses. *Teaching of Psychology*, 45(1), 91–101. https://doi.org/10.1177/0098628317745463

Shotwell, M. (2019). The misuse of genetics: The dihybrid cross & the threat of "race crossing." *The American Biology Teacher*, 81(1), 3–10. https://doi.org/10.1525/abt.2019.81.1.3

Shotwell, M. (2021). The misuse of pedigree analysis in the eugenics movement. *The American Biology Teacher*, 83(2), 80–88. https://doi.org/10.1525/abt.2021.83.2.80

Sparks, R. A., Baldwin, K. E., & Darner, R. (2020). Using culturally relevant pedagogy to reconsider the genetics canon. *Journal of Microbiology & Biology Education*, 21(1), 55. https://doi.org/10.1128/jmbe.v21i1.1901

Stern, F., Kampourakis, K., & Müller, A. (2023). "Genes for a role," "genes as essences": Secondary students' explicit and implicit intuitions about genetic essentialism and teleology. *Journal of Research in Science Teaching*, 60(2), 237–267. https://doi.org/10.1002/tea.21796

Stetsenko, A. (2018). Confronting biological reductionism From a social justice agenda: Transformative agency and activist stance. *Literacy Research: Theory, Method, and Practice*, 67(1), 44–63. https://doi.org/10.1177/2381336918787531

Stitzlein, S. M. (2009). Getting into the habit: Using historical science to understand race in contemporary schools. *Race Ethnicity and Education*, 12(3), 401–416. https://doi.org/10.1080/13613320903178329

Sveden, A., Schwartz, A., Breen, K., Gochyyev, P., & Channaoui, N. (2023). Introduction of the genetic counseling profession by teachers in BIPOC -majority high schools. *Journal of Genetic Counseling*, 32(2), 411–424. https://doi.org/10.1002/jgc4.1650

Sze, J., & Prakash, S. (2004). Human genetics, environment, and communities of color: Ethical and social implications. *Environmental Health Perspectives*, 112(6), 740–745. https://doi.org/10.1289/ehp.6731

Tawa, J. (2020). Does social constructionist curricula both decrease essentialist and increase nominalist beliefs about race? *Science & Education*, 29(6), 1513–1540. https://doi.org/10.1007/s11191-020-00125-7

Tornabene, R. E., Sbeglia, G. C., & Nehm, R. H. (2020). Measuring belief in genetic determinism: A psychometric evaluation of the PUGGS instrument. *Science & Education*, 29(6), 1621–1657. https://doi.org/10.1007/s11191-020-00146-2

Tsai, J. (2021). Building structural empathy to marshal critical education into compassionate practice: Evaluation of a medical school critical race theory course. Journal of Law, Medicine & Ethics, 49(2), 211–221. https://doi.org/10.1017/jme.2021.31

Tsai, J., Ucik, L., Baldwin, N., Hasslinger, C., & George, P. (2016). Race matters? Examining and rethinking race portrayal in preclinical medical education. *Academic Medicine*, 91(7), 916–920. https://doi.org/10.1097/ACM.0000000000001232

Uchenna, E. (2022). Reimagining a culture of equality (R.A.C.E.) lesson. *The American Biology Teacher*, 84(5), 267–272. https://doi.org/10.1525/abt.2022.84.5.267

Venville, G., Gribble, S. J., & Donovan, J. (2005). An exploration of young children's understandings of genetics concepts from ontological and epistemological perspectives. *Science Education*, 89(4), 614–633. https://doi.org/10.1002/sce.20061

Visintainer, T. (2020). "I think at first glance people would not expect me to be interested in science": Exploring the racialized science experiences of high school students of color. *Journal of Research in Science Teaching*, 57(3), 393–422. https://doi.org/10.1002/tea.21597

Wang, A., Shlobin, N. A., DiCesare, J. A. T., Holly, L. T., & Liau, L. M. (2022). Diversity in neurosurgical recruitment and training in the United States: A systematic review. *World Neurosurgery*, 162, 111-117.e1. https://doi.org/10.1016/j.wneu.2022.03.086

Wiggan, G., Pass, M. B., & Gadd, S. R. (2023). Critical Race Structuralism: The Role of Science Education in Teaching Social Justice Issues in Urban Education and Pre-Service Teacher Education Programs. *Urban Education*, 58(9), 2209-2238. https://doi.org/10.1177/0042085920937756

Willinsky, J. (2020). The confounding of race in high school biology textbooks, 2014–2019. *Science & Education*, 29(6), 1459–1476. https://doi.org/10.1007/s11191-020-00104-y

Wispelwey, B., & Tanous, O., & Asi, Y., Hannoudeh, W., & Mills, D. (2023). Because its power remains naturalized: introducing the settler colonial determinants of health Frontiers Public Health, 11, 1-17. https://doi.org/10.3389/fpubh.2023.1137428

Wolfe, P. (2006). Settler colonialism and the elimination of the native. *Journal of genocide research*, 8(4), 387-409.

Wright, O. R. L. (2014). Systematic review of knowledge, confidence and education in nutritional genomics for students and professionals in nutrition and dietetics. *Journal of Human Nutrition and Dietetics*, 27(3), 298–307. https://doi.org/10.1111/jhn.12132

Yang, X., Hartman, M. R., Harrington, K. T., Etson, C. M., Fierman, M. B., Slonim, D. K., & Walt, D. R. (2017). Using next-generation sequencing to explore genetics and race in the high school classroom. *CBE—Life Sciences Education*, 16(2), ar22. https://doi.org/10.1187/cbe.16-09-0281

Young, D. M., Wilton, L. S., & Howansky, K. (2022). Initial evidence for shifting race essentialism beliefs in the classroom. *Teaching of Psychology*, 009862832211273. https://doi.org/10.1177/00986283221127384

Zimmerman, H. T., Weible, J. L., Wright, E. A., Vanderhoof, C., & Jablonski, N. G. (2022). Using youths' personal DNA data in science camps: Fostering genetics learning and socio-emotional attitudes toward science with design-based research. *Science Education*, 106(4), 767–796. https://doi.org/10.1002/sce.21709