EDUCATION

Humane genomics education can reduce racism

Moving instruction "beyond Mendel" can counter inaccurate, essentialist views

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For as long as the concept of race has existed, racial prejudice has been justified on hereditary grounds (*1*, *2*). Justifications of prejudice often misappropriate the work of Mendel, who first expounded a scientific model of inheritance by breeding peas (*3*). Today, our understanding of inheritance has moved far beyond Mendel, and insights from genomics refute the prejudiced idea that racial inequality is determined by genes (*1*). Even so, many believe that inequality is genetic because they are biased by an inaccurate conception of race called "genetic essentialism" (*1*, *2*, *4*). We present data from a randomized trial to argue that if teachers move genetics instruction beyond Mendel and toward more complex genomics concepts—what we call "humane genomics education"—they can protect students from believing in unscientific notions of genetic essentialism and support their scientifically accurate understanding of race as a social construction.

Genetic essentialism is a form of psychological essentialism, which is an early developing bias in humans (*4*). Psychological essentialism is observable across human cultures and refers to the belief that members of a social category share an unobservable and internal essence that determines their traits (*4*). People who endorse genetic essentialism believe that such essences are genetic (*4*), which leads them to believe that same race individuals are genetically homogenous, that races are non-overlapping genetic groups, and that most racial differences are therefore determined by genes (*4*).

Essentialist beliefs are socially dangerous and a biological misconception (*1*, *2*, *4*). For example, genetic essentialist beliefs about race facilitate intergroup hostility (*5*), support for eugenic policies (*6*), discrimination (*4*), and disinterest in cross-racial friendships (*7*). Psychological essentialism also inhibits biology learning because it involves misunderstandings of intraspecific genetic variation (*1*), such as the erroneous belief that human races are like dog breeds (*8*). For example, United States (US) high school students and adults inaccurately estimate that 37% of human genetic variation exists between racial groups (*9*), which is similar to the proportion of genetic variation across dog breeds (≈27-33%) (*8*), but is 7.4 times more than the genetic variation that exists across human continental populations (≈5%) (*10*).

Two alternative conceptions of race are colorblindness and constructionism. People who believe in the former contend that racial discrimination is no longer a problem, or that it can be ignored because race is not socially important, or real (*2*). In contrast, constructionism contends that race is a social concept and that racial disparities are caused by prejudice, discrimination, and institutional racism (*2*, *11*). There is consensus in the social and biological sciences that colorblindness, like essentialism, is scientifically flawed (*2*, *11*), while there is clear evidence that race is socially constructed and that historical and present-day racism are major causes of racial disparities (*1*, *2*, *11*).

There is cross-cultural variation in the development of racial conceptualization (*1*, *2*), and the proportion of US children who believe that each race possesses a genetic essence increases with age (*1*, *2*). Thus, exposure to genetic ideas via informal (e.g., media) or formal learning (e.g., school) is hypothesized to affect the development of genetic essentialism (*2*, *4*).

GENETICS EDUCATION AND ESSENTIALISM

Around the world, students receive a basic genetics education that focuses on single gene inheritance (*1*). In a basic genetics education, students learn (A) Mendel's laws of heredity, and how (B) different versions of a gene (i.e., alleles) are inherited across generations through probabilistic mechanisms that are easily modeled via a Punnett square. Teachers also introduce students to (C) the DNA molecule and to the molecular processes (i.e., the central dogma) that link genotypes to phenotypes. Students often learn how mechanisms A-C operate in humans by exploring the racial prevalence of monogenic diseases such as sickle cell anemia (SCA) and cystic fibrosis (CF) (*1*). All genetics education standards in the US follow this story (*1*).

The problem is that the basic genetics education that the US public receives is a risk factor for development of genetic essentialism during adolescence (*1*). This claim is based on several studies (see (*1*)), particularly findings from randomized control trials (RCTs) showing that learning about monogenic diseases can cause greater belief in genetic essentialism of race (*1*). For example, contrary to what genetic essentialism predicts, there are no gene variants—including SCA and CF alleles—that most individuals in one race possess and no individuals in another race possess. Yet instruction on SCA and CF genotypes in Black and White populations leads students to develop this perception (*1*). This perception then facilitates an increase in the belief that genes determine racial disparities (e.g., in educational attainment) (*1*).

Since basic genetics education does not discuss patterns of racial similarity in the human genome (*1*), and since it does not discuss the multifactorial basis of complex human traits (*1*), students are never exposed to information that explicitly counters genetic essentialist views about race. At best, basic genetics instruction fails to challenge genetic essentialist beliefs about race, and at worst, it could unintentionally lead students to construct them (*1*).

We contend that genetics education needs to move beyond Mendel and toward the complexity of human genomics if it is to prevent the development of genetic essentialism (*1*). To understand why, consider the following three genomics concepts: (D) Roughly 0.1% of the human genome varies between individuals and when population geneticists partition this variable DNA, they find that most variation occurs within geographic populations (≈95%) and much of the genetic variation that occurs across such populations (≈5%) consists of common alleles that vary in frequency (*10*). If "races" are defined as geographic populations, then the essentialist assumption that there is little to no genetic variation among individuals of the same race—and thus that most genetic variation is between races—is wrong; (E) Also, social disparities between races involve differences in complex traits. Since complex traits are multifactorial and influenced by interactions between genes and environments (*12*), it is not scientifically accurate to claim that racial inequality is determined by genetic variation alone (*1*); (F) Indeed, humans inherit their genomes along with their environments and scientists have not yet developed convincing or ethical methods to disentangle gene-environment (G-E) covariance (*1*). Because racial differences in a trait can be environmentally determined even when intragroup differences in that same trait

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are genetically influenced, there is good reason to be skeptical of the claim that racial disparities are genetic: historical and present-day racism have made the environments of racialized populations different (*1*).

Teaching students genomics concepts D-F for the purpose of refuting genetic essentialism is what we call "humane genomics education". RCTs conducted in the District of Columbia, Colorado, California, and Massachusetts already demonstrate that teaching 8th-12th grade students about concept D can cause a reduction in students' genetic essentialist beliefs about race (*1*). This reduction is driven by a change in how students perceive interracial gene variability (*1*). Furthermore, students with a greater understanding of multifactorial inheritance (i.e., concept E) are more likely to disbelieve genetic essentialism after learning concept D (*1*) because they are more likely to develop the perception that races are not that genetically different. Therefore, the connection between genetics instruction and belief in genetic essentialism of race depends on how instruction affects students' perceptions of genetic variation between races (*1*). When students develop an accurate view of such variation (Concept D) their belief in genetic essentialism declines (and vice versa).

That said, those previous RCTs have shortcomings that undermine their educational importance. They have not demonstrated that reductions in genetic essentialism are accompanied by increases in genomics knowledge (Concepts D-F), which undermines the claim that genomics education is responsible for these effects. Also, previous RCTs have not demonstrated if students adopt a more accurate, social constructionist view of race (*2*).

Additionally, the results of previous studies may have been biased toward a reduction in genetic essentialism. For example, the interventions used in previous studies have been implemented by the teachers who helped to design them. Relatedly, previous RCTs have not assessed if student self-reports of essentialist beliefs are affected by social desirability bias.

Finally, we still do not know if humane genomics instruction affects belief in genetic essentialism when it is implemented along with basic genetics instruction (i.e., mechanisms A-C) (*1*). This is a conundrum for educators who are concerned about genetic essentialism and who are obligated to offer a basic genetics education because genetics standards are focused mostly on single gene inheritance (*1*).

This cluster-randomized crossover trial overcomes these shortcomings and is the first to explore how basic genetics vs. humane genomics instruction affects racial conceptualization. We hypothesize (H) that when adolescents participate in humane genomics instruction, they will grow more in their knowledge of genomics relative to those receiving basic genetics instruction (Ha). If this occurs, then (relative to basic genetics instruction) humane genomics instruction should lead adolescents to perceive less genetic discreteness between racial groups (Hb) and attribute complex human traits less to genes (Hc) and more to the environment (Hd). If so, then belief in genetic essentialism should be lower among students receiving humane genomics instruction relative to basic genetics instruction (He).

To investigate the validity of the results, we examine whether educational effects on genetic essentialism are biased by socially desirable reporting. Then, we answer the exploratory research question (RQ): Do adolescents adopt social constructionist or racial colorblind views after humane genomics instruction? We close by estimating the generalizability, clinical significance, feasibility, replicability, and scalability of the humane genomics approach.

EXPERIMENTAL METHODS

Refer to the Supplementary Materials (SM) for all study details, data and code related to our pre-registered randomized trial (*13*). Between December 2019 and May 2022, we recruited 15 teachers (n = 14 high school, n = 1 middle school) and 1063 biology students from six US states (Colorado, Illinois, Indiana, Kansas, New Jersey, and Massachusetts, see Fig. S1). Participating teachers (see Table S1) received 40 hours of professional development (PD) to learn how to implement the humane genomics intervention and how to align their Mendelian and molecular genetics curricula with basic genetics (i.e., mechanisms A-C).

We randomized classrooms to receive six weeks of instruction in two different orders (Fig S1-2). Half of each teacher's classrooms (n = 25) received basic genetics instruction first (for 3 weeks), targeting mechanisms A-C outlined in the section on basic genetics. Then, these classrooms received humane genomics instruction (for 3 weeks), targeting concepts D-F outlined in the section on humane genomics. The other half of classrooms within each teacher (n = 26) received humane genomics first, and then basic genetics instruction second, using identical instructional materials for the same duration.

Critically, the humane genomics condition did not explicitly define or use the terms social constructionism, racial colorblindness, or genetic essentialism. Nor did it expose students to the anthropological and sociological arguments in favor of social constructionism. These decisions ensure that treatment effects on racial conceptualization cannot be attributed to teaching to the test. Also, when teachers covered monogenic diseases (e.g., sickle cell anemia) during basic genetics, they were asked not to discuss racial differences, as prior research predicts such discussions increase belief in genetic essentialism (*1*). This ensures that any treatment effect on genetic essentialism is not biased by an active comparison condition.

We asked students to respond to validated instruments that were administered before instruction began, after instruction concluded during the first half of the crossover trial, and at the end of the study (Table S2). We measured students': (a) basic genetics knowledge, (b) knowledge of genomics, (c) belief in the genetic discreteness of racial groups, (d) genetic attributions for complex human traits, (e) environmental attributions for complex human traits; (f) belief in racial genetic essentialism, (g) belief in social constructionism, (h) colorblind racial beliefs; (i) emotional response to instruction. Constructs b-f target the humane genomics hypothesis (Ha-e). Constructs g-h assess the RQ. Construct i is used to assess the feasibility of implementing humane genomics in classrooms and construct a is used to assess the quality of instruction in the basic genetics condition. Importantly, our experiment can estimate internally valid treatment effects that are well-powered, unbiased by missing data, and replicable with different models (Tables S3-S9).

RESULTS

To estimate the treatment effect of humane genomics instruction in the first half of the crossover trial, we used a two-level random intercept model with Bayesian multiple imputation for monotone missing data (see SM). To test whether these effects were reproducible in the second half of the crossover trial we estimated a 3-level random effects regression using complete case data of all surveys (Fig. 1).

The results of the first model fully supported each component of the humane genomics hypothesis. Relative to basic genetics, classrooms receiving humane genomics instruction had greater knowledge of genomics (β = 0.50, SE = 0.07, t = 7.08, p < 0.001, 95% CI [0.36, 0.64], $R^2_{level\text{-}2}$ = 2.33%, Fig. 1b, time point 1) and less belief in genetic essentialism (β = -0.24, SE = 0.03, t = -6.91, p < 0.001, 95% CI [-0.31, -0.17], $R^2_{level\text{-}2}$ = 11.53%,

Fig. 1f, time point 1). Humane genomics classrooms also had less belief in racial discreteness (β = -2.57, SE = 0.236, t = -10.89, p < 0.001, 95% CI [-3.04, -2.11], $R^2_{level\text{-}2}$ = 35.88%, Fig. 1c, time point 1) and lower genetic attributions for complex human traits (β = -1.39, SE = 0.14, t = -10.17, p < 0.001, 95% CI [-1.65, -1.12], $R^2_{level\text{-}2}$ = 49.5%, Fig. 1d, time point 1). Furthermore, humane genomics classrooms had greater environmental attributions (β = 1.28, SE = 0.12, t = 10.60, p < 0.001, 95% CI [1.04, 1.53], $R^2_{level\text{-}2}$ = 84%, Fig. 1e, time point 1). All effects were reproduced in the second half of the crossover trial (Fig. 1).

We were careful to avoid the possibility that students in the humane genomics condition were aware that genetic essentialist beliefs are socially unacceptable and thus underreported them (i.e., social desirability bias). First, the curriculum and instruction involved in the humane genomics condition did not define or use the term genetic essentialism. Second, we estimated the presence and magnitude of social desirability bias on the baseline survey in the crossover trial using a method called a list experiment. This method revealed no evidence of socially desirable reporting on the genetic essentialism instrument (SM).

We then explored whether students gravitated toward racial colorblindness or social constructionism (RQ). While there was no effect of genetics instruction on racial colorblindness (95% CI [-0.06, 0.10] Fig 1g.), there was a positive effect of humane genomics instruction on belief in social constructionism after the first (β = 0.35, SE = 0.06, t = 5.69, p < 0.001, 95% CI [0.23, 0.47], $R^2_{level\text{-}2}$ = 9.89%, Fig. 1h, time point 1) and second rounds of instruction (Fig 1h).

Generalizability

We conducted a set of exploratory analyses to identify factors that potentially moderated the treatment effect on genetic essentialism, and then used this information in *The Generalizer* software (*14*), which uses propensity score matching to make inferences about the population of schools to which our sample of schools generalizes. We also conducted a random-effects meta-analysis to assess between-state variation in the treatment effect on genetic essentialism and assessed the clinical significance of this effect by estimating the number needed to treat (NNT) .

We estimate that the reduction in genetic essentialism caused by humane genomics instruction has high generalizability to high schools in 20 states and medium generalizability to high schools in another 19 states (Table S10). These claims are further corroborated by the fact that there was no between state variation in the treatment effect on genetic essentialism (Q = 7.21, p = 0.21). The estimated NNT is 14 (95% CI [8, 131]). Therefore, in the states where these results are highly generalizable, we predict that 2 biology students will change their belief in genetic essentialism when a highly trained biology teacher implements our humane genomics curriculum with fidelity in a class of 30 high schoolers.

Scalability, feasibility

Issues related to scalability and feasibility must be explored before claims of generalizability are believable. First, given concerns about discussing race in schools, it is important to establish that humane genomics instruction is emotionally safe for students. Second, the amount of teacher professional development (PD) it takes to achieve the present results is large. Third, the crossover trial cannot tell us which genomics concepts (i.e., D-F) are most important to learn to reduce essentialism.

The humane genomics intervention used in the crossover trial appears to be emotionally safe, as it did not cause students to experience greater frustration, anxiety, or confusion, compared to the basic genetics instruction. In fact, Students of Color reported significantly lower frustration, anxiety, or confusion while learning humane genomics as compared to basic genetics (SM). There was no self-reported emotional effect for self-identified White students (SM).

To address concerns about scalability, we describe results of an additional pre-registered person-randomized trial with N = 1001 undergraduates in the University of California system that employed 60-minute online lessons, each targeting different combinations of humane genomics concepts (i.e., D-F). We replicated all of the crossover trial results for Hypotheses 1b-e (Table S11), although we did not measure genomics knowledge, racial colorblindness, social constructionism, or emotional responses. This replication study (Table S11) suggests that the genetic essentialism result observed in our crossover trial is driven more directly by learning about patterns of human genetic variation within and between US Census races (concept D) rather than multifactorial inheritance (concepts E & F) and it is not moderated by cultural values that highly correlate with undergraduates' political ideologies (see Tables S12-S13).

These findings suggest that humane genomics instruction can be scaled in a relatively cost-effective, emotionally safe, and time-efficient manner via an online platform that helps students understand patterns of genetic variation within and between US Census races.

DISCUSSION

If teachers move beyond Mendel to instruct students about the complexities of contemporary genomics concepts for the purpose of refuting genetic essentialism, they can help students understand that racial disparities are not unreal, unimportant, or the product of genes. Rather they are socially constructed.

Basic genetics instruction, in contrast, yielded none of these benefits to students even though the teachers in our study produced gains in students' knowledge of basic genetic concepts (Fig 1a). Previous studies (*1*) suggest basic genetics education can increase belief in genetic essentialism when students learn about the racial prevalence of monogenic diseases. The fact that we controlled for this factor likely explains why basic genetics instruction did not affect genetic essentialism beliefs. Thus, the reduction in genetic essentialism is attributable only to humane genomics instruction.

Importantly, as students begin to disbelieve genetic essentialism, they also appear to gravitate toward constructionism. This is important because our intervention did not teach students the definition of constructionism. Therefore, this result is not a consequence of teaching to the test. Instead, it appears that students decided that constructionism was more plausible than colorblindness after learning about race and genomics (i.e., concepts D-F).

We contend that the ideal instructional sequence to reduce genetic essentialism is to introduce students to the models of Mendelian genetics (i.e., mechanisms A-C) and then move beyond these models and highlight their limitations using a humane genomics curriculum (see SM). This prediction is most likely to be accurate when highly trained biology teachers implement this instructional sequence in a high school located in one of the states where our results have high generalizability (Table S10). Whether our results generalize to other states or countries cannot be determined with these data. Also, unless educational standards are reformed to include concepts D-F, it will be difficult to reproduce these results at scale because teachers will not have the curricula, professional development, or institutional support to implement humane genomics instruction. Until then, humane genomics instruction will likely need to be delivered to

teachers and students online via short lessons to achieve scale. Our results suggest this will be effective.

That said, one limitation in how our study modeled business-as-usual biology instruction is that students were not taught about racial differences in the prevalence of monogenic diseases during basic genetics instruction. Such disparities are a component of the basic genetics curriculum (*1*). How this information in the basic genetics curriculum interacts with humane genomics instruction is unknown.

Even so, the decision to omit race from a discussion of the monogenic diseases is better understood as a strength rather than a flaw. In fact, diseases like sickle cell anemia (SCA) are incorrectly described and racialized by the basic genetics curriculum (*1*). For example, SCA occurs across racial groups (*15*) and while sickle cell *trait* is caused by variation in a single gene, the severity of sickle cell *disease* is controlled by several genes and gene-environment interactions (*15*). These genomic facts are not discussed in biology textbooks (*1*) even though such facts offer a more accurate view of SCA (*15*). We predict that teaching about SCA through an educational framework rooted in genomics will not reinforce essentialist views and we think this is the most coherent way to link humane genomics instruction with the content of the basic genetics curriculum.

Coherent learning experiences that are implemented repeatedly can create enduring changes in how people view the world. Several humane genomics learning experiences spread over many years of biology instruction will be needed to reduce the prevalence of genetic essentialist beliefs. Our study demonstrates that if biology instructors move beyond Mendel and toward a more humane genomics education, they can sow the seeds for a more genetically literate and less racially prejudiced society.

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Supplemental material

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Fig. 1A-H. Complete case analysis of treatment effects using three-level mixed-effects regression. Red = Humane then basic; Blue = Basic then humane; Bonferroni adjusted 95% CIs. In the second half of the crossover trial, classrooms receiving humane genomics instruction (relative to basic) increased more in genomics knowledge ($\chi^2 = 12.01$, $p = 0.0005$, Fig. 1b), environmental attributions ($\chi^2 = 55.14$, $p < 0.0001$, Fig. 1e), and belief in social constructionism ($\chi^2 = 32.2$, $p < 0.0001$, Fig. 1h); and decreased more in belief in racial discreteness ($\chi^2 = 56.42$, $p < 0.0001$, Fig. 1c), genetic attributions ($\chi^2 = 111.92$, $p < 0.0001$, Fig. 1d), and belief in genetic essentialism ($\chi^2 = 59.73$, $p < 0.0001$, Fig. 1f).