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Gendered Genetics: How reading about the genetic basis of sex differences in biology textbooks could affect beliefs associated with science gender disparities

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Abstract

The belief that men and women differ in science ability because of genetics contributes to gender disparities in STEM in complex ways. In this field experiment, we explore how the content of the genetics curriculum affects beliefs about science ability through its impact on a social-cognitive bias called neuro-genetic-essentialism. Students (N = 460, 8-10th grade) were randomized to read a genetics text that: (i) explained plant sex differences; (ii) explained human sex differences; or (iii) refuted neuro-genetic-essentialism. After reading, students in the two genetics of sex conditions had significantly greater belief in neuro-genetic-essentialism and the innate basis of science ability compared to students who read the text that refuted neuro-genetic-essentialism. Structural equation modeling of the experimental data demonstrated that the effect of the readings on the belief that science ability is innate was mediated by neuro-genetic-essentialism and this indirect effect was significant for girls but not boys. In turn, the belief that science ability is innate predicted lower future interest in STEM for girls, but not for boys. These findings suggest that learning about human genetic difference is not a socially-neutral endeavor. Implications for mitigating gender disparities in STEM are discussed.

Keywords: Gender disparities in STEM, Genetics Education, Genetic Essentialism
Gendered Genetics: Reading about the genetic basis of sex differences in biology textbooks could affect beliefs associated with science gender disparities

The effect of gender stereotypes on gender disparities in science, technology, engineering, and math (STEM) is a well-established phenomenon (Ceci, Williams, & Barnett, 2009; Leslie, Cimpian, Meyer, & Freeland, 2015; Nosek et al., 2009; Storage, Horne, Cimpian, & Leslie, 2016). Gender stereotypes about intelligence can lead six-year old girls to avoid activities, like science, which they believe are for “really, really smart” children (Bian, Leslie, & Cimpian, 2017). In countries where more people endorse gender-science stereotypes there are significantly larger gender disparities in 8th grade science and math achievement (Nosek et al., 2009). At the graduate level, 29% of the variation in female PhD attainment in STEM is associated with how strongly practitioners in any given field (professors, post-docs, and students) believe that science ability is innate (Leslie et al., 2015). In fields where more practitioners exhibit this belief (e.g. computer science, physics) fewer women earn PhDs (Leslie et al., 2015) and bachelor’s degrees (Storage et al., 2016). But, in fields where fewer practitioners endorse this idea (e.g. neuroscience, molecular biology), more women earn PhDs (Leslie et al., 2015) and bachelor’s degrees (Storage et al., 2016).

In this study, we present data from a person-randomized field experiment to explore how the content of the genetics curriculum affects the belief that science ability is innate through its impact on a social-cognitive bias called neuro-genetic-essentialism. We explore how these effects vary by student gender and we argue that gender disparities in STEM degree attainment may be indirectly influenced by how sex difference is addressed in school genetics. Therefore, we claim that learning about human genetic difference is not a socially-neutral endeavor.
(De)constructing Gender Concepts through School Genetics

Gender is not the same thing as sex (World Health Organization, 2016). Whereas sex categories (male, female, intersex) are defined by scientific interpretations of biological variation, a person’s gender is not based purely in their body (West & Zimmerman, 1987; World Health Organization, 2016). Gender refers to beliefs about the attitudes, activities, and abilities associated with sex categories (Gelman & Taylor, 2000; Lee & Collins, 2010; West & Zimmerman, 1987). Gender beliefs vary between people, across cultures, and over time because they are socially constructed (Diesendruck, Goldfein-Elbaz, Rhodes, Gelman, & Neumark, 2013).

When individuals use biological factors to explain social differences between genders they conflate sex and gender. Relative to individuals who endorse social explanations of gender difference, those who endorse biological explanations of gender perceive more differences between sexes in their interests, appearance, and personality (Martin & Parker, 1995). The tendency to conflate sex and gender is attributable to gender essentialism, or the belief that gender categories are discrete, biological, immutable, and stable (Gelman & Taylor, 2000; Haslam, Rothschild, & Ernst, 2000). Gender essentialism is widespread both culturally and developmentally, influencing how people think about the physical and behavioral traits of men and women (Arthur, Bigler, Liben, Gelman, & Ruble, 2008; Eidson & Coley, 2014; Henrich, Heine, & Norenzayan, 2010; Prentice & Miller, 2007; Smiler & Gelman, 2008). Our study explores a form of gender essentialism called neuro-genetic-essentialism, which is the belief that inherent differences in the genes and brains of men and women are a significant cause of gender differences in behavior, intellect, and abilities (Dar-Nimrod & Heine, 2011; Haslam, 2011).

**Neuro-Genetic-Essentialism**
The higher a person scores on neuro-genetic-essentialism scales, the greater the gender bias they exhibit. Experimental activation of neuro-genetic-essentialism can increase transgender prejudice (Ching & Xu, 2017) and gender stereotyping (V. Brescoll & LaFrance, 2004). When men who score high on sexism scales are led to believe that scientific findings support biological explanations of gender difference (versus that science still debates the biological basis of gender difference) they are: (i) more likely to endorse neuro-genetic-essentialism; (ii) view the treatment of men and women in society as fair; (iii) support the social dominance of men in society; and (iv) support gender discriminatory practices (Morton, Postmes, Haslam, & Hornsey, 2009). When neuro-genetic-essentialism is experimentally induced in women, it can reduce their performance on achievement tests (Dar-Nimrod & Heine, 2006; Moè, 2012) and also increase their tendency to engage in gender self-stereotyping (Coleman & Hong, 2008). Belief in neuro-genetic-essentialism can therefore perpetuate sociocultural mechanisms that cause gender inequality.

Neuro-genetic-essentialism is also a socially-motivated bias that is activated more easily under certain conditions (Keller, 2005; Morton et al., 2009). Men who hold more sexist views will use neuro-genetic ideas to justify gender inequality when they feel a need to validate or protect their self-esteem or social status (Morton et al., 2009). Some women will endorse neuro-genetic-essentialist ideas when they feel a need to rationalize their low status in a social system that they believe is just, fair, and good (V. L. Brescoll, Uhlmann, & Newman, 2013). Thus, individuals will use neuro-genetic explanations when making sense of their position in a social hierarchy.

Scholars contend that schooling a sociocultural context for the development of essentialism (Bigler & Liben, 2007). Adolescents might be motivated to use neuro-genetic-essentialist ideas to explain gender differences in school science either because such ideas provide a quick and simple explanation for gendered patterns in school (e.g. see Keller, 2005; Roets & Van Hiel, 2011), such as gender differences in science interest and performance (Baram-Tsabari & Yarden, 2007, 2009,
2010). Also, adolescents may be developmentally predisposed to construct inherent explanations for observable social patterns (Cimpian & Salomon, 2014; Salomon & Cimpian, 2014). This predisposition could increase the risk that students construct neuro-genetic explanations for gender differences in school science after they learn about the genetic basis of sex difference. Consequently, factors operating within schools, such as genetics education, could contribute indirectly to STEM gender inequality by affecting neuro-genetic-essentialism.

**Genetics Education and Neuro-genetic-essentialism**

There is good reason to predict that neuro-genetic-essentialism is affected by the content of the genetics curriculum. Studies have found that science textbooks, science teachers, and science students conflate sex and gender (Bazzul & Sykes, 2011; Bianchini, 1993; Condit et al., 2003; Preston, 2016; Snyder & Broadway, 2004). In addition, priming experiments have suggested a link between belief in neuro-genetic-essentialism and the content of genetics texts. For example, in a lab experiment with undergraduate women, Coleman and Hong (2008) randomized individuals to read a science text arguing for a biological explanation of gender difference or one arguing for a social explanation for gender difference. Relative to those in the social condition, women in the biological condition exhibited significantly greater endorsement of neuro-genetic-essentialism after reading. They endorsed stereotypically feminine traits to a greater extent, they accepted a greater number of feminine traits as self-descriptive, and they were significantly more likely to engage in gender self-stereotyping.

Earlier experimental work has found that biological and social explanations for gender difference reported in science texts can also influence beliefs about the malleability of human traits. Brescoll and LaFrance (2004) randomized undergraduates to read either a biological or
social explanation for gender differences in the ability to identify plants, or to a no text control condition. Relative to the control condition and the biological condition, those in the social condition exhibited significantly lower belief in the idea that personality traits are fixed.

These two studies show that materials designed to communicate social or biological explanations of gender difference can affect endorsement of neuro-genetic-essentialism (among both sexes), gender self-stereotyping (among women), and the belief that personality traits are fixed, and thus, unchangeable (among both sexes). But, while studies have found that made-up experimental materials designed to affect neuro-genetic-essentialism do affect this construct, we do not know if similar effects occur when adolescents read business-as-usual (BAU) biology curriculum materials that teenagers are regularly exposed to in the United States (US).

**How Science Texts Affect Belief in Neuro-Genetic-Essentialism**

The genetics curriculum on sex differences could activate belief in neuro-genetic-essentialism by resonating with any or all of the following four beliefs associated with neuro-genetic-essentialism: the *uniformity* of categories, the *discreteness* of categories, the *underlying essence* of categories and the *causal influence* of this essence on category members (I. Dar-Nimrod & Heine, 2011; Haslam, 2011; Haslam et al., 2000; Martin & Parker, 1995).

The biology curriculum teaches students about the internal genetic causes responsible for sex differentiation. These genetic causes are then used to explain a variety of phenotypic differences between men and women, such as the increased prevalence of colorblindness in men or auto-immune diseases in women (both X-linked disorders). When describing the genetics of sex difference, textbooks will state that human females are XX and males are XY. These facts about sex difference could resonate with beliefs about *an underlying causal essence*. And, if students
infer that male and female categories are discrete due to the presence or absence of the Y chromosome\(^1\), or if they infer that all men are essentially the same because they share the Y chromosome\(^2\), or if they infer that all women are the same because they all have two X-chromosomes\(^3\), then this would constitute the activation of *discreteness* and *uniformity* beliefs.

If our hypothesis is correct, then it should be possible to affect belief in neuro-genetic-essentialism by exposing students to learning materials that discuss the genetic basis of sex differences not only in humans, but also in non-human species, *like plants*. That is, when students read about the genetic basis of sex differences in plants it could unwittingly affect conceptions of human gender difference if students conflate sex and gender. Thus, learning about the genetics of plant sexes may produce a similar increase in neuro-genetic-essentialist thinking as learning about the genetic basis of human sexes. At the same time, the BAU biology curriculum on human sex differences contains information that could lead to greater increases in neuro-genetic-essentialism than the BAU curriculum on plant sex differences. One such example is the phenomenon of Klinefelter syndrome, which occurs when sperm or egg cells receive an extra copy of the X-chromosome, thereby causing affected women to be intellectually impaired. Learning about Klinefelter syndrome could lead students to infer, mistakenly, that genes cause *unaffected* men and women to differ in intellect, because Klinefelter syndrome associates genetics (the X chromosome) with women and intellectual impairment. Thus, the BAU curriculum on human sex differences could be a more potent trigger of neuro-genetic-essentialism than the curriculum on plant sex.

Neuro-genetic-essentialism could be strengthened over time by biology education because students are repeatedly exposed to this kind of content in the biology curriculum. Models of text processing (Van den Broek, 2010) and research on cognitive heuristics (Tversky & Kahneman,
1974) predict that misconceptions will grow stronger when they are repeatedly activated over time. Consistent with this claim, field experiments have found that when adolescents are repeatedly exposed to information about the prevalence of genetic diseases in racial groups in the biology curriculum, it can cause students to infer that races differ in intelligence for genetic reasons and thus grow in their belief in genetic essentialism of race over a single school quarter (three months) (Donovan, 2014, 2016, 2017). Given these findings, it is plausible that when students learn about the genetics of physical differences between sexes it can increase belief in neuro-genetic-essentialism.

However, when misconceptions are identified as incorrect and challenged with conflicting scientific evidence by informational texts they can be changed (Guzzetti, Snyder, Glass, & Gamas, 1993; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Van den Broek, 2010). A text-based curriculum could counteract neuro-genetic-essentialism by triggering it, labeling it as incorrect, refuting it with evidence, and providing students with a coherent alternative explanation for gender difference (Lewandowsky et al., 2012). Such a curriculum would need to explain that the evidence base for social causes of gender disparities in STEM is strong, but the evidence base for biological causes is contradictory and inconclusive (Ceci et al., 2009). It would need to help students learn about the variability within and between the brains of men and women (see Joel et al., 2015 for the largest study to date) and help them understand that while there are sex differences in the brain (Ngun, Ghahramani, Sánchez, Bocklandt, & Vilain, 2011), these differences do not match the kind of variability predicted by essentialism (Joel et al., 2015). Moreover, they could learn that when people believe that men are better at science because of genetics it can socially construct gender disparities in STEM (Bian et al., 2017; I. Dar-Nimrod & Heine, 2006; Leslie et al., 2015; Moè, 2012). Such messages could reduce neuro-genetic-essentialism by conflicting with ideas of
discreteness, uniformity, and biological causation.

If the BAU genetics curriculum does affect neuro-genetic-essentialism as we hypothesize, then it could also affect theories of science ability that are implicated in interest in science.

Neuro-genetic-essentialism, Theories of Science Ability, and Interest in Science

Implicit person theories are lay theories about the malleability or fixedness of human traits (N. Haslam, Bastian, Bain, & Kashima, 2006). People tend to hold one of two kinds of implicit person theories. Either they believe that trait differences between people (like personality, intelligence, or science ability) are fixed and cannot change (an entity theory), or they believe they are malleable and changeable through effort (an incremental theory) (C. S. Dweck, 2006). Implicit theories are implicated in the development of motivation, because individuals are more motivated to develop their abilities when they believe that ability is malleable (Chen, 2012; C. Dweck, 2008; C. S. Dweck, 2006). The motivational effect of the belief that science ability is innate and thus unchangeable (Chen & Pajares, 2010) is why this belief is implicated in science disinterest.

Importantly, individuals may endorse an entity theory for one human trait and an incremental theory for another (C. S. Dweck, 2006). An individual can therefore be an entity theorist for personality but an incremental theorist for science ability. Thus, it is an open question if exposure to biological or social explanations of gender difference affect implicit theories of science ability among adolescents. Furthermore, studies have not established that exposure to scientific information about sex difference affects implicit theories of science ability through its impact on neuro-genetic-essentialism. But, there is good reason to predict that it does.

Studies have found that entity theories of science ability are conceptually linked to neuro-genetic-essentialism (e.g. Brescoll et al., 2013), because people tend to believe that science ability
is innate and beliefs about innate potential are one component of essentialist thinking (Haslam et al., 2006; Haslam et al., 2000; Rattan, Savani, Naidu, & Dweck, 2012). Also, people tend to believe, mistakenly, that if a trait is innate, then it cannot change because it is genetic (V. L. Brescoll et al., 2013). Unsurprisingly, then, studies have found that genetic concepts are automatically associated with fatalistic thinking (Gould & Heine, 2012). Any change in neuro-genetic-essentialism caused by the genetics curriculum could therefore be associated with a change in implicit theories of science ability. If so, then the impact of the genetics curriculum on the idea that science ability is innate, and thus unchangeable through effort, could be mediated by neuro-genetic-essentialism. Furthermore, this indirect effect could be more pronounced among girls because women are a negatively stereotyped group when it comes to science ability.

**Gender Differences in Science Ability Beliefs and Interest in Science**

From a socially-motivated perspective, girls might have more of a motivation to believe scientific messages that undermine the idea that science ability is innate because these messages protect against the threat of gender stereotypes in the domain of school science. Conversely, girls might have more of a motivation to believe scientific messages that confirm the belief that science ability is innate because such messages may help some girls make sense of why they feel like they do not belong in the sciences. That is, the belief that, “I am not a naturally talented science student” helps to explain why you might feel like a social outsider in science class. Alternatively, the automatic association between genetic concepts and fatalistic thinking (Gould & Heine, 2012) that is primed after reading about biological differences between genders has been found to lead some women to believe that it is inevitable that they will develop gender stereotypic traits (Coleman & Hong, 2008) — one of which is ‘low science ability’. For any combination of these reasons, female theories of science ability may be more responsive to scientific messages about gender difference.
On the other hand, one could see how boys benefit from the culturally prevalent stereotype that their gender group will be good at science. This does not mean that messages about the innate basis of science ability are unharmful to males. Many studies demonstrate that entity theories of academic abilities can be harmful in a variety of different ways to males (e.g. see Blackwell, Trzesniewski, & Dweck, 2007; Chen & Pajares, 2010; C. Dweck, 2008; Good, Rattan, & Dweck, 2012). Yet, studies have found that gender stereotypes about math ability and messages about the innate basis of math ability in the school math environment do not interact to affect men’s sense of belonging in their math classes, but such messages do interact to affect women’s sense of belonging in math, and also their interest in taking more math classes (Good et al., 2012). The indirect effect of the genetics curriculum on theories of science ability and interest in STEM could therefore differ by gender because messages about the genetic basis of science ability are more salient for female belonging in science due to the presence of gender-science stereotypes in the environment of school science.

**Summary of Hypothesized Effects and Theoretical Contribution to Education**

In sum, exposure to a genetic explanation for sex differences in plants or in humans relative to a sociocultural explanation for gender difference should produce significant differences in neuro-genetic-essentialism (H1) and implicit theories of science ability (H2) (Figure 1, path A & C). Furthermore, the effect of such explanations on implicit theories of science ability should be mediated by neuro-genetic-essentialism (Figure 1, paths A-C) and this indirect effect should occur for girls but not boys (Figure 1, path D) (H3). Consequently, implicit theories of science ability should predict future interest in STEM for girls but possibly not for boys (Figure 1, path E) (H4).

To date, these hypotheses remain untested, because Coleman and Hong (2008) studied only women and Brescoll and LaFrance (2004) did not disaggregate their findings by participant
gender. Neither study tested for the indirect effect predicted by hypothesis 3. Educationally, there is also the issue of ecological validity. Previous studies on science text effects on neuro-genetic-essentialism have been conducted in psychology laboratories with undergraduates or with adults (V. L. Brescoll et al., 2013; V. Brescoll & LaFrance, 2004; Coleman & Hong, 2008; I. Dar-Nimrod & Heine, 2006; Morton et al., 2009). This does not diminish their theoretical importance, but it does call into question their applicability to contexts like K-12 education. We test these hypotheses with a three-arm field experimental design of text-based genetics instruction that is randomized at the student level within biology classrooms.

**Methods**

**Sample**

Students (N = 460, 8-10 grade) were enrolled in this study from five different schools in the San Francisco Bay Area. Two of the schools were private (13.3% of sample, the middle school and one high school) and one was same sex (6.9% of sample, all boys). One grade level was sampled in each school. Students with assent and parental consent were enrolled in the study.

Table 1 summarizes school level demographics. The private schools reported no information (NI) on demographics but they served high socio-economic status (SES) students. The academic performance index for public schools in the sample ranged between 640-950. From these schools, a total of eight teachers participated in the study, one of whom was male. Self-identified race was not collected because of IRB issues. Fifty-one percent of students self-identified as female. Given these demographics, our experimental study is really a case study that explores the impact of the genetics curriculum on neuro-genetic-essentialism in racially-diverse, urban high
schools serving both high and low SES students in the San Francisco Bay Area. We provide proof-of-concept for our hypotheses, but our findings are not generalizable.

Experimental Conditions

Overview. We employed a person-randomized trial to explore our research questions. The treatments were delivered to students through Qualtrics™. We randomly assigned individual students to treatment conditions within classrooms and then within self-identified genders using the block-randomization available in Qualtrics™. Our randomization therefore ensures that there is equal gender balance across the three experimental conditions and that school and teacher level variables are not confounded with the individual-level random assignment to treatment. One third of our students were randomly assigned to read about the genetics of plant sex differentiation, another third was randomly assigned to read about the genetics of human sex differentiation, and another third was randomized to a reading that refuted the idea that more men earn PhDs in the sciences because men are genetically smarter than women (see Table 2).

Students read and responded to all treatment materials and survey measures on either a laptop or tablet device. At the start of the study, students were asked to respond to a question that assessed their gender-self-identification (male, female, and non-binary - only 1 student chose this option). After students responded to the gender questions, they responded to pre-test measures of the dependent variables and covariates. Next, students read their randomly assigned text and responded to reading comprehension questions about it. Then, they completed a second survey that included post-test measures of the dependent variables (in the order they are listed below). All of this occurred within a single 45-minute class period. The study took place after students had learned about autosomal inheritance but before they had learned about sex-linked inheritance.
Fidelity of Implementation. The study was introduced by teachers during class time as an introductory activity for a new unit on sex-linked traits. Students were told by their teachers that they would be asked to read a science passage and respond to comprehension questions about it. They were informed that the passages were related to the study being conducted in their classroom and that the materials they would read and respond to presented ideas that would be discussed further during the upcoming unit on sex-linked inheritance. Then, students were given computer devices and asked to create barriers between themselves with their binders, so they would not look at another person’s screen. Teachers told the students that this step was necessary in order to help everyone work quietly and independently on the reading task. Students were then given access to an anonymous Qualtrics™ survey link for their classroom. To ensure that these procedures were implemented consistently across classrooms, each participating teacher discussed how to introduce the study using these procedures with the first Donovan.

Treatments. To ensure that the reading treatments represented consensus biological and social scientific understandings about sex and gender differences each reading was constructed by a person who held a MS degree in biology and a PhD in science education (male). They were then reviewed by a person with a PhD in molecular biology (male), a person who holds a MS in sociology (female), and a person (PhD in science education) with expertise in teaching science to culturally and linguistically diverse populations (female).

The genetics of human sex reading was an adaptation of a high school biology text (BSCS, 2007). The genetics of plant sex reading was designed to be conceptually identical to the genetics of human sex reading. It discussed the same concepts, but in plants. The text that refuted neuro-genetic-essentialism was based on findings from meta-analyses or reviews dealing with sex, gender difference, intelligence, stereotyping, and science achievement (Bian et al., 2017; Ceci et
al., 2009; Coley, 2001; Flynn, 1999; Joel et al., 2015; Voyer & Voyer, 2014) or findings were drawn from studies on science ability beliefs (Leslie et al., 2015; Storage et al., 2016).

Earlier, we posited that neuro-genetic-essentialism could be increased or decreased by the biology curriculum if the content in the curriculum resonated with or refuted ideas such as, inherent biological causation, uniformity, and/or discreteness. In Table 2, we provide abbreviated versions of our three treatment texts to show how they resonated with, or refuted, these neuro-genetic-essentialist beliefs. Full versions of the experimental materials can be found in the supplemental. We conducted a computerized text-analysis of the readings with Compleat Lexical Tutor (2017) to assess the lexical differences between texts. Each text was written at the ninth-grade level, which makes it difficult to argue that any treatment effects are attributable to differences in text difficulty. The genetics of human sex and plant sex readings shared 92% of words whereas the refutational text shared 62% of words with the genetics of human sex reading and 65% with the genetics of plant sex reading. Refer to the supplemental for a more comprehensive description of the three treatment texts, including all results from our computerized text analysis.

**Dependent Variables**

**Reading comprehension.** To measure treatment compliance and explore if treatment effects were due to differences in reading comprehension, each text was paired with 12 true-false questions about the main ideas in the text. The questions for the genetics of plant sex and human sex readings were conceptually identical and only differed in the presence or absence of questions about Klinefelter syndrome or polyploidy. All other questions were lexically identical and differed only because they either asked about genetic differences between male and female humans (human condition) or differences between male and female plants (plant condition). The questions
associated with the refutational text mentioned sex categories (male, female) and gender categories (man, woman). Reading comprehension scores can vary from 0 to 12.

**The uniformity and discreteness of gender groups.** To target the neuro-genetic-essentialist belief that all men (or all women) are genetically uniform and that men and women are genetically discrete (see Martin & Parker, 1995), we used a variation of the perceptions of human genetic variation instrument by Donovan (2017). The instrument targets perceptions of the amount of genetic variation between genders relative to the total variation perceived within and between genders. The instrument has two item types: within group genetic variation and between group variation items. Higher scores indicate that students perceive more genetic differences between men and women relative to the differences perceived both within men and within women (Cronbach’s $\alpha = 0.93$). The variable can take on any value between 0 - 100%

**Inherent genetic causes for trait differences between genders.** Research indicates that US citizens believe that human traits and behaviors are caused either by genes, the environment, or by free will (Jayaratne et al., 2009). To measure genetic attributions for trait differences between men and women, we estimated the respective weight that students gave to genetic explanations for trait differences between genders relative to the weight they gave to environmental factors or free will. We created five items that asked students to explain how much they thought gender differences in (i) body structure and function; (ii) brain structure and function; (iii) intelligence; (iv) science ability; and (v) PhD attainment were caused by (a) Differences in the social environments outside of male and female bodies (nurture); (b) Differences in the genes inside male
and female bodies (nature); or (c) Differences in the personal choices men and women make in their lives (free will).

For example, students were told “studies demonstrate that men and women differ in the structure and function of their bodies (Joel et al., 2015; Ngun et al., 2011).” In your opinion, how much do men and women differ in the structure and function of their bodies because of: (i) the social environment outside their bodies; (ii) the genes inside their bodies; (iii) their personal choices? Then they were presented with three slider bars which could be moved between any value ranging from 0-100 which were anchored with the statements “0% of the differences in body structure and function between men & women” and “100% of the differences in body structure and function between men & women.” Students could move the slider bars independently to represent the relative weight they assigned to genetic, social-environmental, and free-will causes. By dividing the genetic causes by the sum of the genetic, environmental and free-will causes, we estimated a “genetic attribution” (Sheldon, 2018) for gender differences on each of the six traits, that ranged between 0-100% (Cronbach’s $\alpha = 0.81$). Refer to the supplemental for more on the psychometrics of this measure.

**Gender essentialism.** Because we developed or adapted the previous two measures, we also included a validated instrument of gender essentialism (Rhodes & Gelman, 2009) in our survey that included eight items on a scale of 7 (Strongly Agree) to 1 (Strongly Disagree) (Cronbach’s $\alpha = 0.81$). Higher scores indicate greater endorsement of gender essentialism.

**Composite measure for neuro-genetic-essentialism.** To reduce the type one error rate, we created a composite measure by adding z-score transformations of the three previously described variables (Cronbach’s $\alpha = 0.78$). This is our main dependent variable. Higher scores on this variable indicate greater neuro-genetic-essentialism. For example, as theory would predict,
this composite measure was positively correlated ($r = 0.35, p < 0.001$) with an item from the modern sexism scale (“Society has reached the point where women and men have equal opportunities for achievement”) (Swim, Aikin, Hall, & Hunter, 1995).

**Implicit theories of science ability.** This construct was measured with the subset of items in the field-specific-ability beliefs scale (Leslie et al., 2015) targeting a person’s personal beliefs about the intransigence and innateness of science ability. The items were adapted for adolescents by substituting the phrase “Personally, I think that when it comes to science” for the phrase “Personally, I think that being a top scholar of [discipline]” (published anchor). This change reflects that the relevant social setting for adolescents is ‘science class’ and not ‘being a top scholar in the field of …’. An example of an item in this scale was “Personally, I think that if you want to succeed in science hard work alone won’t cut it— you need to have an innate gift or talent.” Responses were anchored with 1 (strongly disagree) and 7 (strongly agree) (Cronbach’s $\alpha = 0.5$). Higher scores indicate greater endorsement of entity theories of science ability.

**Future interest in STEM.** We measured this construct with the items in Kosovich, Hulleman, Barron, and Getty (2015): How interested are you in learning more about science, math, or technology?; How interested are you in taking more classes in science, math, or technology?; How interested are you in learning about careers in science, math, or technology? Items were anchored with 1 (not interested) and 6 (completely interested) (Cronbach’s alpha = 0.93).

**Student-Level Covariates**

**The inherence heuristic.** Cimpian and Salomon (2014) argue that psychological essentialism emerges from a cognitive bias which they call the inherence heuristic, or the tendency to explain patterns in the world using the inherent properties of the entities that make up the pattern.
We used a subset of seven items in the inherence heuristic scale (Salomon & Cimpian, 2014) (Cronbach’s alpha = 0.79) (1-strongly disagree to 7-strongly agree) as a covariate in our modeling.

**Statistical Modeling of Hypothesis Tests**

To test our confirmatory hypothesis about the impact of the genetics curriculum on neuro-genetic-essentialism (H1) and our exploratory hypothesis about its impact on implicit theories of science ability (H2) we used two different fixed-effects regressions. To analyze how neuro-genetic-essentialism changed over time in response to treatment we used a 2-level marginal model with pre-tests and post-tests nested within students. We regressed neuro-genetic-essentialism onto indicators for treatment status, time (pre= 0, post = 1), and Time x Treatment interactions, including a vector of covariates for each student’s inherence heuristic scale score and indicators for self-identified gender, sex of science teacher, and school (Equation 1).

*Equation 1:*

\[
\text{Neuro-genetic-essentialism}_i = \beta_0 + \beta_1(\text{Human-sex-text}) + \beta_2(\text{Refutational-text}) + \beta_3(\text{Time}_i) + \\
\beta_4(\text{Time}_i \times \text{Human-sex-text}) + \beta_5(\text{Time}_i \times \text{Refutational-text}) + \beta_6(\text{inherence}) + \beta_7(\text{Female}) + \\
\beta_8(\text{TeacherSex}) + \beta_9(\text{School1}) + \beta_{10}(\text{School2}) + \beta_{11}(\text{School3}) + \beta_{12}(\text{School4}) + \varepsilon
\]

As we report in our results, the estimates from equation 1 demonstrated that the refutational text had significantly lower neuro-genetic-essentialism scale scores than both the genetics of human sex text and genetics of plant sex texts. However, the human and plant sex conditions did not differ significantly in neuro-genetic-essentialism. Therefore, to test for treatment effects on implicit theories of science ability (H2) we collapsed the two genetics text conditions (human and
plant) into a single condition and compared them, as a single experimental condition, to the refutational condition. Using an endpoint analysis with school fixed effects, we regressed implicit theories of science ability onto indicators for treatment status and a vector of covariates for each student’s inherence heuristic scale score, pre-test score on the dependent variable, and indicators for self-identified gender, sex of science teacher, and school (Equation 2).

Equation 2:

$$\text{Implicit theories of science ability}_i = \beta_0 + \beta_1(\text{Refutational-text}_i) + \beta_2(\text{Inherence}_i) + \beta_3(\text{Pre-test}_i) + \beta_4(\text{Female}_i) + \beta_5(\text{TeacherSex}_i) + \beta_6(\text{School1}_i) + \beta_7(\text{School2}_i) + \beta_8(\text{School3}_i) + \beta_9(\text{School4}_i) + \varepsilon$$

For the exploratory tests of hypotheses 3 and 4, we use a structural equation model (SEM) that directly tests whether the theoretical model in Figure 1 achieves a better fit among girls or boys, after controlling for individual differences at baseline in neuro-genetic-essentialism, implicit theories of science ability, and future interest in STEM. We further test the robustness of the mediation effects in H3 by following guidelines in the literature for a Sobel-Goodman test of mediation augmented with bootstrapping (N = 5000 replications) (Preacher & Hayes, 2004).

**Standard Errors and Type I error**

Because the randomization occurred at the student level within classrooms there was no methodological reason to adjust standard errors for classroom level correlations between student outcomes. Furthermore, an analysis of AIC, BIC, and likelihood ratio statistics indicated that model fit was not improved by adding a random effect for treatment across schools or classrooms. Consequently, we report intention to treat estimates at the person level. To reduce the type I error
rate in our confirmatory tests of neuro-genetic-essentialism (H1), we report Bonferroni adjusted
\( p \)-values for all pairwise comparisons between treatments (\( N = 3 \) comparisons \( \alpha/3 = 0.016 \)). Per
guidelines in Schochet (2008), we do not adjust \( p \)-values for type I error in our exploratory tests
of effects on implicit theories of science ability (H2), or in our models of hypotheses 3 and 4.

**Baseline Equivalence**

There were no significant differences between conditions in the relative proportion of male
and female students (\( \chi^2 (2) = 0.06, p = 0.97 \)) and a MANOVA indicated that conditions did not
differ significantly at baseline in science ability beliefs, future interest in STEM, inheritance-
heuristic scale scores, or in neuro-genetic-essentialism (Pillai’s trace statistic = 0.01, \( F(8,880) =
0.74, p = 0.66 \)). Additionally, after treatment, students in the three experimental conditions did not
differ in their comprehension of the three different texts (\( F(2, 457) = 1.0, \ p = 0.35 \)), making it
difficult to argue that reading comprehension confounded our treatment effect estimates.

Only 6.3% of students had missing data for any variable and patterns of missing data did
not vary by treatment (\( \chi^2 (8) = 2.07, p = 0.98 \)). Because data was missing at random, we report
treatment effects without imputation. However, all of our results can be replicated with imputed
data and the marginal model we use to test hypothesis 1 will produce unbiased estimates of
treatment effects when data is missing at random (Rabe-Hesketh & Skrondal, 2008).

**Results**

**Hypothesis 1**

We predicted that exposure to a genetic explanation for sex differences in plants or in
humans relative to a sociocultural explanation for gender difference should produce significant
differences in neuro-genetic-essentialism. Consistent with our predictions, Figure 2 shows that students assigned to the genetics of plant sex and genetics of human sex conditions both exhibited a significant increase in neuro-genetic-essentialism ($\beta = 0.53$, $SE = .148$, $p = 0.001$, Bonferroni $p < 0.05$, 95% CI [.24, .82]). In contrast, the students in the refutational condition showed a significant decline in neuro-genetic-essentialism relative to the other two conditions ($\beta = -1.47$, $SE = .199$, $p = 0.001$, Bonferroni $p < 0.05$, 95% CI [-1.86, -1.08]). Students in the plant sex and human sex conditions did not differ significantly in their change over time ($\beta = 0.17$, $SE = .216$, $p = 0.413$, 95% CI [-.24, .60]).

After treatment, students in the refutational text condition had significantly lower endorsement of neuro-genetic-essentialism than students in the genetics of plant sex ($\beta = -1.52$, $SE = .195$, $p = 0.0001$, Bonferroni $p < 0.05$, 95% CI [-1.9, -1.13]) or human sex conditions ($\beta = -1.74$, $SE = .19$, $p = 0.0001$, Bonferroni $p < 0.05$, 95% CI [-2.1, -1.3]). But after treatment, students in the plant sex and human sex conditions did not differ significantly ($\beta = 0.22$, $SE = .195$, $p = 0.243$, 95% CI [-.15, .61]). None of the above effects varied significantly by gender ($ps > 0.1$).

We hypothesized that these effects would occur because the texts either resonated with or refuted essentialist ideas such as discreteness, uniformity, or inherent biological causes. To explore that hypothesis further, we report effect sizes on each subcomponent of our composite measure of neuro-genetic-essentialism. Comparing the refutational text to the plant or human sex conditions, treatment effects were largest for genetic attributions (Cohen’s $d = 0.76$), then perceptions of genetic variation (Cohen’s $d = 0.5$), and then the gender essentialism scale (Cohen’s $d = 0.23$). Looking within the genetic attributions measure, treatment effects were largest for differences in body structure and function (Cohen’s $d = 0.62$), then brain structure and function (Cohen’s $d = 0.61$), then intelligence (Cohen’s $d = 0.48$), then science ability (Cohen’s $d = 0.4$), and finally PhD
attainment (Cohen’s $d = 0.28$). Among subcomponents of the perceptions of genetic variation instrument, treatment effects were equally large for variation within men (Cohen’s $d = 0.26$) and variation within women (Cohen’s $ds = 0.26$), but there was no effect on variation between men and women (Cohen’s $d = 0.003$). This suggests that the readings caused differences in neuro-genetic-essentialism by targeting beliefs about inherent biological causes and genetic uniformity.

**Hypothesis 2**

We predicted that exposure to a genetic explanation for sex differences in plants or in humans relative to a sociocultural explanation for gender difference challenging neuro-genetic-essentialism would produce significant differences in theories of science ability. While implicit theories of science ability did not differ between the genetics of plant sex or genetics of human sex conditions ($p = 0.59$), students in the refutational condition exhibited significantly lower scores on the implicit theories of science ability scale compared to the plant and human sex conditions ($\beta = -0.17, SE = .082, p = 0.035, 95\% CI [-.33, -.012]$) suggesting that the refutational condition caused a decrease in the belief that science ability is innate and/or that the two genetics texts on sex differences caused an increase in the belief that science ability is innate (Figure 3).

To further explore what drove these effects we analyzed the data with a variation of the marginal model in Equation 1, above. Initially, we found that there was no pre-post change in the belief that science ability is innate among students (male and female) assigned to either of the two sex conditions, but there was a marginally significant decline in entity theories of science ability among students assigned to the refutational text relative to the two sex conditions ($\beta = -.174, SE = .092, p = 0.061$). However, when we disaggregated the effect by student gender we found a significant increase in entity theories of science ability among girls assigned to the plant or human
sex texts relative to those assigned to the refutational text ($\beta = .28$, SE = .12, $p = 0.017$) and no significant pre-post change for girls in the refutational condition ($\beta = -.09$, SE = .097, $p = 0.34$). For boys, there was no statistically significant treatment effect on pre-post changes in theories of science ability comparing the refutational condition to the two sex conditions ($\beta = -.06$, SE = .14, $p = 0.69$). Thus, main effects on science ability beliefs appear to be driven by girls who read one of the two genetics texts on sex differences and then increased in the belief that science ability is innate. Boys’ implicit theories of science ability were apparently not affected by the experiment.

**Hypotheses 3 and 4**

We predicted that the effect of scientific explanations on implicit theories of science ability would be mediated by neuro-genetic-essentialism and that this indirect effect might occur only among girls (Figure 1, H3). Also, we predicted that implicit theories of science ability would predict future interest in STEM among girls, but possibly not among boys (Figure 1, H4). Figure 4 summarizes the results of a SEM analysis that explored hypotheses 3 and 4.

Our SEM reached conventional levels of model fit (CFI = 0.992, RMSEA = .054, SRMR = 0.031) (Hooper, Coughlan, & Mullen, 2008). However, an analysis of group-level fit statistics demonstrated that our SEM fit girls in our sample well ($\chi^2(6) = 5.24, p = 0.513$), but not boys ($\chi^2(6) = 14.242, p = 0.027$) (Figure 4). A Sobel-Goodman test of mediation augmented with bootstrapping further supported this claim, demonstrating that, for girls, 52% of the total treatment effect on implicit theories of science ability was mediated by neuro-genetic-essentialism (bootstrapped indirect effect: $\beta = -0.12$, bias corrected 95% CI [-0.23, -0.04]). However, the indirect effect for boys was not significant. Because the indirect effect of treatment on implicit theories of science ability occurred only for girls, hypothesis 3 is supported. Consistent with
hypothesis 4, implicit theories of science ability were significantly and negatively associated with future interest in STEM in girls ($\beta = -0.09, \text{S.E.} = 0.04, p = 0.025$), but not in boys ($\beta = -0.03, \text{S.E.} = 0.04, p = 0.48$) (Figure 4). In the pre-test data (Figure 4), neuro-genetic essentialism and implicit theories of science ability were also significantly and positively associated ($\beta = 0.11, \text{S.E.} = 0.03, p = 0.0002$) for girls. Both were also negatively associated with future interest in STEM for girls in the pre-tests (Entity theories: $\beta = -0.26, \text{S.E.} = 0.075, p = 0.0006$; Neuro-genetic-essentialism: $\beta = -0.145, \text{S.E.} = 0.041, p = 0.0003$). However, there were no significant associations between any of these variables among boys in our sample either prior to, or after reading the experimental texts.

**Discussion**

In summary, exposure to a genetic explanation for sex differences in plants or in humans relative to a sociocultural explanation for gender difference produced significant differences in neuro-genetic-essentialism and implicit theories of science ability, thus supporting hypotheses 1 and 2. Furthermore, the effect of such explanations on the belief that science ability is innate was mediated by neuro-genetic-essentialism and this indirect effect was significant for girls but not boys, thus supporting hypothesis 3. Finally, implicit theories of science ability measured after exposure to the readings predicted future interest in STEM for girls but not for boys, thus supporting hypothesis 4. Consequently, the confirmatory and exploratory hypotheses laid out in Figure 1 were supported by the findings of our experimental design laid out in Figure 4. Our results can be explained by the hypothesis that gendered ideas about science ability are affected by genetics education because people conflate sex and gender due to neuro-genetic-essentialism.

**Hypothesis 1**
In our content analysis of the treatment materials, we demonstrated that the genetics of plant sex and human sex conditions both provided the inputs necessary to activate essentialist beliefs like uniformity, discreteness, and inherent biological causation (Table 2). We also showed that our intervention text directly refuted those same ideas. When we decomposed the treatment effects of our confirmatory analyses we found that effect sizes comparing the refutational condition to the other two conditions were greatest for the items targeting beliefs about inherent biological causes and the uniformity of men (or women). Our confirmatory results can therefore be explained by a single mechanism. The human and plant sex conditions provided the inputs to activate essentialist beliefs about inherent biological causation and the uniformity of same sex individuals, whereas the refutational text challenged those same ideas.

The reading on the genetics of sex differences in plants may have produced an equivalent increase in neuro-genetic-essentialism as the reading on the genetics of sex differences in humans (Figure 2) because psychological essentialism is a prevalent bias that affects how people reason about non-human categories like plants (Medin & Atran, 2004) and also gender categories (Park, Banchefsky, & Reynolds, 2015). Since people conflate sex and gender because of essentialism (Valdes, 1996), the reading on plant sex differentiation activated gender essentialism, because it primed gender in the context of genetics by using sex labels like male and female.

Replication studies could further test this mechanism by including a survey only control condition and also a control condition that includes a genetics text that does not mention sex differences in any species. If there is elevated essentialism in the plant or human sex conditions compared to both of these control conditions, then this would suggest that our mechanism is correct. Another line of research that could further test this hypothesis would be to explore whether the activation of neuro-genetic-essentialism increases after students learn about sex-differences in
animal species. If our plant findings are replicated when students learn about sex differences in other non-human species, then this would suggest that these effects are driven by a conflation of sex and gender that arises out of gender essentialism. If replicated in this way, then the issue we are raising here could be larger than the content in the genetics curriculum on humans or plants.

If we think more broadly than biology education, these findings raise questions about how informational texts used in other subjects might affect gender conceptions during adolescence. Social studies texts are a logical venue to explore how discussion of gender difference affects belief in essentialism, especially social studies texts written to address specific dimensions of the history, psychology, sociology, or anthropology dimensions of the C3 Framework for Social Studies State Standards (Swan et al., 2013). Studies that investigate how exposure to information in the social studies curriculum and information in the genetics curriculum interact to affect the development of neuro-genetic-essentialism during high school could further our understanding of how gender conceptions are constructed through education. To gain a more complete picture of this phenomenon future studies should also explore the moderating role of teacher gender beliefs, instructional design, and school context. Because we did not explore these moderating factors, our confirmatory findings are limited in their generalizability to genetics education.

**Hypotheses 2, 3 and 4**

We have demonstrated that the content in the human genetics curriculum can impact the belief that science ability is innate and that this effect may be mediated by neuro-genetic-essentialism in girls in our study (Figure 4). Although the evidence for our mediated effect would have been stronger if we had shown a time-lagged mediation, scholars have argued that entity theories of science ability are conceptually linked to neuro-genetic-essentialism (e.g. Brescoll et
al., 2013). This link is likely because people tend to: (i) believe that science ability is innate and beliefs about innate potential are one component of essentialist thinking (N. Haslam et al., 2006; Nick Haslam et al., 2000; Rattan et al., 2012); (ii) believe, mistakenly, that if a trait is innate, then it cannot change because it is genetic (V. L. Brescoll et al., 2013); (iii) automatically associate genetic concepts with fatalistic ideas (Gould & Heine, 2012). Given that our claims of mediation are theoretically warranted, then why was the treatment effect on theories of science ability mediated by neuro-genetic-essentialism in girls, but not in boys?

Arguably, the indirect effect was constrained to one sex because females labor under negative stereotypes about their intelligence and science ability in school science (Dasgupta & Stout, 2014), whereas males do not. The social motivation to endorse either a genetic or a social explanation of science ability could therefore be amplified for girls in the domain of school science because this is a venue where late adolescent women feel low social belonging (Dasgupta & Stout, 2014). For comparison, in math classes, where girls encounter stereotypes similar to those they face in science, studies have found similar effects (Good et al., 2012). Messages about the innate basis of math ability and the stereotype that women have less math ability than men interact to reduce a sense of belonging in math among females, but not males (Good et al., 2012). However, the message that math ability can be developed through practice can protect women from these social belonging effects and prevent their erosion of interest in taking more math classes (Good et al., 2012). Our results are consistent with these findings from undergraduate math education.

We found evidence that neuro-genetic essentialism and theories of science ability were significantly and positively associated among girls in our sample prior to the experiment and there were no significant associations between either of these variables among boys in our sample before the experiment (Figure 4). Furthermore, entity theories of science ability and neuro-genetic-essentialism were both negatively associated with interest in STEM among girls in our sample, but
these variables were not related in boys. Thus, the significant indirect effect for girls (and not boys) could be a consequence of these variables being more tightly linked for girls before the experiment began, arguably because of each variable’s relationship to a sense of social belonging in the environment of school science (or rather lack thereof).

We cannot be sure that social belonging is a contextual factor associated with the indirect effect we observed, because we did not measure it. Future studies should explore this interaction as well as the domain specificity of these effects. For example, if the content of the genetics curriculum influences the construction of genetic beliefs about gender difference, then does this effect spill over into how girls (or boys) make sense of their math or engineering abilities? And, if so, then how does this spill over effect occur? A logical study to explore these questions could involve leveraging variability in the timing of when students learn genetics. One could estimate if entity theories of math ability and social belonging in math, measured in math class, exhibit time-lagged changes after students learn about the genetics of sex in biology class. In essence, the main issue to explore moving forward is whether and how these effects persist when students walk out of the science classroom into new social and educational contexts.

Although future studies may find that the effects reported here are context dependent, it is important to note that our results do converge with prior experiments conducted in other contexts. Previous studies have found that exposure to a biological explanation of gender difference (relative to a sociocultural explanation) produce differences in gender self-stereotyping (Coleman & Hong, 2008) and implicit theories of personality (V. Bresco & LaFrance, 2004) in a psychology lab.

What makes our findings interesting is how they also diverge from these two previous studies. To our knowledge, this is the first experiment to demonstrate that implicit theories of science ability can be impacted by informational texts through their impact on neuro-genetic-
essentialism. This finding is novel because individuals can simultaneously hold entity theories of personality and incremental theories of science ability. Consequently, there was no guarantee that our experiment would affect implicit theories of science ability in the same way that previous experiments have affected implicit theories of personality (V. Brescoll & LaFrance, 2004).

Our work also diverges with the findings of Brescoll and LaFrance (2004). They found that entity theories of personality were driven down by exposure to a sociocultural explanation of gender difference because, they argued, it primed students to make situational rather than dispositional attributions for behavior. Unlike Brescoll and LaFrance (2004), we found evidence that entity theories of science ability increased among girls who read one of the two genetics texts. Thus, our results are more in line with the idea that the two genetics of sex readings drove an increase in dispositional attributions for behavior among girls. One possible reason for this discrepancy could be that Brescoll and LaFrance (2004) did not disaggregate their results by participant gender. For instance, at first, when exploring the main effects of treatment, we replicated the effects in Brescoll and LaFrance (2004) by showing a decline in entity theories among students assigned to the refutational condition. It was only when we estimated this effect among girls alone that we found the opposite effect: an increase in entity theories of science ability driven by the two genetics of sex conditions rather than a decrease driven by the refutational text.

Future research needs to resolve this divergence. It could be that implicit theories of science ability and personality respond differently to sociocultural or genetic explanations of gender difference. Because we did not measure implicit theories of personality in our study, we cannot evaluate this proposition. But if beliefs about science ability and personality are linked together because they share a common etiology in neuro-genetic-essentialism, as prior work suggests (e.g.
see Martin & Parker, 1995), then the divergence between our study and Brescoll and LaFrance (2004) needs a better explanation.

Our results suggest that biological explanations of sex difference can increase entity theories of science ability and probably also personality because of their impact on neuro-genetic-essentialism. This is possible because genetic concepts and fatalistic ideas about human abilities are implicitly associated in the minds of individuals (Gould & Heine, 2012) and therefore genetic ideas about gender could lead individuals to believe that they will inevitably develop gender stereotypic traits (Coleman & Hong, 2008). If this fatalistic-essentialist schema is activated within the sociocultural context of the science classroom, then it could be more damaging to girl’s future interest in science because messages that increase the belief that science ability is innate could make some girls feel like they do not belong in science. Conversely, when evoked, this same schema could also make some girls more aware that they will encounter students and teachers in future science classes who hold gender biases about female science ability. An increased awareness of the gender biases that women face in science could also erode a sense of belonging in science among some girls. In line with both of these arguments, we detected a negative correlation between entity theories of science ability and future interest in STEM among girls, but not among boys in both the pretest and posttest data (Figure 4).

In summary, the findings in Figure 4 are in line with our more general claim that neuro-genetic-essentialism is implicated in gender disparities in STEM fields because of its relationship with implicit theories of science ability and future interest in STEM. Consequently, educational factors that affect the development of neuro-genetic-essentialism could exacerbate or attenuate STEM gender disparities.
Conclusion and Limitations

Over the last century, academics and lay-persons alike have regularly made the claim that if gender difference is a natural product of genetic or neurological factors, then women can be excluded from STEM careers because they are not genetically ‘fit’ for such careers (see Damore, 2017 for such an argument and Molteni & Rogers, 2017 for a critique of Damore). This study tentatively suggests that the way we teach about sex differences in the genetics curriculum could be one factor, among many, that affects the prevalence of this belief. In turn, our findings offer evidence for the hypothesis that gender disparities in STEM could, in part, be affected indirectly by the content of the genetics curriculum even when the focus of the curriculum is not related to cognitive abilities. When the content of the human genetics curriculum challenges neuro-genetic-essentialism, it could reduce the belief that science ability is innate and thus reduce gender inequality in STEM. But, when the content of that curriculum activates neuro-genetic-essentialism it could augment this belief and further entrench gender inequality in STEM.

The limitations of this study mean that we do not yet have the definitive evidence to prove that the content of the genetics curriculum affects gender disparities in STEM. There is still ambiguity about the mechanism in our experiment, there is the possibility that our results were influenced by Solomon effects (i.e. that the pretest measures interacted with the treatments to produce these effects and without the pretest the effects would be different), and our study lacks external validity. We also acknowledge that our assessment of reading comprehension was crude and that future studies might find that these effects are confounded by comprehension. We found no evidence of confounding induced by reading comprehension, because scores on our comprehension assessment did not differ across experimental conditions after students were exposed to our treatment texts. A lexical analysis of the texts also demonstrated that each text was
written at the same reading difficulty (9th grade). Furthermore, our treatment groups were baseline equivalent, suggesting that there was an even distribution of students of different reading levels within each arm of our experiment. While the internal validity of our study was not apparently jeopardized by reading comprehension, it is possible that the external validity of these results will vary across students that differ in reading level or across schools that vary in their approach to literacy-based instruction in science. Replication studies could test this moderating claim.

Even though our findings are limited in external validity, they are nevertheless consistent with our hypotheses and they converge in interesting ways with past studies (e.g. V. Brescoll & LaFrance, 2004; Coleman & Hong, 2008; Martin & Parker, 1995). All of this leads us to conclude that future research may well establish that gender disparities in STEM are indirectly affected by the way that genetics education discusses sex and gender difference. To prove this larger claim, the results of this study need to be replicated in other demographics and extended by other studies. Future studies must rule out alternative explanations for these results (e.g. by using double-blinded trials to rule out Hawthorne effects) and longitudinal experiments, retrospective cohort studies, or prospective cohort studies are needed to show that a significant amount of the variation in gender participation in STEM is associated with the way that we teach about gender and sex in biology. Those studies would also need to be supplemented with content analyses that explore how genetics curricula resonate with, or refute, neuro-genetic-essentialism. Additionally, we still need to study how enduring these effects are and whether instruction makes them stronger or longer lasting. For example, would a more constructivist learning experience make a difference compared to a reading? Would repeated exposure to these ideas over one or more years make a difference?

Although these lines of evidence do not yet exist, our work does suggest that learning about human genetic difference is not a socially-neutral endeavor. Previous field experiments have found that content in the genetics curriculum can affect racial biases among adolescents (Donovan, 2014,
2016, 2017). This experiment suggests that genetics education could also affect gender bias. If genetics education does indeed affect social cognition, then we need to do more research that explores how to teach genetics in a more socially responsible manner.

**Notes**

1 Even though autosomal DNA and the X chromosome make them similar.

2 Even though men have different variations of that chromosome.

3 Even though women have different variations of the X-chromosome.

4 To further illustrate this point, consider the texts used in prior experiments. These studies have asked participants to read about the genetic causes of gender differences in the ability to identify plants (V. Brescoll & LaFrance, 2004) or behavioral, personality, and cognitive differences between genders (Ching & Xu, 2017; Coleman & Hong, 2008; Morton et al., 2009). Although psychology undergraduates may encounter genetic explanations for psychological differences between genders, biology students in the K-12 pipeline do not. Rather, from seventh grade onwards, biology students are regularly exposed to genetic explanations for physical differences between sexes, but not psychological differences. From an educational perspective, then, we do not know if learning about the genetic basis of physical differences between sexes unwittingly affects beliefs about gender difference.

5 For example, for history (D2.His.4.6-8., D2.His.5.6-8., D2.His.3.9-12), for psychology (D2.Psy.2.9-12., D2.Psy.8.9-12., D2.Psy.9.9-12., D2.Psy.10.9-12., D2.Psy.12.9-12.), for sociology (D2.Soc.2.9-12., D2.Soc.12.9-12., D2.Soc.13.9-12., D2.Soc.14.9-12., D2.Soc.15.9-12., D2.Soc.16.9-12.) and for anthropology (Concepts 1 & 3).
References


**Table 1.** Demographics of Sampled Schools

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<th>% American Indian/Alaskan Native</th>
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<th>% Black</th>
<th>% Hispanic</th>
<th>% Native Hawaiian/Pacific Islander</th>
<th>% White</th>
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<th>Co-Ed</th>
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Note: Free and reduced-price lunch (FRPL), Co-educational school (Co-Ed), No information (NI)
Explained the field specific ability beliefs hypothesis and the data supporting it (Leslie et al., 2015; Storage et al., 2016) (refute inherent biological cause). It explained that someone might believe that science ability is innate because they think that intelligence is caused only by a person's genes and not by the efforts that individuals put into learning. But, studies show that a person’s intelligence can grow over a lifetime (Flynn, 1999). And, because intelligence can change, a person’s intelligence is not fixed in place by their genes. Instead, social factors play a big role in a person’s intellectual development in the sciences (Ceci et al., 2009) (refute inherent biological cause).

The text returned to the opening questions stating that men do not earn more science degrees than women because their biology makes them better at science. Rather, this belief makes science learning environments threatening to women (refute inherent biological causes and discreteness).
Figures

Figure 1. Theoretical Model of Study
Figure 2. Main effects of treatment on neuro-genetic-essentialism
Figure 3. Main effects of treatment on entity theories of science ability
Figure 4. SEM results disaggregated by gender

a. SEM results for girls

b. SEM results for boys

Note: Randomized text type is an indicator variable that takes on a value of 1 if a student was assigned to the refutational text and a value of 0 if a student was assigned to the genetics of plant sex or genetics of human sex text. Standardized coefficients shown in figure. Not significant (NS), * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$