How Do Students Critically Evaluate Outdated Language That Relates to Gender in Biology?

Ryan D. P. Dunk,[†]* Sarah J. Malmquist,[‡] Kristina K. Prescott,[‡] Sharday N. Ewell,[†] Jeremiah A. Henning,[§] and Cissy J. Ballen[†]

[†]Department of Biological Sciences, Auburn University, Auburn, AL 36849; [‡]Department of Biology Teaching and Learning, University of Minnesota, Minneapolis, MN 55455; [§]Department of Biology, University of South Alabama, Mobile, AL 36688

ABSTRACT

Cisheteronormative ideologies are infused into every aspect of society, including undergraduate science. We set out to identify the extent to which students can identify cisheteronormative language in biology textbooks by posing several hypothetical textbook questions and asking students to modify them to make the language more accurate (defined as "correct; precise; using language that applies to all people"). First, we confirmed that textbooks commonly use language that conflates or confuses sex and gender. We used this information to design two sample questions that used similar language. We examined what parts of the questions students modified, and the changes they recommended. When asked to modify sample textbook questions, we found the most common terms or words that students identified as inaccurate were related to infant gender identity. The most common modifications that students made were changing gender terms to sex terms. Students' decisions in this exercise differed little across three large biology courses or by exam performance. As the science community strives to promote inclusive classrooms and embrace the complexity of human gender identities, we provide foundational information about students' ability to notice and correct inaccurate language related to sex and gender in biology.

INTRODUCTION

Throughout its 400 year history in the Western world, science has been dominated by white, cisgender men; while they do not form a homogeneous population, general trends in scientific values, approaches, and conclusions are inevitable whether science is conducted by a subset of privileged individuals (Elliott, 2017; McGee, 2021; Costello *et al.*, 2023). This is true in any field but is particularly prevalent in sciences due to the myth of the scientist as an objective party (McComas, 1996). However, as the United States has become more diverse, STEM (Science, Technology, Engineering, and Mathematics) fields have been slow to change the demographic dominance of white cisgender men (Chang and ChanTzeng, 2020; Casad *et al.*, 2021). This has far-reaching implications for what science is valued and conducted, but little research has focused on how this impacts curricular materials that communicate fundamental concepts in biology.

While many identities are underrepresented and misrepresented in science, we focus on widespread cisheteronormative depictions in life sciences textbooks. Specifically, we focus on norms and assumptions that confound gender identity with sex as assigned at birth (Hobaica *et al.*, 2019). In textbooks, manifestations of cisheteronormativity can be seen in descriptions of inheritance patterns or human reproduction: for example, pedigrees which often reduce couplings to binary identities and use gendered language (i.e., man and woman) rather than biological classification (i.e., male and female; Hales, 2020). While textbooks are only one aspect of instruction in biology, they offer a static representation of norms in a discipline and present an opportunity to evaluate the messaging – both explicit and implicit – being received by individuals who

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*Address correspondence to: Ryan D.P. Dunk (rzd0065@auburn.edu)

are new to the field. Textbooks and other educational materials have been highlighted as potential agents of change that promote learning and inclusion for students who hold diverse identities (Hales, 2020; Zemenick *et al.*, 2022). Examining the implicit biases present in scientific fields and analyzing pedagogical approaches may help to mitigate the impact of that historical legacy (e.g., Segura-Totten *et al.*, 2021).

Constant exposure to cisheteronormative depictions of humans in biology textbooks can invalidate the experiences of students who identify with a gender identity different than the one typically associated with their sex as assigned at birth. Hereafter we will use *transgender* as an umbrella term to describe transgender, nonbinary, genderfluid, gender queer, agender, and other gender variant individuals (Davidson, 2007; GLAAD, 2023; PFLAG, 2023; Human Rights Campaign, 2023), though we recognize that this definition includes individuals who do not identify specifically as transgender (Matsuda, 2023).

In this study, we explore cisgendered language in introductory biology textbooks and investigate student awareness of this language using hypothetical textbook questions. Below, we define sex, gender, and biological essentialism. Then, we present queer theory as our theoretical lens to explore this topic in greater detail, followed by a brief summary of previous work on the experiences of transgender individuals in the United States. Finally, we explore the ways in which sex and gender are commonly conflated in biology educational settings.

Defining Sex, Gender, and Biological Essentialism

Sex is an unclear concept in biology, referring both to the physical traits of individuals and their reproductive behavior. Nonhuman organisms display a fascinating diversity of mating systems related to sex (Roughgarden, 2013), or may not possess sexes at all. For example, in ray-finned fishes, sequential hermaphroditism – in which animals switch from egg to sperm production based on environmental contexts – is common (Avise and Mank, 2009). Fungi have “mating types” rather than sexes; some taxa have thousands (Kothe, 1996). Despite this diversity, cisheteronormativity and a human-centered worldview has led to some relatively myopic perceptions of sex (Monk *et al.*, 2019; Ah-King, 2022).

Across the natural world, sex is used as a categorization system that frequently includes more than two phenotypes and is usually related to gamete size or compatibility. In contrast, when focusing on humans, sex often refers to a binary categorization of male or female based on an overlapping suite of traits including physical characteristics, chromosomes, hormone levels, gene expression, and gamete production. However, there are not clean cutoffs for any of these traits that delineate male or female sex (Štrkalj and Pather, 2021). Further, though gamete production is often the defining trait of sex differentiation in biology, we label people based on their similarity to other males or females, even if they do not produce gametes, as in childhood, old age, or any number of medical conditions. When we are concerned with organisms other than humans, the tendency to cluster individuals and ignore rare variation is not often considered harmful, though it may lead to careless exclusion of potentially valuable insights. But in humans, even beyond the limitations above, intersex individuals are relatively common. While difficult to get a fully accurate count due to many intersex conditions being underdiagnosed, the most recognized figure suggests that 1.7% of humans may be born with variations that classify them as intersex in some form (Fausto-Sterling, 2000), a figure close to the percent of individuals worldwide who are born with red hair (Cunningham *et al.*, 2010). This diversity is often erased in the classroom as instructors simplify our biological complexity (Casper *et al.*, 2022).

In contrast, gender is a social concept. Most commonly, gender is referred to using terms that reaffirm the sexual binary (in English, man or woman). However, additional gender designations exist in human societies, both currently and in the past (Herdt, 1994). Identities that exist outside of the sex and gender binaries have existed throughout history both in the western world (DeVun, 2021) and worldwide, including a large variance of identities found in the indigenous tribes of the Americas (Robinson, 2020), the Samoan fa’afafine (Kanemasu and Liki, 2021), south Asian hijra (Singh and Kumar, 2020), and many others. Thus, while physical presentation determined by sex plays a role in the gender that someone may be perceived as, gender exists well beyond the bounds of biology, and needs sociological understandings to appreciate (Risman *et al.*, 2018).

Viewed generally, biological essentialism is a series of beliefs in substantive differences between groups based on biological characteristics that are enduring, fixed, and prototypical (Greene, 2021). When applied to gender, essentialist thinking asserts that binary gender distinguishes two homogenous groups of people who differ physically, cognitively, and behaviorally because of their affiliation in discrete categories that is fixed at birth as a matter of natural law (Harden, 2023). Although essentialism in all forms has been repeatedly shown to be biologically inaccurate (Block, 1995; Herd *et al.*, 2019; Harden, 2023; Madole and Harden, 2023), essentialist ideas remain pervasive in society and higher education (Dar-Nimrod and Heine, 2011).

Queer Theory as a Theoretical Framework

Queer theory is a series of analytical approaches which seek to disrupt the cisheteronormative social assumptions of sex, gender, and sexuality (Jagose, 1996; Snyder and Broadway, 2004). Heteronormativity was first understood to refer to a cultural assumption of heterosexual attraction and sexual activity as “normal” (Sumara and Davis, 1999) but has been expanded to integrate the assumption of cisgender identity as well (Schilt and Westbrook, 2009). Throughout this paper, we will often use “cisheteronormative” to refer to this linked concept, but may use both cisnormative or heteronormative where appropriate, and we trust that the reader will keep in mind the ways in which these concepts are closely linked.

In this work, we adopt queer theory as our broad theoretical framework and challenge the cisheteronormative assumption that equates sex and gender. In doing so, we characterize gender as a social phenomenon or construct outside the realm of biological study, while simultaneously acknowledging the impact biological sex has on gender expression and societal expectations and experiences (Fausto-Sterling, 2019). We seek to understand the ways in which gender is misidentified in the context of undergraduate biology and explore alternate language that is more accurate for use in a biological classroom setting. Broadly, our approach attempts to divorce biological sex from the social aspect of gender as a refutation of those who use misunderstood biological notions as a means of upholding hegemonic systems of oppression (Kincheloe and McLaren, 2005). This approach builds on previous work that uses queer theory to examine curriculum and pedagogical materials (Sumara and Davis, 1999; Snyder and Broadway, 2004; Rodriguez and Pinar, 2007; Reimers, 2020; Parise, 2021).

Transgender Identity in the United States

One of the most maligned groups in recent years has been transgender and gender nonconforming individuals – violence against transgender individuals has more than doubled in recent years (2020 and 2021) compared with just 5 years prior (FBI Uniform Crime Reporting Program, 2023). These individual acts of violence occur alongside state-sponsored dehumanization, represented in legislation directed against transgender individuals. The frequency of this political violence has reached an all-time high, with over 400 bills introduced from January to May 2023 alone – more than in the previous 4 years combined (Shin *et al.*, 2023). This increased bigotry comes at a time when the number of individuals in the United States (U.S.) who openly identify as transgender is growing. Younger individuals are more likely to identify as transgender; a Pew Research Center survey found 5.1% of adults aged 18–30 identify as transgender or nonbinary as compared with 1.6% of adults aged 30–49 and 0.3% of adults aged 50 and over (Brown, 2022). Another study identified that U.S. youth (aged 13–17) were the most likely to identify as transgender (Herman *et al.*, 2022).

Transgender Identity in Biology

Those who practice and teach biology possess values, implicit biases, and stereotypes that result from exposure to disciplinary norms and social contexts. Therefore, curricula in biology communicate worldviews that align with those norms, such as heteronormativity and cisnormativity (Casper *et al.*, 2022; Costello *et al.*, 2023). With an increasing number of individuals identifying as transgender, ensuring our curricular materials are accurate and affirming of transgender identities becomes increasingly important (Cooper *et al.*, 2020). While the biology classroom is not the only place where changes need to be made to affirm and support transgender individuals, it does have an undeniable role (Cooper *et al*., 2019; Busch *et al*., 2022). Transphobic rhetoric tends towards a biological essentialist approach (Pearce *et al.*, 2020; Henderson, 2022; Lu and Jurgens, 2022), which asserts that gender differences are rooted in fixed sex differences. Belief in gender essentialism has been empirically linked to lower support for legal rights for transgender individuals (Roberts *et al.*, 2017; Wilton *et al.*, 2019), and antitransgender legislation assumes a biological basis for gender, for example in legislation regarding transgender sport participation (Desjardins *et al.*, 2022) or bathroom use (Murib, 2020). Thus, failure to challenge biological essentialism potentially leads to the misuse of biology in support of harmful ideologies (Bickford, 2024). Examples include the use of essentialist views to support harsher criminal justice outcomes (Kraus and Keltner, 2013; Tawa, 2023), involuntary sterilization (Stubblefield, 2007; Murray, 2022), and even genocide (Keller, 2005). Biologists have a healthy tradition of speaking out against the misuse of biology to support essentialist viewpoints (e.g. , Lewontin *et al.*, 1984; Gould, 1996), but it is also important to remember the ways in which biologists have historically contributed to gender essentialism (e.g., Martin, 1991; Schiebinger, 2004). Thus, research understanding and challenging the roots of educational norms that support essentialism should be of interest and import to all biologists.

Confusion of Sex and Gender in Biology

Undergraduate biology courses typically cover a wide variety of organisms, but often focus on human processes (e.g., Pobiner, 2012) because students (especially future medical professionals) find this taxon particularly engaging. Consequently, topics that relate to human identities are commonly encountered in biology classrooms, underscoring the importance of efforts toward more inclusive pedagogy (Dewsbury and Brame, 2019). The lack of clarity in our understanding of sex in biology contributes to confusion over the important differences between sex and gender. However, the tendency for instructors and students to confound these terms sets up the potential for *content-related* microaggressions and alienation (Casper *et al.*, 2022).

Evidence shows that textbooks replicate the tendency to confound sex and gender terminology. An analysis of high school statistics textbooks found that conflation of sex and gender was a common occurrence, and no examples discussed nonbinary individuals or nonheterosexual relationships (Parise, 2021). An early study of high school biology textbooks either excluded nonheterosexual behavior entirely (in five out of eight cases), or only mentioned it in terms of the disease AIDS (Snyder and Broadway, 2004); this study did not specifically mention transgender individuals in its findings, but it did include them in the methods. A study of Swedish high school biology texts found promotion of harmful stereotypes and outdated language regarding transgender individuals (Junkala *et al.*, 2022), and a recent review of high school biology textbooks found no differentiation between sex and gender in their discussion of humans (Donovan *et al.*, 2024). College evolution textbooks have been shown to replicate human cultural biases in their presentation of female animals as comparatively smaller, weaker, and more responsible for parental care than male individuals (Fuselier *et al.*, 2018). In a study of four Anatomy and Physiology textbooks, King *et al.* (2021) found that all conflated sex and gender both implicitly and explicitly. While previous research has detected the presence of flawed or outdated language in textbooks, there is no work, to our knowledge, that documents the extent of students' ability to notice this content in their (often required) course materials. Therefore, the current work, which seeks to understand what students notice in biology curricular materials, is an important contribution to describing the roots of bias and related societal challenges. However, it is worth underscoring that we should work to make textbooks' language more inclusive whether or not students notice because it is ethical and increases accuracy of the materials.

Research Questions

In the absence of updated, common language surrounding sex and gender in the context of biology education, we set out to document students' ability to critically evaluate outdated or noninclusive language in hypothetical biology textbook questions. We addressed three specific questions:

1. Regarding how students identify and change non-inclusive language in hypothetical biology textbook questions:

a. What are the most common edits students make to gender-associated language when it is presented to them?
b. Do students make edits to gender-associated language more often when the term gender is used?

2. Does the tendency to edit gender-associated language differ in frequency between courses or by course performance?

We predicted that college biology textbooks would use gender-associated language when discussing biological sex in humans and that students would be better able to identify inaccurate language that used the term "gender", compared with "man", "woman", "boy", or "girl." We thought that students would be more likely to critique inaccurate language if they were students who were taking a more advanced course, as they would likely have had more exposure to these differences. We also thought that students would be more likely to critique inaccurate language if they achieved a higher grade on their course final, as the difference between sex and gender was discussed in all courses studied.

METHODS

Positionality

We believe that acknowledgement of our identities is an important aspect of contextualizing our study at all phases. We all identify as Biology Education Researchers and represent a variety of career stages, including an associate professor in biology education research, two assistant professors in biology, a teaching associate professor in physiology, a teaching assistant professor biology, and a biology education postdoctoral researcher. We combine to represent decades of experience both conducting STEM education research and teaching undergraduate biology courses. Among us, we have representation of individuals who hold queer gender, queer sexual orientation, and cishet identities, as well as Black and white racial identities. At least one of us identifies as a first-generation student and scholar. These identities, and others not discussed, provided us with unique and limited perspectives when exploring student responses.

Textbook Analysis

Our first step in developing our realistic textbook questions was to review a convenience sample of six recently published introductory biology textbooks for language related to sex and gender (Singh-Cundy and Shin, 2015; Urry *et al.*, 2017; Houtman *et al.*, 2018; Hillis *et al.*, 2019; Mader and Windelspecht, 2019; Morris *et al.*, 2019; for the remainder of the text, we refer to these as Textbooks 1–6 to avoid singling out individual textbooks and underscore the widespread prevalence of our results across curricular materials). We then examined all sample problems from the text in the chapters related to meiosis and/or genetics and looked for questions that used human examples to match the questions of interest we hoped to create. In these textbook sections, we identified any textbook problem(s) that used terms associated with gender and transcribed the question verbatim (Box 1).

We analyzed six recently published introductory biology textbooks for content related to sex and gender. When we looked in the glossary and index of each book for definitions of the terms sex or gender, we observed that none of the books defined gender, though one referred to "gender determination" in the index and in-text when discussing sex determination. One textbook defined sex in the glossary, by referring to the entry on sexual reproduction.

Next, we looked at all practice questions in the chapters related to meiosis and genetics. Specifically, we examined each question with human examples to determine the presence of gender-associated language. Each textbook studied had gender-associated language in these practice problems. Some of this gendered language is common in biology, such as calling parents and offspring "mother" and "daughter", and we have not included those examples here. We have also not included examples where gender-associated language was used but had no influence on possible interpretation, for example, in sample problems discussing blood type. However, other practice questions use much less precise gendered terms that have no biological definition ("woman", "man", "boy", or "girl") when discussing aspects of biological sex (Box 1). A complete list of gender-associated terms that we identified in sample problems contained in the chapters on meiosis and genetics in biology textbooks can be found in the Supplemental Materials (Supplemental Table S1).

Incorporating Realistic Textbook Questions

Based on observations of actual biology textbook questions, we created two sample questions intended to test students' discrimination between terms associated with sex and gender (Box 2). We chose this method to avoid the results being too closely tied to any one textbook, as it is a pervasive issue. These questions were added as extra credit (completed = credit) questions on the final exam for three courses at a large, public R1 university in the midwestern United States (taught by S.J.M. and K.K.P.). The courses were: A) a nonmajors' introductory-level biology of sex course ($N = 223$); B) a nonmajors' introductory-level human biology course ($N = 135$); and C) a majors' human and animal physiology course ($N = 171$; Table 1). Students in course A all received question 1, while students in courses B and C were randomly shown either question 1 or question 2. Notably, all courses covered and emphasized human biology, used similar definitions of sex and gender, and explicitly distinguished the terms from one another. Our anonymized database included student responses and student performance on their final exam.

We designed two questions that used gender-associated terms to explain the biological concepts of sex and parentage (Box 2), using the examples from the reviewed textbooks as a guide. We created novel questions (King *et al.*, 2023) to highlight numerous specific instances where gender-associated terms might appear. Students were asked to read these and make edits in a manner that would make the proposed question more accurate, with "accurate" being defined in the question as "correct; precise; using language that applies to all people." We used this definition to help students think about inclusive language without using the term "inclusive" specifically, which could potentially be polarizing and/or leading. By avoiding that specific term, we believe these results are more likely to reflect students' general understanding and awareness.

Coding

We used repeated rounds of inductive coding to classify how students modified the sample textbook questions. To create

BOX 1. Examples of gender-associated terms in biology textbook sample problems. We observed many examples of cisheteronormative assumptions in the sample textbooks, and here present some examples where those assumptions may lead to inaccurate answers

Textbook 1

"Red-green color blindness is inherited as an X-linked recessive trait. Two parents with normal color vision have a child who is red-green color-blind. Is the child a boy or a girl? What are the genotypes of the child's parents? If the parents, what is the probability that the child will be red-green color-blind?"

"A man with a rare Mendelian disorder has a father and grandmother who are also affected. No one else in his family, including his two children, is affected. What does this indicate about the inheritance of the disorder?"

"Explain why men are more commonly affected by X-linked recessive traits than women are."

"Explain why men with a rare X-linked recessive trait seldom have affected sons."

Textbook 2

"How many copies of each gene are found in the diploid cells of a woman's body?"

"Create a Punnett square to illustrate the offspring that could result if Samuel had children with a noncarrier woman. What is the probability that a son would have XSCID? What is the probability that a daughter would be a carrier of XSCID?"

A question matching terms related to fetal testing for genetic disorders consistently referred to a "woman's uterus." Question was too long to include direct quote.

Textbook 3

There were no sample problems where gender-associated terms contradicted with sex-associated terms in a way that would affect the answer.

Textbook 4

"In North America, the X-linked form of red-green color blindness affects about 8 percent of men, but only 0.5 percent of women. Why is this condition more common in men?"

"Can a woman have X-linked red-green color blindness? If so, how? Draw a three-generation pedigree of a woman with this condition. Include the woman's parents and her five children (three girls and two boys), and assume that her husband is not color-blind."

Textbook 5

"A man with a mitochondrial disease mates with a woman who does not have a mitochondrial disease. What is the probability that their offspring will be affected?"

Textbook 6

"Neither Tim nor Rhoda has Duchenne muscular dystrophy, but their firstborn son does. What is the probability that a second child will have the disease? What is the probability is the second child is a boy? A girl?"

"A man with hemophilia (a recessive, sex-linked condition) has a daughter without the condition. She marries a man who does not have hemophilia. What is the probability that their daughter will have hemophilia? Their son? If they have four sons, what is the probability that all will be affected?"

"Pseudohypertrophic muscular dystrophy is an inherited disorder that causes gradual deterioration of the muscles. It is seen almost exclusively in boys born to apparently unaffected parents and usually results in death in the early teens. Is this disorder caused by a dominant or recessive allele? Is its inheritance sex-linked or autosomal? How do you know? Explain why this disorder is almost never seen in girls."

these codes, we blocked each student response into three areas that involved gendered language that we intentionally included in our sample textbook questions. For example, for the first question, these blocks were simply the three sentences in the sample question. We then created a spot for each sentence to determine what style of edits were made to the gendered language. R.D.P.D. and an undergraduate research assistant created the initial codes by reading a subset of responses and beginning to define and generalize the edits made. We thus created initial codes that summarized and generalized the potential edits made by students to the sample textbook problems, creating a draft codebook consisting of codes and example edits. As coding continued, we compared all newly created codes to previously coded sections and confirmed that all instances were properly coded. In this way, R.D.P.D. coded all responses ($N = 353$ student responses). After this round of coding, R.D.P.D. finalized a set of examples in the draft codebook. This codebook was used by a secondary coder (S.N.E.) to code a portion of the responses (9.3%; 33 student responses). R.D.P.D. and S.N.E. compared codes and achieved an initial intercoder reliability of 89%. Discrepancies were mostly due to presence of multiple codes and were resolved to full agreement via conference. After conference, R.D.P.D. conducted a final review of all coded responses to align them with the finalized codebook. For our coding, we found 23 unique codes, but due to low number of instances for many, here we present data for the seven most common codes (Table 3).

Analyses

We measured the frequency of changes in specific sections of the sample textbook questions and coded the types of changes students made. We included individuals in our analysis who made no changes but indicated agreement with the passage, but removed individuals who wrote nothing about the question (no response). Nonresponse differed across course and question from 0 to 11%. We calculated percent frequencies of our main code of interest ("Gender to Sex") and compared frequencies between courses and by final exam performance within courses. We split students into two approximately equal sized groups, comparing students with 80% or greater performance versus students with performance lower than 80%.

BOX 2. Instructions and textbook sample questions provided to students for editing. Sites that are bolded and underlined show words and terms that students frequently edited, and are the focus of our study. We use emojis adjacent to the sites throughout the manuscript to assist in readers' recall of student edits, but the emojis (as well as the bold/underlined text) were not featured on the version presented to students

Instructions

Imagine you have been hired to make language in biology textbooks more accurate ("accurate" is defined as correct; precise; using language that applies to all people). How might you change the following textbook practice question?

Question 1

"A **woman and her husband** are expecting a baby. The **mom** passes on an X chromosome and the **dad** passes on a Y chromosome. What will be the **gender** of the baby?"

Question 2

"Your friend tells you she knows that there is a 50% chance her baby will be a **boy** because the baby's **gender** is always determined by the X or Y sex chromosome it gets from the **dad**. Is your friend correct? Why or why not? "

RESULTS

Research Question 1: Question Edit Sites and Content

We created two hypothetical questions similar to the content in introductory biology textbooks. These questions were related to the genetics of sex determination in human infants and each question had gender-associated language used in three locations. We analyzed these sites (Box 2) in each question for edits students made with an emphasis on terms related to gender (e.g., woman, dad). We found that students commonly edited the content (Table 2). The most edited site referred to "the gender of the baby" (Table 2; Question 1; "Baby Gender"). Between 72–90% of students across the courses identified this site as inaccurate. The second most edited site referred to "the baby's gender" (Table 2; Question 2; "Baby Gender"). Between 75–77% of students across courses identified this site as inaccurate. The least edited site referred to "the X or Y sex chromosome it (the baby) gets from the dad" (Table 2; Question 2; "Dad"). Between 31–37% of students across courses identified this site as inaccurate.

After establishing *where* students made most of their edits, we explored *how* they edited each site in the sample passages. We did this by developing codes that characterized the types of changes students made (Table 3). For the sake of brevity, we only present codes if over 10% of students reported them in at least one site in one course. Seven codes achieved that threshold value (Tables 3 and 4). Four of those codes directly changed terms related to gender (e.g., rather than a man and woman are having a child, a student would suggest "an XX individual and an XY are expecting a child"), and three codes were unrelated to gender (e.g., rather than assume a heteronormative couple are expecting a baby, a student would suggest "a couple is expecting a baby"; Table 3). The most prevalent code was "Gender to Sex", which was used when students suggested the sample question change a gender term to a sex term. For example, students recommended changing "man" to "male." Some students changed terms in a way that described an individual's chromosomes, gonads, or anatomy beyond sex organs, changing "man" to "an XY individual." Students also made edits that were unrelated to gender-associated terms, for example, incorrectly editing the question to say that the mother passes down

TABLE 1. Comparative information about each course. Course A was a nonmajors' course on the evolution and biology of sex; Course B was a nonmajor's course on human biology and biomedical ethics; Course C was an advanced majors' comparative human and animal physiology course. Values represent percentages

		Course A	Course B	Course C
Year	First-year	27.80	36.92	0.00
	Second-year	35.87	26.15	7.60
	Third-year	23.77	20.00	9.94
	Fourth-year or Above	12.56	16.92	82.45
Major	Biology	0.44	3.70	98.25
	Other STEM majors	14.35	28.15	1.17
	Non-STEM	52.02	31.85	0.00
	Undeclared	33.18	32.59	0.58
Gender	Cis Man	34.33	45.24	N/A*
	Cis Woman	59.20	50.00	N/A*
	Transgender*	4.98	2.38	N/A*
Race/Ethnicity	White	59.07	63.01	62.44
	Asian	23.55	17.92	27.70
	Black	7.14	5.78	6.10
	Hispanic	5.79	8.09	2.35
	Native American	1.35	1.73	0.00
	Native Hawaiian or other Pacific Islander	0.00	0.58	0.00

*Transgender here is used in the same manner as throughout the text, and includes a variety of noncisgender identities reported. Self-reported gender information was not available for Course C.

TABLE 2. Frequency of site edits across all courses

Question 1			
Site	Course A	Course B	Course C
Woman/Husband	36%	53%	52%
Mom/Dad	44%	49%	59%
Baby Gender	72%	79%	90%
No Change	9%	13%	5%
No Response	11%	0%	0%
Question 2			
Site	Course A	Course B	Course C
Boy		54%	58%
Baby Gender		75%	77%
Dad	N/A	31%	37%
No Change		6%	6%
No Response		3%	2%

"an XX chromosome" (in normal circumstances, each parent will only pass on a single sex chromosome, as stated in the sample question).

While a variety of these edits are in line with our theoretical framework, we felt the "gender to sex" code (Table 2) best captured the change we were interested in and was also the most numerically prevalent. Thus, we focused our remaining questions on the patterns of that code across edit sites and courses.

Gender to Sex Frequency

We explored the overall frequency of edits when students changed gender-associated language to sex terms, which we categorized as "Gender to Sex." We investigated which gender-associated terms were changed most often. We found that "Baby Gender" in both Question 1 and Question 2 were more frequently associated with this code than other sites in our proposed questions (Figure 1). In both questions, these were the only sites where the term "gender" appeared ("What will be the gender of the baby?"/"…the baby's gender is always determined by…"). The other site where the "Gender to Sex" code was frequently observed was at "Boy" in Question 2, which was also associated with a newborn baby ("…her baby will be a boy…"). This code was less frequently applied across the other three sites (<20%), though no site had an absence of this code. These less frequent sites had the gender-associated terms "woman", "husband", "mom", and "dad."

Research Question 2. Differences by Course and Performance

Next, we explored how these codes were applied differently between courses. We looked at the frequencies of the Gender to Sex code in both Question 1 and Question 2 (Figure 2). We found few differences between the courses. In Question 2, Course C had slightly higher percent changes across all three sites, but never a greater difference than around 10%. In Question 1, we found even closer frequency between all three courses at "Woman/Husband" and "Mom/Dad", but at "Baby Gender" (where gender is specifically mentioned), we found that course B was less likely than either Course A or C to have changed "gender" to a sex-associated term. Specifically, we found that 63% of individuals in Course A made this edit, and 74% in Course C, compared with 43% in Course B.

Finally, we explored the difference in code frequency based on final grade performance. Again, we investigated this difference across all sites in both Question 1 and Question 2 (Figure 3). At all sites, we found that students awarded higher

TABLE 3. Description and examples of codes found

Codes	Description	Example student edit
Gender to Sex	A term indicating gender (e.g., man) was changed to a term referring to biological sex (e.g., male).	*A woman and her husband are expecting a baby* → "A female and a male are expecting the birth of a child"
Gender to Chromosomes	A term indicating gender (e.g., man) was changed to a term referring to sex chromosomes (e.g., an XY individual).	*A woman and her husband are expecting a baby* → "An XX individual and an XY are expecting a child"
Gender to Gonads	A term indicating gender (e.g., man) was changed to a term referring to reproductive sex organs or "primary sex characteristics" (e.g., an individual with testes).	*What will be the gender of the baby?* → "Which primary sex characteristics will the baby likely develop?"
Gender to Anatomy	A term indicating gender (e.g., man) was changed to a term referring to an anatomical structure beyond reproductive organs (e.g., "sex characteristics").	*the dad passes on a Y chromosome* → "the individual with male sex characteristics passes on a Y chromosome"
Inclusive Parents	Parent terms were changed to not assume a married, heterosexual cisgender couple.	*A woman and her husband are expecting a baby* → "A couple is expecting a baby"
Chromosome Clarification	An edit was made to the description of the chromosomes passed from parent to child. Most often, this edit incorrectly suggested 2 sex chromosomes were passed on per parent.	*The mom passes on an X chromosome and the dad passes on a Y chromosome* → "The mom passes on two X chromosomes and the dad passes on an X and a Y chromosome"
Term Clarification	An edit was made to terms to make them seem more "scientifically correct" (e.g., changing "baby" to "child").	*The mom passes on an X chromosome and the dad passes on a Y chromosome* → "The maternal parent passes on an X chromosome and the paternal parent passes down a Y chromosome."

TABLE 4. Codes reflecting changes at each question site across courses A-C. We only present codes which achieved over a 10% prevalence at a site in at least one course. Many student edits may have included more than one code at each site, so percents may not sum to 100

Site	Codes	Course A	Course B	Course C
Question 1				
Woman/ Husband	Gender to sex	14%	19%	15%
	Gender to Chromosomes	1%	6%	12%
	Inclusive Parents	13%	19%	17%
Mom/ Dad	Gender to Sex	13%	9%	19%
	Chromosome Clarification	11%	2%	4%
	Inclusive Parents	7%	19%	11%
Baby Gender	Gender to Sex	63%	43%	74%
	Gender to Gonads	<1%	15%	6%
	Gender to Anatomy	0%	13%	2%
	Gender to Chromosomes	0%	6%	12%
Question 2				
Boy	Gender to Sex	N/A	18%	27%
Baby Gender	Gender to Sex	N/A	42%	50%
	Term Clarification	N/A	15%	8%
Dad	Term Clarification	N/A	10%	6%

grades (defined as those who were awarded an 80% or better on their final exam) were more likely to make "Gender to Sex" edits than students awarded lower grades. This difference was not large in most cases (Figure 3), but was more pronounced at "Baby Gender" on Question 1 ("What will be the gender of the baby?") and at "Boy" on Question 2 ("…her baby will be a boy…").

DISCUSSION

Our study confirmed the presence of inaccurate gender-based language in introductory biology textbooks and investigated the ability of undergraduate biology students to evaluate similar curricular materials for the presence or absence of inclusive language. We found that when students were presented with a novel question and a prompt to make it more accurate, students commonly modified gender-associated terms (e.g., "man", "woman", "boy", and "gender") to be sex-associated (e.g., "male", "female", and using "sex" instead of "gender"). These changes more frequently occurred with the term "gender" compared with gender-associated descriptor terms (e.g., "woman"). Students changed gender-associated terms to sex-associated terms in similar frequencies across courses, and we found a consistent, but not large, difference between students who were awarded higher grades compared with students who were awarded lower grades, with students who were awarded higher grades making edits more often. Taken together, this indicates that either not all students were aware of a difference between sex and gender, or they were not able to recognize gender-associated terms as incorrect in a biological context. Here, we explain our findings related to student assumptions regarding sex and gender as well as the role curricular materials have in enforcing those beliefs.

Student Perceptions of Sex and Gender are Shaped before Entering the College Classroom through Social Context and Language

Why did some students fail to recognize and correct gender-associated terminology in biology materials? One possibility may be student assumptions based on their reading of the prompt. In our examples, all instances of "gender" were referring to infants. It is possible that students were more likely to feel a need to correct the language surrounding infants who have not been socialized into a gender identity versus adults who have. That is, students may assume that the mom in our questions identifies as a woman and mother. However, we specifically asked students to use "language that applies to all people" and this assumption ignores that gender can manifest in a variety of ways that do not necessarily align with sex (Westbrook & Schilt, 2014). The inability of students to modify gender-associated descriptor terms may also be due to differing conceptualizations regarding sex, gender, and inclusion. Within the question prompt, the terms sex and gender were intentionally not mentioned, and no terms were operationalized. Thus, students were left to make corrections based on their interpretations of how language could be better made to "(apply) to all people." While students were given descriptions and definitions of sex, gender, and the difference between the two during the semester, all students entered the classroom with gender-based stereotypes and cis-heteronormative assumptions derived and internalized from various social and educational contexts (Westbrook & Schilt, 2014; Koenig & Eagly, 2014; Donovan *et al.*, 2019; Hentschel *et al.*, 2019; Ahnesjö *et al.*, 2020; Stuhlsatz *et al.*, 2020).

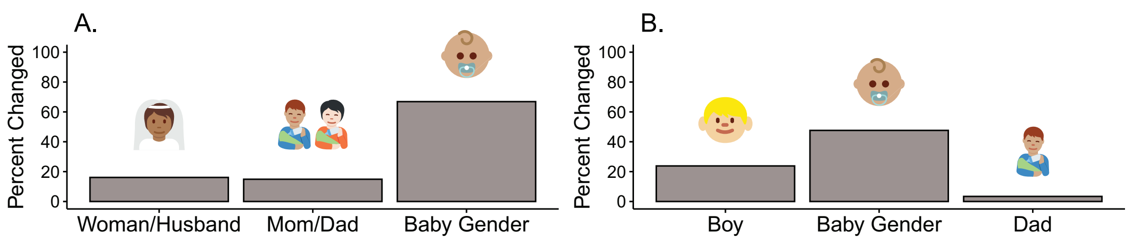

FIGURE 1. Edits of gender-associated terms to sex-associated terms at all three sites in each question. Question 1 is displayed on the left (A), and Question 2 on the right (B). Across questions, students most frequently noticed and changed the site about a baby's gender.

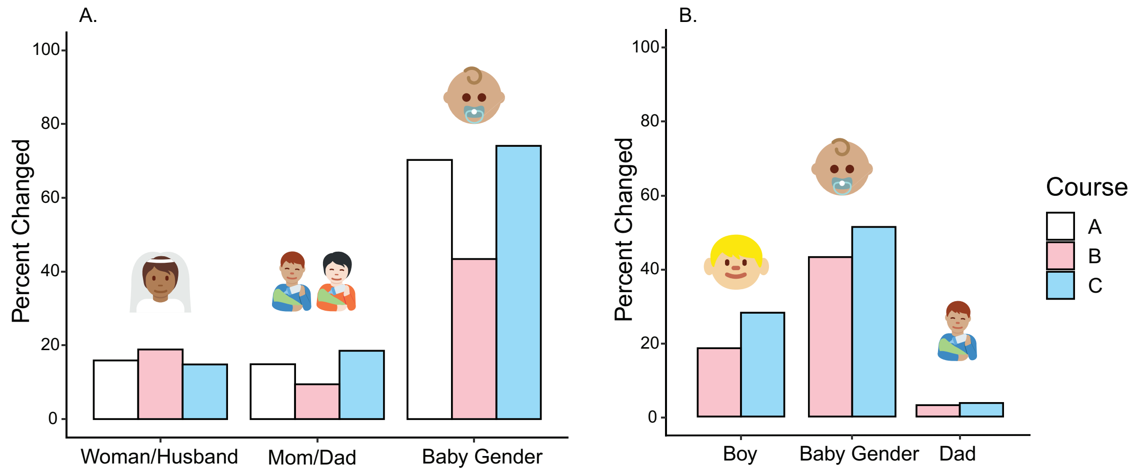

FIGURE 2. Edits from gender-associated terms to sex-associated terms at all three sites across courses. Question 1 is displayed on the left (A), and Question 2 on the right (B).

Several previous studies highlight the pervasive use of essentialist language among 8–10th grade students, and the potential influence curricular materials have on student understanding of sex and gender. Donavan *et al.* (2019) randomized students into one of three treatment groups that read about: (1) genetics of human sex using sex language (i.e., male and female), (2) the genetics of plant sex using sex language (i.e., male and female), and (3) refuting gender essentialist beliefs about men and women and offering a research-based explanation of the social causes of gender disparities in STEM fields, using gender and sex language. They found that students exposed to the genetics reading of human *or* plant sex were more likely to endorse genetic essentialism beliefs and hold an innate basis of science ability compared with those in the treatment that explicitly refuted these ideas and emphasized the social causes of gender disparities in STEM. This demonstrates that curricular content has the potential to affect essentialist beliefs and bias, and through structural equation modeling, demonstrated this effect had its strongest impacts on girls. Stuhlsatz *et al.* (2020) built off this foundational work and examined the language that students used across these treatments, and the extent to which students conflated sex and gender in their writing about genetics. They found that students exposed to the genetics reading of human or plant sex used gender language interchangeably, frequently conflating the two terms. Students in a group that explicitly refuted essentialist thinking were also less likely to use sex language in their responses, and more intentionally used the two terms with their distinct meanings. Taken together, these studies highlight the importance of incorporating clear instruction that distinguish sex and gender, and their results reinforce that students will readily update their existing conceptual framework about an idea with new information. However, as we stress below, this new information is not often provided in undergraduate science.

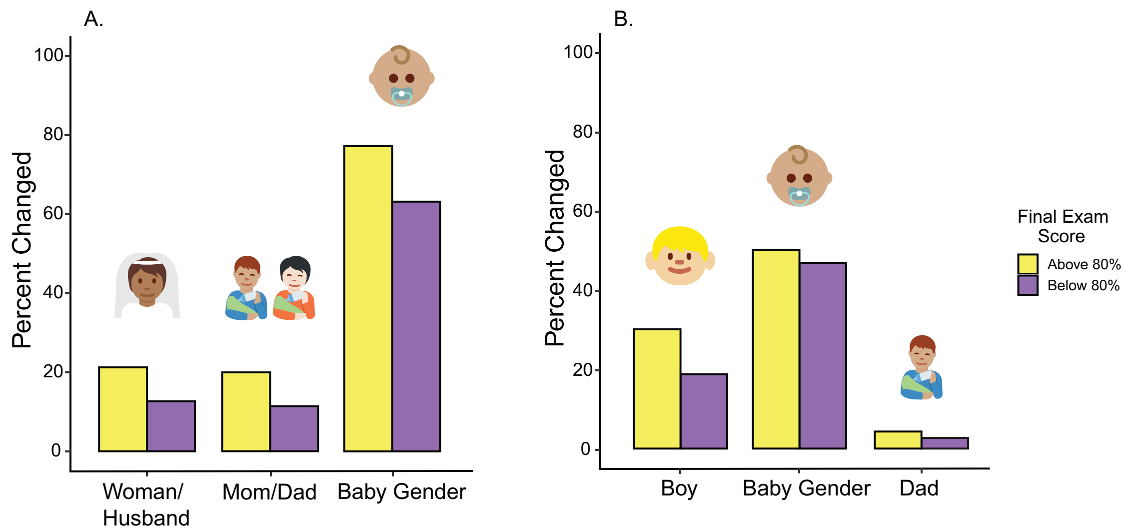

FIGURE 3. Edits from gender-associated terms to sex-associated terms at all three sites by course performance. Question 1 is displayed on the left (A), and Question 2 on the right (B).

Undergraduate Curricular Materials Conflate Sex and Gender

While inaccurate perceptions of sex-associated and gender-associated terms are developed before entering higher education, students are exposed to the same conflated language in their undergraduate coursework. We found that introductory biology textbooks also fuse sex and gender and use gender-associated terms to refer to biological sex characteristics. In other words, while a substantial proportion of the undergraduate students in this study recognized inaccurate language, this was not consistently the case among experts in the field who wrote the curricular materials for the course. As we discussed previously, sex is a complicated topic in biology, referring to the reproductive act, mating types, gamete production, chromosomes present, and more. Thus, it is not surprising that biology textbooks may not have a simple way to define or refer to the broad topic of sex. However, in attempting to humanize the curriculum, we found numerous instances where gender-specific terms were used in place of sex, in ways that are incorrect and uphold cisnormative assumptions.

This confirms findings from others who found cisheteronormative assumptions dominate textbooks across fields and subjects within biology (Snyder and Broadway, 2004; Bazzul and Sykes, 2011; Fuselier *et al.*, 2018; Junkala *et al.*, 2022; King *et al.*, 2021; Parise, 2021; Donovan *et al.*, 2024), and specifically reveals a pattern of dismissal or erasure of transgender identities in the biology curriculum through the equating of gender to binary, biological sex (Junkala *et al.*, 2022; King *et al.*, 2021; Parise, 2021). This erasure fails to challenge student misconceptions about the difference between sex and gender and may inadvertently reenforce them, as evidenced by some of our student responses. Future work will profit from explicitly testing the impact that inaccurate language has on student understanding of these terms.

Implications for Instructors

Overall, our results show promise for the ability of students to identify and correct gendered language in defiance of established cisheteronormative and essentialist conceptions of sex and gender. It is difficult to identify where their alternate conceptions derive from. As we have shown, it is likely not from existing textbooks. An important form of queer resistance to dominant cisheteronormative narratives is the creation of counter-narratives which center and affirm a diversity of nonnormative gender and sexuality expressions (Jaekel and Nicolazzo, 2017; Keenan, 2017; Bruns, 2023).The increasing acceptance and affirmation of queer and trans identities makes it likely that these students have been exposed to individuals who hold them, and may even be familiar with the embedded counternarratives of persistence these individuals hold. Further, these students encountered classroom discourse from instructors (i.e., S.J.M. or K.K.P.) that helped to deconstruct gender essentialist beliefs, and may have been exposed to similar messaging in other courses.

Our results further suggest that additional effort in the biology classroom that highlights the difference between sex and gender will better inform students about these topics. We recommend instructors implement gender-inclusive curricula that challenge binaries, promote social justice, embrace multiple ways of knowing, acknowledge intersectionality, incorporate and celebrate student experiences/perspectives, and use gender-inclusive language (Wright and Delgado, 2023). Zemenick *et al.* (2022) provided six recommendations towards this end, including highlighting biological diversity early in the semester. Specifically, they propose that instead of simplifying topics and presenting them as a rule with exceptions, instructors should present multiple examples of the diversity of sex, gender, and sexuality observed in nature (e.g., examples of sexual dimorphisms and social systems) at the outset of a topic (Zemenick *et al.*, 2022). In this way, instructors communicate to students that *variation is the norm*. To further normalize variation in sex, gender, and sexuality, instructors should also present students with role models with diverse identities (see also Unsay, 2020; Armada-Moreira *et al.*, 2021; Simpson *et al.*, 2021), develop a classroom culture based on respect, and use inclusive language (Hales, 2020; Zemenick *et al.*, 2022). Instructors are also encouraged to acknowledge the influence of cisnormative and heteronormative biases on science and our interpretations (e.g., exclusion of female mammals from biomedical research due to assumptions about hormonal cycles) and challenge students to identify biases related to sex and gender and uncover explicit connections between these concepts and society (Zemenick *et al.*, 2022).

The next recommendation centers on the terminology used in the classroom. For example, a genetics lesson may incorporate terms such as paternal and maternal without regard for the cultural connotations regarding sex, gender, and sexuality that are associated with each term. As a result, the use of this terminology can covertly reinforce the misconception that there is a biological basis for traditional human gender roles (Zemenick *et al.*, 2022). Thus, we suggest that instructors actively define terms in context (e.g., sex) and use precise, inclusive language when teaching sex- and/or gender-related terms.

Similarly, Long and colleagues (2021) have proposed an inclusive biology curriculum framework that can be used to create lessons that emphasize the diversity of sex, gender, and sexuality. In this framework, instructors are encouraged to consistently provide accurate content that is inclusive of gender. As mentioned previously, students are frequently exposed to gender messaging that prompts students to place living things into two groups (Ching and Xu, 2017; Donovan *et al.*, 2019). For example, students are often taught that in humans, women produce eggs while men produce sperm. This can result in the assumption that any woman should be able to produce eggs, though this is not true for many women (e.g., transwomen, postmenopausal women). To counteract this, when possible, instructors should use specific and consistent terminology according to the organ, function, or pattern being studied (Long *et al.*, 2021). For example, genetics problems could refer to chromosomes derived from the egg and sperm (Zemenick *et al.*, 2022) and discuss X-linked traits based on the number of copies of the X chromosome. Fully integrating this practice would go a long way towards eliminating confusion, as gender-associated terms would never be used. However, additional time spent emphasizing the diversity of sex, gender, and sexuality across all living things (Long *et al.*, 2021) and empowering students to explore their questions about the relationship between gender and sex is important to further eliminate confusion.

Inclusion of Transgender Individuals in STEM

Current research on transgender participation in STEM is lacking, and the data we do have often look at all LGBTQ+

individuals pooled together, which minimizes the documentation of discrimination and biases faced by gender variant individuals (Atherton *et al.*, 2016). University-led strategies for transgender student protections are often inadequate (Marine and Catalano, 2014), forcing students to rely on their personal development of support structures (Kersey and Voigt, 2021; Hill *et al.*, 2021; Campbell-Montalvo *et al.*, 2022); such policy failure demands much additional work to better serve transgender students. While exact estimates of the percent of transgender students in the STEM disciplines is not available, transgender students are less likely to pursue college degrees in general (Sansone, 2019) and are less likely to enroll in STEM programs (Maloy *et al.*, 2022) when compared with their cisgender peers. Further, upon enrolling, transgender STEM students often find the STEM disciplines to be unwelcoming (Cooper and Brownell, 2016; Henning *et al.*, 2019; Miller *et al.*, 2021; Casper *et al.*, 2022; Forbes, 2022).

Ultimately, our hope is not only for better informed cisgender students, but for fully included transgender students. Students are not exposed to scientists with diverse identities in textbooks (Wood *et al.*, 2020; Simpson *et al.*, 2021), in primary literature (Del Carmen and Bing, 2000; West *et al.*, 2013; Cech *et al.*, 2021), or even in science outreach media (Ashford *et al.*, 2017; King and Pringle, 2019). This creates a feeling that diverse identities are not valued in STEM (Collins, 2018), as students must be able to see their "possible selves" reflected in disciplinary fields and curricular materials to fully integrate into the scientific community (Schinske *et al.*, 2016; Costello *et al.*, 2024).

While our focus here is a narrow start, we hope that the adoption of more inclusive curricular materials can serve a role in increasing participation and sense of belonging for transgender students in STEM. Much work remains beyond this representation in curricular materials, and we challenge the reader to continue to identify the ways in which they can leverage their privilege to create a STEM environment that is truly open to and in concert, rather than conflict, with transgender identities. We have highlighted several sources that instructors can use as a start to embrace student gender identity in their classrooms (e.g., Cooper *et al.*, 2020; Hales, 2020; Zemenick *et al.*, 2022), but biology as a field needs to engage more directly and more critically with the increasing misuse of biological knowledge by bad-faith actors. The study of biology inherently lends itself well to understanding of diverse ways of living, with its demonstration of countless ways of being, for example regarding sex and sexual behavior. We call on biology faculty to notice and embrace this enormous variation, which may help validate the experiences of individuals with gender identities that do not align with binary societal expectations in the United States.

LIMITATIONS

This work begins to uncover student ability to differentiate between sex-associated and gender-associated terms and explore student preference for correctly using the former in biology settings. As such, we made choices that reflected our hope to obtain results that would build a foundation for further studies. Ultimately, this led to a qualitative-only study, and future work should add quantitative exploration of this topic. Second, we did not analyze the reasoning behind student choices in more detail. Future work will include interviews that explore student choices. That was not feasible on this set of anonymized data. Third, we did not include one of the textbook questions in course A, and so cannot rule out the possibility that this could have led to different responses compared with courses B and C, though all students only saw one question. We also cannot rule out the possibility that classroom context impacted student responses in a way that is difficult to account for. Finally, in the current study, we collected demographic data separately from the study, and due to limitations related to student privacy, were unable to connect student responses to their gender identity or LGBTQ+ status. Future work will examine whether gender-oppressed groups (e.g., women, transgender students) are more likely to make edits and notice noninclusive language in biology textbooks, which is an important and logical next step to the research.

CONCLUSIONS

We show that while the conflation of sex and gender is common in introductory biology textbooks, students can detect and correct inaccurate language. We support calls for a diversity-first approach to biology education (Zemenick *et al.*, 2023), and encourage instructors to clarify the difference between sex and gender in their teaching of biology. Further, we promote the use of specific, biologically accurate terminology in the classroom to avoid student confusion and promote an inclusive classroom environment.

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