Six Principles for Embracing Gender and Sexual Diversity in Postsecondary Biology Classrooms

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Sexual and gender minorities face considerable inequities in society, including in science. In biology, course content provides opportunities to challenge harmful preconceptions about what is "natural" while avoiding the notion that anything found in nature is inherently good (the appeal-to-nature fallacy). We provide six principles for instructors to teach sex- and gender-related topics in postsecondary biology in a more inclusive and accurate manner: highlighting biological diversity early, presenting the social and historical context of science, using inclusive language, teaching the iterative process of science, presenting students with a diversity of role models, and developing a classroom culture of respect and inclusion. To illustrate these six principles, we review the many definitions of sex and demonstrate applying the principles to three example topics: sexual reproduction, sex determination or differentiation, and sexual selection. These principles provide a tangible starting place to create more scientifically accurate, engaging, and inclusive classrooms.

Keywords: higher education, biology education, inclusivity, equity, LGBTQIA2S+

Myriad systemic and institutionalized barriers have contributed to a well-documented lack of diversity in science, technology, engineering, and mathematics (STEM; Hurtado et al. 2010, Ceci and Williams 2011, Chang et al. 2014). To help correct this inequity and work toward a more just world, modern STEM educators can employ teaching approaches that make their classrooms more inclusive spaces to students with marginalized backgrounds and identities (Tanner et al. 2013, Dewsbury and Brame 2019, Emery et al. 2021). In the present article, we focus on teaching approaches aimed at inclusivity related to gender and sexual minorities. Broadly, we include lesbian, gay, bisexual, transgender, queer, intersex, asexual, and two spirit people, as well as identities that do not fit neatly into those labels (LGBTQIA2S+) to fall under the umbrella of gender and sexual minorities, and the needs of this population are the focus of this article. We acknowledge that LGBTQIA2S+ students are not a homogenous group and that the students' needs will also depend on race, class, disability status, and other identities.

Despite advancements in recent decades, sexual and gender minorities face considerable obstacles and inequities in scientific culture. Undergraduate students belonging to sexual minorities are less likely to complete their STEM degrees than their heterosexual peers (Hughes 2018). Many LGBTQIA2S+ scientists consider quitting their jobs because of harmful workplace climates (Gibney 2019) and are more likely to intend to leave STEM altogether than are their peers (Cech and Waidzunas 2021). Despite evidence that LGBTQIA2S+ underrepresentation in STEM is similar to that of other historically marginalized groups, this phenomenon is still not well understood, likely because of the lack of relevant demographic data available (Freeman 2020). Correcting this inequity will require multifacetted solutions that target systemic, cultural, and institutionalized scales. Because of their unique platform in reaching large numbers of students early in their postsecondary education, biology instructors can contribute to these efforts by teaching biology in a way that is mindful of creating a welcoming environment for students while retaining high biological accuracy.

In biology classrooms, course content is inseparable from norms about human bodies, human behaviors, and ideas about what is "natural" in regards to humans (Ah-King 2013b). Biologists and biology instructors are embedded within social contexts that govern how they observe, interpret, and communicate about the natural world. Therefore, biology curricula are often influenced by common but, importantly, not universal (e.g., Oyěwùmí 1997) worldviews, such as heteronormativity and cisnormativity, which implicitly hold that heterosexuality and cisgender identities are the only normal and valid identities for humans to inhabit

https://doi.org/10.1093/biosci/biac013 Advance Access publication 16 March 2022

or express (Knain 2001, Bazzul and Sykes 2011, Ah-King 2013b). At their most harmful, biology courses can reinforce harmful stereotypes, leaving students with the impression that human gender and sexual diversity are contrary to “basic biology” or even that they themselves are “unnatural.” At their most beneficial, biology courses can teach students to question heteronormative and cisnormative biases in science and society. On a larger scale, by encouraging an inclusive and accurate understanding of gender and sex in nature, biology education has the power to advance antioppressive social change. Furthermore, it is likely that such changes will benefit not only students with marginalized gender and sexes but also groups with overlapping needs, especially women and people who do not conform to traditional gender roles (e.g., stay-at-home dads, strong women). Many equitable teaching strategies have been shown to benefit both majority and minority groups. For example, many straight, cisgender men are harmed by narrow stereotypes about masculinity and manhood (Smith and Johnson 2006, Tagler 2012, Kahalon et al. 2018) that can be instilled or reinforced by traditional biology education.

Effective and inclusive biology education has the power to allow all students to better understand their own lives, regardless of what their body, gender identity, sexual preferences, or family looks like (Gender Spectrum 2020). Many students are already aware of sexual and gender diversity from their lived experiences and are often interested and invested in these topics, whether on a personal or social level. From a cognitivist perspective, students learn new concepts by incorporating them into semantic networks that link related concepts and experiences (Regehr and Norman 1996). If biology students are confronted with concepts relating to sex and gender that are incompatible with their prior experiences, they will have difficulty incorporating this new information and applying it to their own lives. On the other hand, introducing concepts that are explicitly relevant to the lives of students can increase engagement with course material and help students understand abstract concepts (Hughes 2000, Eccles 2009, Lents 2013). Moreover, biological concepts are more useful to students when they can use them to understand their own experiences (Kember et al. 2008). It is clear, therefore, that teaching sex- and gender-related topics in biology in an inclusive and accurate manner can aid students in building on their semantic networks and meeting learning objectives.

Despite the importance of embracing gender and sexual diversity in biology classrooms, very little guidance on best practices is available to postsecondary biology instructors (for exceptions, see Cooper et al. 2020, Hales 2020), nor are educators given enough support to learn and incorporate evidence-based teaching practices (Bathgate et al. 2019). Creating an inclusive classroom around issues related to sex and gender can prove challenging for many instructors, who are often working with limited time and resources and are expected to teach complex biological topics in a prescribed curriculum. As a result, instructors often rely on omission, simplification, and generalization to help students process the large amount of unfamiliar information presented in biology courses. This process of pedagogical reduction (Lewin 2018), although it is often necessary and helpful for instructors, can also sometimes act as a barrier to teaching biology inclusively and accurately when employed without consideration of unintended impacts. For example, omission, which is the avoidance of certain information, can be damaging if it removes important biological or social context related to sex and gender. Simplification, which includes relying on binary thinking or ignoring complexity, can obscure the fact that sex, sexuality, and gender may be better described as spectrums rather than prescriptive (and limiting) binary categories. Generalization, which is when a group is treated as homogenous and variation within is ignored, can erase the diversity of the natural world, as well as the identities and experiences of many people. In the present article, we provide tools to help postsecondary biology instructors introduce the field of biology inclusively and accurately by selectively reducing their use of omission, simplification, and generalization.

To teach biology in an inclusive and scientifically accurate manner that embraces sexual and gender diversity, we propose six guiding principles (figure 1, supplemental table S1). Specifically, we suggest that instructors teach diversity first, provide social and historical context, use inclusive language, show the iterative process of science, present students with diverse role models, and develop a classroom culture of respect and inclusion. These six principles are intended to be applied at the college or university classroom level, but may also be useful tools for high school science teachers, science communicators, and other educators. For tools aimed specifically at the K–12 level, please see www.genderinclusivebiology.com and Long (2019). Although each principle is presented separately, we emphasize that they should be applied in tandem when possible. In support of our main principles, we also provide a box outlining the definitions of sex in biology (box 1) and three boxes focused on curricular topics with direct relevance to gender and sexual diversity and inclusion in biology curricula: sexual reproduction (box 2), sex determination or differentiation (box 3), and sexual selection (box 4). Our hope is that these boxes illustrate how the six outlined principles can be generally applied to other sex- and gender-related topics in the undergraduate biology curriculum, including but not limited to genetics, physiology and anatomy, and animal behavior. Although these principles are good starting places for biology instructors, they are neither exhaustive nor immutable. Future research on the efficacy of different pedagogical tactics and the continued incorporation of a growing diversity of viewpoints will undoubtedly build on and modify these principles. Regardless, our hope is that these guidelines can serve as useful starting points for educators interested in building more inclusive and accurate classrooms for students from gender and sexual minority groups and beyond.

Figure 1. Summary of six principles for embracing gender and sexual diversity in postsecondary classrooms (the inner circle) and traditional compared with proposed approaches for implementing principles (the outer circle).

Principle 1: Diversity first

The natural world is staggering in its diversity. Almost everywhere we look in nature, we find variation; sexual diversity within and across sexually reproducing organisms and sex and gender diversity in *Homo sapiens* are no exceptions. Unfortunately, this diversity is often erased in the classroom, perhaps because of the challenge of describing biological complexity. For many topics, instructors must make decisions about how to simplify biological complexity so that it can be understood by students. A common strategy is to focus on a simple and general biological "rule" first, and then, if time allows, discuss "exceptions to the rule" only after the basic pattern has been established. For example, when discussing sex determination, educators might begin and end with a simplified discussion of developmental pathways in humans and animals with XY determination systems. Intersex and other developmental pathways (e.g., Bachtrog et al. 2014), if they are discussed, are presented as deviations from the norm, and, in humans, are often unnecessarily pathologized.

We propose presenting diversity within and across species first as opposed to last. This can help avoid the

Box 1. The many definitions of *sex* in biological research and beyond.

In an informal review of seven commonly used introductory biology textbooks, we found that sex is mentioned but never defined. This is perhaps an understandable omission given the many connotations of the word *sex* in science and culture. *Sex* can refer to myriad acts including but not limited to copulation (see box 2), whereas other times it refers to some combination of the gametes, chromosomes, genitalia, hormones, appearance, and behavior an organism is born with or develops over time (Lehtonen and Kokko 2014). When left undefined, these many meanings lead students to form inaccurate and sometimes damaging assumptions about these traits and behaviors, especially related to their congruence and use in social or medical categorizations. To clarify this complexity to students and correct misconceptions, we recommend providing trait-specific definitions of sex as they are relevant in biological research and its applications (Karkazis 2019), referring to sexual dimorphisms and emphasizing their complexity over defining sex in most cases, and distinguishing trait-based definitions from acts and behaviors.

In this approach, providing a definition of gametic sex may be the most broadly applicable and useful for biological research and applications (Roughgarden 2013), particularly when reproduction is of interest (Karkazis 2019). Gametic sex can be defined by the size of gametes an organism produces, when gamete dimorphism (anisogamy) is present (Hoekstra 1990, Hurst and Hamilton 1992, Billard et al. 2011). Specifically, in anisogamous organisms, smaller gametes are called "male" by convention, and larger gametes are called "female." Individuals in some species produce only one gamete size throughout their life and these individuals are therefore often classified as "egg producing" or "female" or as "sperm producing" or "male" by extension.

It is important to note, however, that a gametic definition of sex, although it is sometimes useful, fails to support a binary classification of organisms or represent an essential property of life. For example, many species produce multiple sizes of gametes simultaneously or sequentially throughout their lives (hermaphrodites), in which case individuals are neither female nor male or are only female or male at a given point in time. In addition, many common organisms—such as ciliates, algae, and fungi—have equal-size gametes (isogamy) and do not therefore have gametic sexes (Hoekstra 1990).

Two additional distinctions are critical for understanding this and other definitions of sex. First, gametic sex should not be used as shorthand to refer to an array of traits that can be, but are not universally, associated with gamete size. Such associations are called sexual dimorphisms (see box 3). Gametic sex should be distinguished from these more complex and variable dimorphisms including variation in chromosomes, anatomy, hormones, appearance, and behavior (see box 4). This distinction allows scientists and biology instructors to discuss general patterns associated with dimorphic gamete production while including within-sex, hermaphroditic, and intersex diversity.

Second, gametic sex and higher-level sexual dimorphisms should be distinguished from the concept of gender. Gender is an exclusively human classification, determined by social role and self-identity rather than dimorphic traits. This important distinction prevents students from conflating discussions of gametic sex or sexual dimorphisms with gender identity in humans.

misconception that the average or most common phenotypes in one taxa, species, or population is what is "natural" or "normal" among all populations or species. By presenting diversity first, students learn that variation and diversity in sexual reproduction strategies, sex determination systems, and sex-associated behaviors is vast and normal; in other words, diversity the biological rule, not the exception! See boxes 2–4 for examples of teaching diversity first for sexual reproduction, sex determination, and sexual selection. For more specific examples of life's diversity, see Roughgarden (2013) and a database of examples compiled from this work at www.genderinclusivebiology.com/newsletter/evolutions-rainbow-a-queer-species-database-of-200-organisms. We note that there is a great need and demand for more ready-to-use educational materials that illustrate examples of sexual diversity across the biological world to support this principle, and we hope to see more such resources developed.

Presenting diversity in the class can have three main benefits. First, it can help normalize human diversity in the classroom. Students may be more able to understand why there is so much variation in humans and that there is nothing fundamentally "unnatural" about not fitting into narrow cultural norms of gender identity, behavior, or sexuality. Second, an emphasis on both intra- and interspecies variation can set the stage for understanding the evolution of diverse reproductive systems and strategies. Intraspecific variation is a prerequisite for evolution and, eventually, interspecific variation, and presenting examples of intraspecific variation in nonhuman species is directly relevant for student perception of variation within humans. Presenting interspecific variation is also powerful, because it allows for a greater diversity of examples in the classroom than if teaching intraspecific variation alone, and facilitates the presentation of systems that are powerful teaching tools and symbols of natural systems that counter societal messaging about what is "natural" (e.g., females with "male" traits, species with sneaker reproductive males, species in which the males rear young or carry embryos). Finally, it can help students avoid inappropriate generalizations, such as assuming that what is typical for one taxa applies to other taxa—and, therefore, humans.

Two concerns may arise among instructors regarding the principle of presenting diversity first. First, instructors might worry that this approach will add to student cognitive load. However, education research has shown that

Box 2. Applying the principles: Sexual reproduction.

Reproduction is a key defining feature of life and a primary focus of many biology courses. Sexual reproduction is most often defined as "any form of reproduction in which genes from two parents are combined via fusion of gametes, producing offspring that are genetically distinct from both parents" (Freeman 2017). In biology textbooks and lectures, this definition is often shortened to simply "the fusion of egg and sperm to form a zygote." We argue that these definitions are biologically inaccurate and contribute to a less inclusive classroom environment.

Defining sexual reproduction as the fusion of egg and sperm to form a zygote does not encompass the diverse mechanisms by which sexual reproduction is achieved. Anisogamous species produce two sizes of gametes, which are categorized by size: Small gametes are called sperm and large gametes are called eggs. Isogamous species produce only one size of gamete, which are neither egg or sperm. Furthermore, some isogamous species do not sexually reproduce via the fusion of two gametes but instead fuse after germination. Therefore, the commonly used definition of sexual reproduction (fusion of an egg and sperm to form a zygote), although it is a useful shorthand, is not always appropriate or biologically accurate.

Aside from its pitfalls in terms of biological accuracy, the way that sexual reproduction is defined and taught in many biology classrooms also leads to pitfalls in inclusivity. As units on sexual reproduction often focus on organisms that undergo fusion of egg and sperm to form an offspring, textbooks commonly refer to males and females. However, as was mentioned in box 1, textbooks often fail to define gametic males (sperm producers) and gametic females (egg producers). This omission is usually coupled with the omission of hermaphrodites (sperm and egg producers). These omissions can lead students to think that binary gametic sex is biologically universal and fixed, creating a biologically inaccurate and less inclusive learning environment.

Our suggestions for biology instructors are the following:

Present diversity first

Discuss species with a wide variety of reproductive systems, as opposed to focusing solely on anisogamous species with two sexes that reproduce via fertilization (e.g., hermaphroditic and isogamous species).

Provide historical and social context

Explain that the term hermaphroditism has been used inaccurately as a derogatory term for intersex people.

Use inclusive language

We suggest a definition of sexual reproduction that would be more biologically accurate: "reproduction involving meiosis, giving rise to offspring that have unique combinations of genes." This definition is inclusive to both isogamous and anisogamous species, individuals that undergo selfing, and species that undergo alternation of generations. Furthermore, instead of referring to parents in a genetics or pedigree lesson, use terms that don't assume traditional family structures (e.g., egg producer, sperm producer, biological parent).

highlighting complexity actually enhances student learning (Randler and Bogner 2009). Recent work focused specifically on undergraduate animal behavior courses has demonstrated that presenting diversity first does not negatively affect learning objectives (Sarah Spaulding, University of Louisville, Louisville, Kentucky, personal communication, 9 April 2019). If time is limited and a diversity of taxa cannot be presented, instructors should emphasize to students that they are learning only one instance of many. For example, if an instructor is teaching about sexual reproduction using pollination of flowering plants as a case study, they should specify in which taxa pollination occurs and the proportion of living things that use pollination to reproduce, while stressing that the mechanisms of sexual reproduction vary widely between taxa (see principle 2, box 2). In general, if instructors specify which taxa they are referring to, this prevents their students from assuming that the mechanism they are learning applies to all organisms on Earth. Ultimately, explicitly nesting your examples into a diverse "tree of life" context, even briefly, can help combat students' development of the unintended impression that individual examples are biologically normal, average, or superior.

A second potential concern is that this principle, if it is simplistically applied, will perpetuate the appeal-to-nature fallacy—that is, the argument that anything found in nature is inherently good (Tanner 2006). This is problematic, because it can suggest that students *need* examples of specific behaviors or biologies in nature to validate human experiences or, alternatively, that anything found in nature is justified in humans. We emphasize that presenting diversity first should only demonstrate that we should expect diversity, including among humans, but this does not present a value argument. Rather, it combats the incorrect assumption that nonbinary categorizations, intersex characteristics, same-sex sexual behavior, transgender identities, gender nonconforming presentation and behavior, and so on are unnatural, which is, itself, often used against LGBTQIA2S+ people in an appeal-to-nature argument (e.g., Newman and Fantos 2015).

Principle 2: Present the social and historical context of science

Biological discoveries continually influence society, whereas social change, in turn, influences biological discoveries. For example, female mammals have been historically excluded

Box 3. Applying the principles: Sex determination or differentiation and sexual dimorphisms.

Sex determination refers to biological systems that allow development of sexual dimorphisms. Sexual dimorphism is when individuals of the same species tend to have different genotypes or phenotypes associated with dimorphic gamete production. These topics are traditionally taught in biology in a manner that emphasizes several inaccurate, oversimplified, and noninclusive ideas.

First, sex determination is usually presented as a simple, deterministic process. Educators often emphasize the XY chromosomal sex determination system common in mammals and present only select elements of this process. For example, the SRY gene, found on Y chromosomes, is often described as a “master switch” from which “maleness” arises (Kashimada and Koopman 2010, Offner 2010). This approach notably ignores or deemphasizes interactions between this process, secondary mechanisms, and chance events that produce nonbinary results on both individual and evolutionary time scales (Kropatsch et al. 2013, Abdel-moneim et al. 2015, Grilo and Rosa 2017, Li et al. 2020, Rosenwohl-Mack et al. 2020). It also ignores the diversity of sex determination systems that exist across nature involving a variety of genetic, hormonal, social, and environmental mechanisms (Piferrer 2013, Bachtrog et al. 2014). Ignoring this diversity, or presenting examples of it as strange anomalies, obscures the true complexity of sex determination processes.

Second, teaching materials often conflate the outcomes of sex determination with gender identity and presentation. For example, diagrams are coded with blue and pink colors, and figures with dresses and pants are presented as the inevitable outcome of these processes (e.g., Bachtrog et al. 2014, Cornell 2016). Even temperature-dependent sex determination in turtles is often taught with gendered mnemonics like “hot chicks and cool dudes.”

Finally, even if sex and gender are not conflated, the many possible outcomes of sex determination are. Different types of sexual dimorphisms (gametes, hormones, anatomy) are presented as inextricably linked and indistinguishable outcomes of sex determination (e.g., Cornell 2016), leading students to assume that all sexual dimorphisms are equally binary and congruent with gametic sex. In reality, sexual dimorphisms do not occur in the same way, or at all, in all species at all levels of biological organization. For example, gonad dimorphism, a type of sexual dimorphism in which different-size gametes occur in separate bodies with specialized associated reproductive organs, is common among insects and mammals, rare among plants, and heterogeneous in fish and noninsect invertebrates (Bachtrog et al. 2014).

Our suggestions for biology instructors are the following:

Present diversity first

Start by presenting diverse sex determination systems across species. Emphasize the increasing diversity of possible outcomes as one moves up in levels of biological organization.

Use inclusive language

Clearly define sexual dimorphism and distinguish its different forms. Be specific when referring to gamete dimorphisms compared to gonad dimorphisms, behavioral dimorphisms, and so on.

Show the iterative process of science

Sex determination is understood by many scientists today as a complex negotiation between organisms’ genetics, hormones, and environment (e.g., Osvaldo and Metzenberg 2013, Kuroki and Tachibana 2018). Understanding sex determination as a negotiation between multiple factors over time clarifies how sex determination processes result in diverse outcomes.

Provide social and historical context

Emphasize that sexual dimorphisms are only some of many sources of variation within species, and that other sources of variation (age, rearing environment, genetic chance, etc.) are also biologically important. The influence of sex- and gender-related social constructs on research has led to strong emphasis on sex (usually superficially defined) as a variable to explain intraspecies variation. Although this emphasis has led to important insights, it is often to the exclusion of other mechanisms of variation, and obscures overlap among individuals with differing gamete production or other dimorphisms.

from neuroscience and biomedical research for decades under the assumption that female mammals, because of hormonal cycles, are inherently more variable and cannot provide reliable data (Shansky 2019). Although this bias persists (Beery and Zucker 2011, Orr et al. 2020), it is now more common to include female mammals in research and is, in fact, mandated in human clinical trials by many prominent funders (Beery and Zucker 2011). This shift occurred in part because the underlying assumption was disproven (Prendergast et al. 2014) but also because women researchers discovered that excluding female mammals caused harm to many women (Correa-de-Araujo 2006). There are still numerous issues with testing for and reporting sex differences in scientific research, prompting calls for increased training in this area (Garcia-Sifuentes and Maney 2021). Furthermore, it is increasingly recognized that testing for only binary sex differences excludes and harms many others that fall outside this binary (Reisner et al. 2016). Teaching students about biological research alongside its social and historical context can help them learn to identify biases, understand the socially influenced discovery process (Knain 2001), and prevent these biases from perpetuating.

Not only can teaching societal context affect student understanding of biology, but it can also enhance student

Box 4. Applying the principles: Sexual selection.

Lessons on sexual selection largely focus on the evolution of sex-associated traits and behavior in two superficially defined sexes ("males" and "females" in the present article). Generally, textbooks demonstrate the concept of "choosy females" versus "competing males" with a handful of highly sexually dimorphic species from few taxa—mostly mammals and birds (Fuselier et al. 2016)—and then provide students with a simplified model of sexual selection to explain these sex differences. The model, based on past work by Darwin (1871, Darwin and Wallace 1958), Bateman (1948), and Trivers (1927), suggests that anisogamy leads to different potential rates of reproduction (PRR) in males and females, with males producing cheaper gametes and therefore having the ability to produce offspring more quickly; that differences in PRR lead to a biased operational sex ratio (OSR), with more males available for mating than females at any one time; and that the biased OSR drives mating competition among sperm producers and mate choice among egg producers.

When this simple model of sexual selection is the only one presented to students, it leads them to believe that anisogamy is the predominant determining factor for female and male reproductive behavior and morphology. Students may consequently develop several false dichotomies in their thinking; they may assume sperm producers always have cheap reproduction, high competition over mates, and strong selection for competition-related traits, whereas egg producers have expensive reproduction, selectivity in mating, and no meaningful selection on competition-related traits. This erases diversity both within and between species, and students are left with little accounting for the huge array of social systems and sexual dimorphisms that in fact occur in nature.

The choosy-female versus competitive-male paradigm can therefore falsely suggest that traditional gender roles are biologically determined and the norm across all animals, which may make students who do not conform to traditional gender roles feel alienated or othered by the curriculum. When only given examples of binary, heteronormative dimorphisms and social systems, LGBTQIA2S+ students or students from nontraditional family structures may feel viewed as "unnatural."

Our suggestions for biology instructors are the following:

Present diversity first

Start by presenting diverse examples of sexual dimorphisms and social systems. Consider highlighting diversity in terms of the extent and type of sexual dimorphisms, the number of sexes or sex morphs, and the extent and expression of differing in modes of mating and parental care.

Provide historical and social context

Point out that taxonomic bias (Zuk et al. 2014, Kokko 2017) and heteronormative assumptions have been present in sexual selection theory from its conception to present day (Dewsburry 2005, Ahnesjö et al. 2020). Because of these biases, significant avenues of research have historically been overlooked, including evolutionary explanations for the predominance of same-sex mating across the animal kingdom (Monk et al. 2019) and competition or multiple mating in females (Clutton-Brock 2007, Kokko 2017, Hare and Simmons 2019).

Show the iterative process of science

Instructors should note that critical scientific debate has arisen over some fundamental principles of traditional sexual selection theory, including debate over Bateman's (1948) findings and mixed support for some subsequent predictions (e.g., the prediction that males gain higher reproductive success from mating multiply than females do; Tang-Martínez and Ryder 2005, Gowaty et al. 2012, Tang-Martínez 2016, Hoquet et al. 2020). Furthermore, many modern researchers have suggested that traditional models or definitions of sexual selection do not adequately explain diversity both within and across species (Kokko and Jennions 2008, Kujiper et al. 2012; Roughgarden 2013, Evans and Garcia-Gonzalez 2016, Schact et al. 2017, Hare and Simmons 2019, Ahnesjö et al. 2020). For example, environmental factors (e.g., Saino et al. 2004, Candolin and Evers 2007, Twiss et al. 2007, Gillespie et al. 2014) and the effects of complex social systems (e.g., Candolin and Evers 2007, Cockburn et al. 2008, Hall et al. 2008) drive or modify the evolution of sex-specific traits (Miller and Svensson 2014, Evans and Garcia-Gonzalez 2016, Clutton-Brock 2017, Schact et al. 2017). See also Ah-King (2013a) and Schärer and colleagues (2012) for a debate around the concept of sex roles and the importance of anisogamy in determining sex differences in behaviors and life history strategies.

understanding of society. Providing context allows instructors to make more explicit connections between biological concepts and societal issues that affect students' lives. Biology is a vital component of general postsecondary education because understanding biological principles allows students to better understand who humans, as biological organisms, are and where they came from. Providing context can increase accuracy and teaching effectiveness by addressing student misconceptions and demystifying the scientific process (Knain 2001, Lin et al. 2002, Rudge et al. 2014). It also allows instructors to discuss how cultural norms of the time influence the topics scientists chose to investigate and their findings. Explicitly addressing these misconceptions has been shown to enhance student engagement rather than distract from learning (Verkade et al. 2017).

Providing context is especially important when teaching topics related to sex and gender, because of the cultural importance of these topics. Instructors should explain how biological concepts relate to associated cultural concepts with which they are already familiar. For example, when the term *hermaphrodite* is used in a biological context, it refers to organisms that can produce both small and large gametes (reproductive cells), either simultaneously or sequentially throughout their lives. Teaching biology students about hermaphroditism is aligned with principle 1, because it presents diversity first and allows the students to understand that a large proportion of species cannot easily be divided into “males” and “females” (boxes 1–3). However, it is important to note that the term *hermaphrodite* has another meaning in common usage: It is a derogatory term referring to people with intersex characteristics, those who are born with genetic, hormonal, or physical characteristics that do not fit neatly into binary definitions of *male* and *female*. Intersex characteristics are an important form of intraspecies diversity in humans occurring in approximately 1.7% of births (Fausto-Sterling 2000) but are not equivalent to hermaphroditism. When biology instructors explain that the term *hermaphrodite* cannot refer to humans (and that there are no known hermaphroditic mammals), this discourages the uninformed use of this derogatory term and makes biology classrooms more inclusive.

Principle 3: Use inclusive language while teaching

“Words create worlds.” This quote, sometimes attributed to philosopher Abraham Joshua Heschel, testifies to the importance of choosing language carefully. The way we talk about biological systems both reflects and generates ideas about how those systems work (Martin 1991). Biology instructors teach students explicitly and implicitly about how the world works through how they define and use terminology. For example, consider the world implied by a genetics lesson that refers only to reproduction between “mothers” and “fathers” (Long 2019). Would this world feel welcoming to students who were adopted or who are coparented with same-gender partners? Would it be consistent with their lived experiences? Compare this to a lesson that employs more precise language, such as *egg producer*, *sperm producer*, *biological parent*, and *chromosomes derived from the egg, sperm, or gamete*. These conversations about language have been taking place in the context of medical education for the last decade (King 2010, Madsen et al. 2017, Štrkalj and Pather 2020), but have largely been absent in the context of biology education (although, for one exception, see Hales 2020).

Culturally loaded sex- and gender-related terms are often used in biology classrooms without careful thought and discussion. This is especially true of familiar terms, such as *male*, *female*, *sex*, *paternal*, *maternal*, *mother*, and *father*. Students and instructors alike may fail to notice that these terms imply and affirm cultural norms around sex, gender, and family structure that can be inaccurate and harmful. We therefore suggest, whenever possible, using inclusive, precise terminology that does not assume sex and gender binaries or traditional, nuclear family structures. Sex- and gender-related terms should also be defined as clearly as possible. For example, the word *sex* is routinely used in biology courses but is rarely defined and is therefore burdened with many loaded, overlapping, and contradictory meanings (box 1). Finally, language choices can subtly reinforce biological bases for traditional gender roles in humans. For example, the words *nurture* and *hunt* are often used in biological descriptions of gametes and reproduction. Language around eggs often suggests a passive role in reproduction, which is inaccurate (Martin 1991, Campo-Engelstein and Johnson 2014) and which may cause incorrect generalizations about the behavior of egg-producing individuals. Encouraging students to develop an inquiring attitude toward culturally loaded biology language may reduce the harm of these terms and help students develop important critical-thinking skills (Kekäläinen and Evans 2018).

For sex- and gender-related biology terms, we believe it is imperative to provide definitions that are as inclusive, accurate, and precise as possible. We propose three guiding questions that biology instructors can follow when considering their definitions of sex-related terms:

Does the definition apply equally well to humans and fungi? A definition can never encompass all of life’s variety, but it should be as phylogenetically inclusive as possible. If the definition needs to be more specific for pedagogical or scientific reasons, be explicit about what taxa it applies to, or your students may assume that it applies to all organisms.

Does the definition privilege one species’ system of sexual reproduction, sex determination, or sex-associated patterns of behavior over others? An unbiased definition will open students’ eyes to the diversity of sexual strategies in nature. Again, if the definition must favor certain taxa, specify which taxa it applies to.

If the term has another meaning in common usage, does it explicitly distinguish the scientific and common usage? Especially for terms with heavy cultural baggage, cavalier usage without giving context can be harmful to affected students.

For more resources and suggestions for inclusive sex-related terminology, see the Project Biodiversify working definitions list (www.projectbiodiversify.org/definitions) and Gender Inclusive Biology’s Language Guide (www.genderinclusivebiology.com/bettersciencelanguage).

We suggest that instructors regularly revisit their terminology and definitions. Over time, language evolves in response to changing cultural and scientific understandings. What is considered an inclusive and precise definition today (such as our definition of gametic sex in box 1), may be considered outdated tomorrow.

Principle 4: Show the iterative process of science

Practicing biologists are aware that the scientific process is nonlinear and iterative. An important part of teaching science to postsecondary students is complexifying the simple cookbook version of the scientific approach that they have likely previously learned. One approach to show the iterative process of science is to teach students how scientists view and use models (Krajcik and Merritt 2012, Svoboda and Passmore 2013). We use models to simplify complexity, but we are constantly retesting, refining, and adding to them. Showing how scientific models change over time goes hand in hand with providing historical context to the information being presented (see principle 2). Moreover, a primary goal of new educational standards is to teach students how scientists use models, rather than presenting immutable facts (AAAS 2011). This approach has been shown to be more effective and engaging than teaching facts (Fuselier et al. 2016).

Showing the iterative process of science allows students to see how biological models often begin simple and general, to the exclusion of sexual diversity. As models are developed further, with more data and collaboration, they are often refined to encompass more complexity and diversity. For example, past sexual selection theory emphasized how sex differences in gamete size (anisogamy) and differential reproductive investment can drive the evolution of sexual dimorphic behaviors and morphology (box 4). Despite evidence suggesting that humans may be only weakly sexually dimorphic (Reno et al. 2003), early evolutionary models of animal behavior contributed to biological essentialist ideas about human males being inherently highly competitive and human females being driven primarily by the need to rear young. Biology instructors can teach their students traditional models of sexual selection while also describing how these models have been challenged and refined over time to include the effects of complex social systems and environmental drivers of sexual dimorphism (e.g., Tang-Martínez and Ryder 2005, Gowaty et al. 2012, Hoquet et al. 2020). For an example of a simple model that includes some of these additional socioecological factors, see figure 1 in Kvarnemo and Simmons (2013). More broadly, instructors may discuss how these new models can help account for the diversity of inter- and intraspecies variation in morphology and behaviors found in nature (box 4).

Principle 5: Present students with diverse role models

One reason students from marginalized groups leave STEM majors is a lack of relatable and supportive role models (Hurtado et al. 2010). Role models inspire students, provide psychological support, and help them adopt a growth mindset about intelligence (Koberg et al. 1998). For students from marginalized groups in particular, relatable role models can help them perform better (Marx and Roman 2002, Lockwood 2006). Therefore, a simple way to support LGBTQIA2S+ students—who leave STEM majors at higher rates than their straight peers (Hughes 2018)—is to expose them to relatable role models from diverse backgrounds and identities.

Despite the importance of relatable role models for marginalized students, most scientists featured in biology curricula are white, heterosexual, cisgender men, and, as a result, marginalized students often do not see their identities represented (Wood et al. 2020). Instructors should be intentional about introducing their students to biologists from diverse backgrounds and identities, and there are several approaches instructors can take to integrate this into biology courses. For example, instructors can complement or replace content about historical scientists with content about diverse contemporary scientists, or they can assign a small project in which the students research relatable role models. College instructors at Western Washington University assigned their students to find relatable role models and to create slide decks highlighting the researcher and their work to feature on the Project Biodiversify website. Fortunately, a growing number of resources exist to help educators incorporate scientists representing a diversity of marginalized identities into their educational materials. These include www.500queerscientists.com, www.500womenscientists.org, www.projectbiodiversify.org, www.diversifyeeb.org, www.scientistspotlights.org, www.skypeascientist.com, and www.blackintheivory.com. Instructors can also search Twitter for scientists to spotlight by using hashtags such as #diversifySTEM #womeninSTEM, #queerinSTEM, and #transinSTEM. In general, it is most helpful to not only mention scientists from a diversity of backgrounds but to add content that helps students see those scientists as full people and researchers (Schinkske et al. 2016). Discussing scientists' research and their contributions to the field and presenting humanizing information when possible can help avoid a situation where the instructors are unintentionally tokenizing scientists from certain groups in their lectures, which could have negative impacts on their students.

Principle 6: Develop a classroom culture of respect and inclusion

One of the most rewarding parts of teaching is the "human" aspect—that is, the pedagogical relationships formed between the instructor and the students and among the students. The first five principles relate to the content of biology courses, including what information is presented, how it is presented, and in what order. Inclusive pedagogy is much more than choosing the right content for courses. It is about building relationships and a classroom atmosphere in which all students feel valued and a strong sense of belonging (Dewsbury and Brame 2019). Students from groups that have historically been excluded from scientific culture, including sexual and gender minorities, may not feel that they belong in science classrooms or in science careers (Hughes 2018, Gibney 2019). Therefore, it is the responsibility of biology instructors to take extra care in making these students feel welcome.

Strategies for creating an inclusive biology classroom environment have already been developed in detail by previous authors (Dewsbury and Brame 2019, Cooper et al. 2020), and we briefly summarize several strategies in the present article. Instructors can work to make all students feel welcome by building professional relationships with students that are founded on respect and nonjudgement. To develop and nurture such relationships, instructors must confront their unconscious biases, such as homophobia, transphobia, or interphobia, through education and self-reflection. Consider attending LGBTQIA2S+

sensitivity training, often offered by campus pride and GSA (gay–straight or gender and sexuality alliance) centers. The Society for the Advancement of Biology Education Research recently published 14 recommendations to create a more inclusive environment for LGBTQ+ individuals in academic biology (Cooper et al. 2020). Several of these recommendations relate to developing a classroom culture of respect and inclusion, including being thoughtful about the use of humor in the classroom, not assuming the gender or sexuality of individuals, and creating opportunities for individuals to choose to reveal their pronouns and names if they feel comfortable (Cooper et al. 2020). By developing an awareness of how LGBTQIA2S+ identity affects students' experiences of the biology classroom and by engaging with students empathetically and authentically, instructors can create meaningful and inclusive learning experiences (Dewbury and Brame 2019).

Conclusions

Biology classrooms represent powerful opportunities to teach sex- and gender-related topics accurately and inclusively. The sexual and gender diversity displayed in human populations is consistent with the diversity that characterizes all biological systems, but current teaching paradigms often leave students with the impression that LGBTQIA2S+ people are acting against nature or "basic biology." This failure of biology education can have dangerous repercussions. As students grow and move into society, becoming doctors, business people, politicians, parents, teachers, and so on, this misconception can be perpetuated and weaponized. Our hope is that this article helps to combat that scenario by stimulating the adoption of accurate and inclusive teaching practices. By putting diversity first, presenting social and historical context, using inclusive language, showing the iterative process of science, presenting students with diverse role models, and developing a classroom culture of respect and inclusion, biology instructors can begin to correct harmful misconceptions about biology, sex, and gender.

Looking ahead, we anticipate that the impact of inclusive biology classrooms will not end with the final exam but will extend to affect students' lives and eventually research and healthcare systems. However, it is important to remember that the principles presented in the present article are just starting places. Future pedagogical research supporting evidence-based approaches to embracing gender and sexual diversity in biology classrooms will continue to build on and update our current understanding of best practices for creating inclusive classroom environments. Ultimately, researchers and educators will continue to build on the work done thus far to create more accurate and inclusive biology education.

Acknowledgments

Sarah Jones, Shaun Turney, Alex Webster, and Ash Zemenick are co-first authors, having contributed equally to the development of ideas, research, and writing the manuscript from initial draft to submission. We would like to thank the many biology educators who attended Project Biodiversify workshops to consider and discuss these issues from 2018–2022. We are also grateful to the attendees of the Definition of Sex Workshop in 2020 for thoughtful and critical examinations of the definitions of sex, and to the three anonymous reviewers whose comments greatly improved the manuscript. This material was partially supported by National Science Foundation grants no. DEB-1831164 and no. DUE-2012014.

Supplemental material

Supplemental data are available at *BIOSCI* online.

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