Supplemental Material

CBE—Life Sciences Education

Casper *et al*.

Supplementary Materials

These supplements contain the following:

A. Interview questions for three interview sequence

Interview One – Experiences in their class

1. Please briefly describe the biology classes you've taken
2. What topics in biology did you particularly feel excited about or enjoy learning about?
   - *If no topics stood out*, ask if there was anything they found more interesting or stood out?
3. What about these topics made them particularly exciting or enjoyable to learn about?
4. We recognize that gender is only one facet of how people see themselves. We welcome you to speak on your gender identity as well as any other identities that you feel are relevant for fully answering the question. How did you feel your gender and other identities were related to these classes?
5. Did your identities feel welcomed in your biology classes?
   - *If participant unsure about the question*: do you feel like you need to act differently or change how you act or what you talk about when you are in your biology classes?
6. What has been your experience of learning about sex and gender in biology classes?
   - What topics directly addressed sex and gender?
7. Are there ways these topics have been taught or discussed that made you feel uncomfortable?
   - *Interviewer note*: Ask why if the student does not explain why the materials made them feel a particular way.
8. Are there ways these topics have been taught or discussed made you feel included?
   - *Interviewer note*: Ask why if the student does not explain why the materials made them feel a particular way.
9. Are there ways you wish these topics had been taught and discussed in your class?
   - *Interviewer note*: Ask why if the student does not explain why the materials made them feel a particular way.
10. Is there anything else you want to tell us about?

Interview Two – Experience of their own identities in the setting of their biology classes

1. Based on your experiences in biology classes and interactions with instructors, how do you think instructors of your biology classes conceptualize sex and gender, and the relationship between the two?
2. How do you define sex and gender, and the relationship between the two?
   - *Interviewer note*: Make sure they define sex and gender in their answer.
3. Can you describe your identities that feel relevant to you when sex and gender are discussed in a biology class?
   - *Interviewer note*: If they talk about identities other than gender identity, ask them to explain more about their salient identities. Also ask any gender identity clarifications follow-up questions that feel relevant/useful.
4. Did you expect your biology classes to discuss your identities?
5. Where could your identity have come into the discussion?
6. Can you think about a time a topic or discussion in a biology class was counter to your own experience of identity and/or made you feel uncomfortable because of one of your identities?
   - *If they can, follow up with*:
     i) "Can you describe what about the topic or discussion made it stand out to you or made you uncomfortable? Was this a common experience for you?"
     ii) How did this experience make you feel? How did you deal with these feelings?
     iii) Is that typical of how you deal with this type of experience in biology classes?
     iv) What could have made you feel better supported?
7. What topics and discussions in your biology courses (if not in biology can expand to courses generally) have made you feel "seen"? Why did they make you feel this way?

8. Beyond the classrooms, have you had experiences with people in biology that have made you feel "seen" (if not in biology expand to college generally)? What about in college?
   - *If they have with bio folks*, follow up with:
     i) How did this experience make you feel this way? (i.e., what did the person do and why did that matter to the interviewee)
   - *If they have not with bio folks,* clarify: Is this because you don't interact with a lot of people in biology or is it because people it biology don't make you feel seen?
     i) *If it is because they haven't felt seen*, could they give an example or explain why they feel that way
9. What about in your personal life? Do you have people there who make you feel seen? What is that like?
10. Is there anything else you want to tell us about?

Interview Three – Influence of experiences on professional identity development, relationship with other students and faculty.

Card Sort Instructions. We're going to ask you to go a card sort activity that focuses on some common microaggressions that students can experience at college. The purpose of the activity is to get a sense of the range of experiences you've had in biology related to gender identity. You may opt out of this activity at any time, and can skip to interview questions now if you'd prefer.

Please lay these seven cards out on a spectrum of strongly disagree that you've had this experience to strongly agree that you've had this experience. You are welcome to place the cards at the same place in the spectrum, if they are the same amount of agreement/disagreement. For example, if you strongly agree with two cards, you don't have to rank them in order of which you agree with more.

You may opt out of this activity at any time.

Topic of each cards:

- Feeling invisible in biology
- Feeling unwelcome in biology
- Feeling like you don't fit into the biology community
- Being misunderstood by people in the biology community
- Watching what you say or do around people in the biology community
- Hiding part of your life from people in the biology community
- Having very few people you can talk to about your gender identity/expression in the biology community
- Having very few people you can talk to about your academic identity outside of biology

1. *As they place a card:*
   a) Can you give an example of when you've experienced this? Were there particular identities that felt most salient for you during this experience?
   b) How common is this feeling or experience for you?
   c) How has this experience impacted you?

*Following competition of the card sort***:**

2. How did these kinds of experiences affect your relationship with your professor and/or teaching assistant?
3. How did these experiences affect your relationship with your classmates?
4. How did these experiences affect your interest in science?

5. How did these experiences impact your sense of belonging in your biology classes and in a biology related career?
6. Are there other experiences not captured in these cards that have impacted your relationships with others in biology?
7. Are there other experiences not captured in these cards that have impacted your ability to see yourself in a biology-related career?
8. What could have made your experiences in biology classes better?
9. What do you think your experience could have been like if someone with identities similar to you had taught your biology classes?
10. How do you see this person's identities as influencing how they teach biology?
11. Is there anything else you want to tell us about?

B. Table of codes for Themes 1 - 3

Supp. Table 1: Master narratives identified by students with queer genders in biology courses (Theme 1).

Narratives in Biology Courses	**Definition**	**Example Quotes**
Gender essentialism	A belief that genders and gender roles are natural, biologically derived categories; that there is a "natural essence" of femaleness or maleness that influences one's behaviors and proficiencies.	*As content inclusive of only binary sexes*: "In [biology course] we talked about different animals and their sexes, but there's also a spectrum with sexes in animals and we never touched on that. We just don't talk about it and touch upon it at all." [Student 4] *As explicit statements upholding binary understand of sex*: "My professor said there are only two [sexes] and that's according to biology and it'll never change" [Student 3]
Biology as neutral	Social identities, personal beliefs, and political beliefs were not relevant to the biology classroom. Biology classes are politically neutral that should not offend anyone.	*Don't talk about identities*: "[Biology professors] they're really neutral, they just choose not to speak about [sex and gender]. They think it's touchy and they want to be politically correct." [Student 4] *Instructors' do not share personal beliefs on TNG identities*: "[Student] definitely have to guess. It's not very clear or apparent what [biology professors] opinions are" [Student 3]

Supp Table 2. Harms resulting from the master narratives in biology courses (Theme 2).

Belonging	*Exclusion* (n=5). Feeling unwelcome or different in biology courses because of gender identity	*The moment that [sex & gender topics] come up in class, I look around and people are in agreement with it.… If the professor said [the color] is red, it's red. They're not looking to challenge these ideas. They're not looking into the exception; they're not asking these questions…. It makes me extremely uncomfortable around my peers. I'm not close with my peers in my science classes as much as I am close with my peers [in other classes]. [Student 4]*
	Cognitive dissonance (n=1). Mental discomfort from conflicting beliefs	*I felt a little bit overwhelmed and kind of confused because…what he was saying and what I was feeling were very contradictory…[and] it kind of stuck with me, obviously.* [Student 3]
	Lack of identity safety (n=5). Absence of clear signals demonstrating queer genders	*If you don't see the safe zone sticker, if [professors] don't initiate the conversation, can we really share who we are with them? …Cis-het students have it so much easier*

	welcome in biology courses.	*because … they don't have that barrier of having to … come out to [their] Professor. Are they going to accept me? They don't have to do that.* [Student 5]
	Erasure (n=5). Gender identities not being addresses in biology courses.	*I guess the clearest example for … feeling invisible in biology would simply be the literature, the topics, the materials [and] largely anything that we're covering in class usually, the curriculum itself.… it was only [in one class] that I felt … I saw some examples [that were outside the binary] yeah and even then it was only like a few."* [Student 5]
	Relationship harm (n=5). Reduced ability to make meaningful relationships with instructor or peers.	*[Erasure] makes me feel less connected at a human level with my peers and my professors. I'm not in the position to create very connecting relationships. I'm there to get the job done and then get out, you know? I feel like I'm not included in the community. They didn't make a space [for me].* [Student 4]
Interest	*Bored* (n=3). Content based on binary sex/gender is boring. More inclusive content would enhance interest.	*"… the one that I always think about is talking about all the hermaphroditic plants …. These variances um can be found in in all of nature in all animals … I found that really interesting that I guess the way in which it's described as like maybe just a human phenomenon, or some a select subgroup of people want to do their own thing and think their own thoughts and this is so weird when it's ubiquitous in nature. [Student 5]*
Professional Preparation	*Performance* (n = 1). Exclusive nature of biology courses impacts academic success.	*"I'm just not going to answer the clicker questions… because I don't feel like [the questions] applies to me. I lost some points, but I was like I was, I was very adamant on not answering" [Student 1]*
	Access to opportunities (n=3). Erasure of gender identities limiting students' access to resources & opportunities.	*"[Lack of identity safety] gives me a hard time building personal relationship with [instructors] and then that prevents me from getting letter of recommendation so I can pursue future you know academic endeavors and I think that's a barrier for a lot of LGBTQ students."* [Student 1]
	Missed opportunity to educate (n=4). Exclusion of content on diverse gender identities does not prepare students to work with diverse people in their careers & does not provide a space to learn about themselves.	*"You're teaching a class of people who are going to be scientists, people going to be researchers, people who're gone to be healthcare providers. It brings a huge effect … to a lot of other people's lives, and I would expect with them to be aware [of] that. I felt like that was such a good opportunity. To go over … and to reconstruct what gender and sex is in society, but I guess the professor just didn't wasn't really aware of that."* [Student 1]

Supp Table 3. Resilience strategies to resist harms (Theme 3)

Strategy	**Example Quote**
Lowered expectations of biology content	*I don't think I felt any type of way when I didn't see [my biology courses being] very inclusive. If I had seen it, I would have been happy, but when I didn't see it … I wasn't sad about it. I didn't expect it. It was … biology being consistent with the rest of the world…"* [Student 4]
Focused on larger goals	*"I let it motivate me to work harder to so that I can reform health care, reform curriculum, reform the way health care is taught, reform the way biology is taught, because. It's one thing to be a member of the LGBT community but it's another thing to shape the community."* [Student 1]
Connected with people in biology they know are safe	*"There have been people who have been in my women's and gender studies classes who then I see in my biology class and I feel seen by them. They're awesome; I love them. But yeah everybody else I just kind of keep my distance."* [Student 2]
Searched out alternative sources of biology information	*I would internalize them a lot and then try then to be productive with them and try to look more into it delve deeper into the topics, even through YouTube or whatever I can find. Any resource that would talk about it. I learned later all the how many bio resources there are even on YouTube like a not just Khan Academy, but um a crash course and all these other ones that talk about a lot of different topics in really interesting ways.* [Student 5]
Developed critical thinking skills	*"I didn't feel right about [my professor's presentation of sex]. I was like I don't know if I agree, and so I decided to think about that, and simmer on it and research more…. and I decided since then, that I would keep their opinions out at a distance and make my own."* [Student 3]

C. A brief annotated bibliography of approach articles, book chapters, & books on the diversity of sex, gender, and sexual behavior in nature.

Below is a list of selected papers and book chapters that A. Casper & S. Eddy use in their own undergraduate biology courses to teach about the diversity of sex and reproduction and/or helped shaped their thinking on these topics.

Sex Determination

Bachtrog, D., Mank, J. E., Peichel, C. L., Kirkpatrick, M., Otto, S. P., Ashman, T.-L., Hahn, M. W., Kitano, J., Mayrose, I., Ming, R., Perrin, N., Ross, L., Valenzuela, N., Vamosi, J. C., & The Tree of Sex Consortium. (2014). Sex Determination: Why So Many Ways of Doing It? PLoS Biology, 12(7), e1001899. https://doi.org/10.1371/journal.pbio.1001899

- This paper discusses 12 different mechanisms by which sex is determined across species and identifies common misconceptions about sex determination. It discusses examples of organisms that use each mechanism of sex determination.

Pennell, M. W., Mank, J. E., & Peichel, C. L. (2018). Transitions in sex determination and sex chromosomes across vertebrate species. *Molecular Ecology*, *27*(19), 3950-3963.Unique contribution: sex determination is not a progression

- This paper demonstrates that how sex is determined and what sexes are present within a species and in a clade can change over evolutionary. One of its unique contributions is that it demonstrates that at least in fishes it is just as common to move from separate sexes to hermaphrodites as it is to move from hermaphrodites to separate sexes. This demonstrates that the condition of separate sexes is not necessarily the penultimate state like students may assume.

Furman, B. L. S., Metzger, D. C. H., Darolti, I., Wright, A. E., Sandkam, B. A., Almeida, P., Shu, J. J., & Mank, J. E. (2020). Sex Chromosome Evolution: So Many Exceptions to the Rules. Genome Biology and Evolution, 12(6), 750–763. https://doi.org/10.1093/gbe/evaa081

- This paper discusses a range of ways that sex chromosomes have evolved, including a discussion of the evolution of plant sex chromosomes. It includes clear figures that show sex chromosome evolution.

Furman, B. L. S., Cauret, C. M. S., Knytl, M., Song, X.-Y., Premachandra, T., Ofori-Boateng, C., Jordan, D. C., Horb, M. E., & Evans, B. J. (2020). A frog with three sex chromosomes that co-mingle together in nature: Xenopus tropicalis has a degenerate W and a Y that evolved from a Z chromosome. PLOS Genetics, 16(11), e1009121. https://doi.org/10.1371/journal.pgen.1009121

- This paper provides an example of a frog species whose sex determination mechanism is currently in transition. This species current has three different sex chromosomes and, currently, there are multiple chromosome combinations that can lead to an individual developing testes or ovaries. This paper helps readers understand sex determination as a changeable and changing process, rather than a fixed system.

Variation in Reproductive Behaviors (i.e., there are no typical sex roles)

Tang-Martínez, Z. (2016). Rethinking Bateman's Principles: Challenging Persistent Myths of Sexually Reluctant Females and Promiscuous Males. The Journal of Sex Research, 53(4–5), 532–559. https://doi.org/10.1080/00224499.2016.1150938

- This paper critiques Bateman's principles about sexual selection (the classic story of promiscuous males and coy females). The critique draws on both the social context of Bateman's work (how assumptions of his time could have influenced his conclusions) and numerous biological examples that counter Bateman's principles. Although long, it is very clearly written and includes a concise table that synthesizes the arguments present in the paper.

Roughgarden, J. (2013). Chapter 6: Multiple-Gender Families. In: *Evolution's rainbow: Diversity, gender, and sexuality in nature and people (75-105)*. Univ of California Press.

- This chapter explores how individuals of the same sex within a species can vary both in appearance and reproductive behaviors (e.g., there is no one way to be female even within a species). These differences are more commonly referred to as alternative mating tactics, but Roughgarden argues that they could also be seen as genders. She also highlights in this chapter how bias and background assumptions can influence scientific explanations for such variation within sex.
- *Note*: In general, the first eight chapters of this book are an accessible survey of the diversity of sex, gender, and orientation in organisms (with a focus on vertebrates).

No Traits Universally Determine Sex, Within or Across Species

Gorelick, R., Carpinone, J., & Derraugh, L. J. (2016). No universal differences between female and male eukaryotes: Anisogamy and asymmetrical female meiosis. Biological Journal of the Linnean Society. https://doi.org/10.1111/bij.12874

- This paper provides an extensive discussion of potential universal differences between male and female organisms across all eukaryotes, with the determination that there is no universally applicable definition that differentiates male and female organisms. This paper is impressively encyclopedic in its coverage.

Sanz, V. (2017). No Way Out of the Binary: A Critical History of the Scientific Production of Sex. Signs: Journal of Women in Culture and Society, 43(1), 1–27. https://doi.org/10.1086/692517

- This article describes the many different traits (anatomy, gonads, hormones, chromosomes, genes and brains) that researchers have tried to use to universally distinguish the sexes in humans. Each one of them has exceptions. Sanz also explores how various organizations such as the Olympics decide which of these traits to prioritize when they do not all align in a body.

Sexes and Mating Types

Billiard, S., López-Villavicencio, M., Devier, B., Hood, M. E., Fairhead, C., & Giraud, T. (2011). Having sex, yes, but with whom? Inferences from fungi on the evolution of angiosamy and mating types. Biological Reviews, 86(2), 421–442.

- This paper provides an in-depth discussion of existing hypotheses on the evolution gamete size (same size - isogamy, versus different sizes – anisogamy) and mating type (gametes are different molecularly). Through discussing these hypotheses in relationship to different fungi, the paper provides insights into understanding how and why different genetic determination of sex/mating type and reproductive strategies can lead to different species evolving and maintaining zero to thousands of mating types, as well as why only two different sizes of gametes have volved in isogamous species. Of note, this paper includes some discussion of species that only reproduce sexually through self-fertilization, and therefore benefits of sexual reproduction that are not related to genetic recombination.

Heitman, J., Kronstad, J. W., Taylor, J. W., & Casselton, L. A. (Eds.). (2007). Sex in Fungi. ASM Press. https://doi.org/10.1128/9781555815837

- Fungi employ a range of reproductive strategies and the chapters in this book provide in-depth coverage of this range and explores why these different reproductive strategies evolved. This provides insights into the many different ways sexual and asexual reproduction occurs. Chapters in the last section of the book, “The Implications of Sex,” discuss the importance of sexual reproduction in fungi and other organisms.

Genetics and Physiology of Sex and Gender

Fausto-Sterling, A. (2012). *Sex/gender: Biology in a social world*. Routledge.

- This short book is a primer for undergraduates that brings biology and gender studies in conversation with each other to explore how sex and gender develop over a person’s lifetime. This book has many powerful contributions but one of the most important is

that the influence of innate biological elements (hormones, genes, and brains) and culture cannot be disentangled when considering sex and gender.

Hyde, J. S., Bigler, R. S., Joel, D., Tate, C. C., & van Anders, S. M. (2019). The future of sex and gender in psychology: Five challenges to the gender binary. *American Psychologist*, *74*(2), 171.

- Hyde and colleagues clearly and approachably summarize how current research in neuroscience, neuroendocrinology, developmental psychology and psychology broadly challenge the idea of binary sex and gender. They propose instead that researchers should consider that sex and gender are tightly intertwined, are multi-dimensional, and each individual in a mosaic of traits that do not align with only one category of sex/gender.

Polderman, T. J., Kreukels, B. P., Irwig, M. S., Beach, L., Chan, Y. M., Derks, E. M., ... & Davis, L. K. (2018). The biological contributions to gender identity and gender diversity: bringing data to the table. *Behavior genetics*, *48*(2), 95-108.

- In this review Polderman and colleagues discuss how polygenic traits work, how they are studied in humans, and present a synthesis of the evidence of genetic and environmental influences on gender identity. In addition, this paper role models an ethical and community approach to science: acknowledging past wrongs done to queer folks in the name of science and engaging the community impacted by the research.

Syngamy (fusion of two gametes or fertilization) and Parthenogenisis

Booth, W., Schuett, G. W., Ridgway, A., Buxton, D. W., Castoe, T. A., Bastone, G., Bennett, C., & Mcmahan, W. (2014). New insights on facultative parthenogenesis in pythons. Biological Journal of the Linnean Society, 112(3), 461–468. https://doi.org/10.1111/bij.12286

- This paper provides an overview of facultative parthenogenesis (reproduction by a single individual without mating, in a species where they also reproduce sexually by mating) in vertebrates, and then focuses on specific cases of facultative parthenogenesis in two species of pythons. The paper includes discussion of different methods of parthenogenesis that can lead to offspring that are genetically different from the parent and each other (terminal fusion automixis, in which offspring are only half clones of their parent).

Ryder, O. A., Thomas, S., Judson, J. M., Romanov, M. N., Dandekar, S., Papp, J. C., Sidak-Loftis, L. C., Walker, K., Stalis, I. H., Mace, M., Steiner, C. C., & Chemnick, L. G. (2021). Facultative Parthenogenesis in California Condors. Journal of Heredity, 112, 569–574. https://doi.org/10.1093/jhered/esab052

- This paper discusses the discovery of facultative parthenogenesis in California Condors. Because the two females who reproduced parthenogenically were housed with fertile males, their offspring were assumed to be produced through sexual reproduction. However, genome mapping of all California Condors for the last 30+ years revealed the two individuals who were produced through facultative parthenogenesis. The implications of this paper include the benefits of facultative parthenogenesis, and the likelihood that facultative parthenogenesis is more common across bird species than previously thought.

Heesch, S., Serrano-Serrano, M., Barrera-Redondo, J., Luthringer, R., Peters, A. F., Destombe, C., Cock, J. M., Valero, M., Roze, D., Salamin, N., & Coelho, S. M. (2021). Evolution of life cycles and reproductive traits: Insights from the brown algae. Journal of Evolutionary Biology, 34(7), 992–1009. https://doi.org/10.1111/jeb.13880

- This paper provides great insights into the evolution of reproduction with same and different sized gametes has evolved through a phylogenetic analysis of brown algae. It includes a discussion of the evolution and loss of parthenogenesis (a gamete growing into an adult organism without fertilization) in both eggs and sperm. It also provides an overview of different types of lifecycles. The results demonstrate how phylogenetic analyses can help refute long-held assumptions about the evolution of reproduction and different sized gametes.

Variation in Sexual Behaviors

Roughgarden, J. (2013). Chapter 8: Same-sex sexuality. In: *Evolution's rainbow: Diversity, gender, and sexuality in nature and people (75-105)*. Univ of California Press.

- In this chapter Roughgarden reviews same-sex sexuality across vertebrates. She highlights evolutionary explanations, particularly those that posit same-sex sexuality is adaptive. In parallel, she explores why there has been so little research on and recognition of same-sex sexuality in nature.