Finding Mercie in a College Biology Course for Nonmajors

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Dedications Page

“Beneath every history, another history” ~Hillary Mantel

“I was sand, I was snow—written on, rewritten, smoothed over” ~Margaret Atwood

To all the women who faced headwinds as they sailed in pursuit of their destinies, and to all the girls with big dreams—may you journey boldly and travel far.

Abstract Page

This dissertation investigates how the numerical representation of women in small collaborative groups influences their learning in a college biology class for non-majors focused on sex, gender, and society. Prior to the start of the semester, the researchers divided students into all-male, all-female, or mixed-gender groups of varying sex ratios. The investigators then addressed how the identity-driven local ecology of these groups shaped student engagement and the emergence of scientific reasoning. Results from two separate but related studies demonstrated that all-female groups outperformed mixed-gender and all-male groups across a range of behavioral, affective, and performance metrics. Yet, a narrower focus on the emergence of scientific reasoning roles and behaviors in all-female groups revealed striking variation among these groups. One all-female group routinely used higher-order science reasoning moves, while another failed to perform academically, because students in this group struggled interpersonally. Data from semi-structured interviews suggest that all-female grouping does increase a sense of belonging in female-identified students—especially if they previously experienced invidious discrimination in science spaces and are thus vulnerable to social identity threat. However, the results also suggest that this type of grouping does not function as a panacea, and that additional social identities and lived experiences modulate whether single-sex grouping results in learning gains or deficits.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Consider the following scenario, involving two freshman roommates at a typical university in the United States: Sarah[1] and Mercedes (Mercie, to her friends). Sarah starts the academic year excited to pursue an engineering degree. Sadly, she soon encounters several gender mediated psychosocial barriers (Chen et al., 2021), from science classrooms dominated by men to invidious messaging from her peers and instructors (Hildebrand, Monteith, Carter, & Burns, 2022; Maloy, Kwapisz, & Hughes, 2022). Sarah begins to experience stereotype threat (Deemer, Lin, & Soto, 2016) and trust and belongingness concerns (Höhne & Zandler, 2019a), both of which impact her academic performance, professional aspirations, and general wellbeing (Schuster & Martiny, 2017). Eventually, Sarah changes her major and leaves the STEM world behind (Höhne & Zandler, 2019b).

Scientists, educators, and policy makers in the past few decades have become rightfully concerned with the educational and social context that leads students like Sarah to de-identify with their STEM career aspirations (Lauer et al., 2013). And multiple interventions have been proposed to mitigate the “chilly” college classroom environment that engenders this domain de-identification (e.g., Jordt et al., 2017). Yet comparatively

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[1] Boucher and Murphy (2017) poignantly recount Sarah’s journey in their seminal chapter on gender, identity, and STEM education. Their use of Sarah as a rhetorical device helped conceive Mercedes as the analogue for non-majors.

less attention has been paid to the university experience of nonmajors like Mercedes, who exited the STEM field long before they entered college.

Mercedes dreads science instruction, perhaps because she experienced continuous, demeaning interactions from her instructors and classmates in the K-12 setting (Dare & Roehrig, 2016; Wieselman, Dare, Ring-Whalen, & Roehrig, 2020). Or perhaps she internalized messaging at home and in the classroom that depress women's ability to think quantitatively or reason scientifically (e.g., female teachers' contagious math anxiety, Ganley, Schoen, LaVenia, & Tazaz, 2019; parent-child transmission of math anxiety, Casad, Hale, & Wachs, 2017; low math self-concept in women, Sax, Kanny, Riggers-Piehl, Whang, & Paulson, 2015; sex-specific STEM anxiety and neural connectivity, Gonzalez et al., 2019). Regardless of the reasons for her previous withdrawal from the STEM world, Mercedes must once again enroll in a science course to fulfill the general education requirements of most colleges and universities. During the first day of class, Mercedes will look around the room and feel alone; but she is not alone. Taking the science class for non-majors with her are Jodi, a bodybuilder with a wicked sense of humor; Hyo-rin, an international student from South Korea; Sonia, a first-generation Latine[2] student; Leonora, a female-identified transgender student; and

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[2] While (<5% of) Latinos and Latinas raised in the United States rely on the "LatinX" construction to denote gender neutrality, this dissertation follows the long and well-established global tradition of using "e" at the end of gendered Spanish words to render them gender inclusive (del Río González, 2021). Further, people living in Latin America, Spain, and other Spanish-speaking countries understand that pan-ethnic terms such as LatinX hurtfully conflate people from disparate cultures. These citizens, including the author

Titilayo, a student of Nigerian descent. This dissertation uses a mixed methods approach to explore how social identity and culture impact the experiences of these and other students' academic experience in a nonmajors biology class. While this research foregrounds gender as a unifying characteristic, it also relies on an intersectional lens (Crenshaw, 1989; 1991; Kozlowski, Larivière, Sugimoto, & Monroe-White, 2022) to investigate the influence of other identity-level variables, such as race, age, and country of origin (Canning, LaCosse, Kroeper, & Murphy, 2020). Intersectionality understands that social categorizations such as race, class, and gender develop within interrelated systems of disadvantage—in this case, within college science classrooms and post-secondary institutions.

The following chapter (Chapter 2) provides a comprehensive review of the literature. The chapter opens with an exploration of sex and gender, and how these two social categories may alter the objective and subjective academic experiences of female-identified students. It then transitions to a broad discussion of social identity theory, and how group-based stigmatization may activate social identity threat in vulnerable students. After that, the chapter switches from a description of the psychosocial profiles of college students to a description of the education setting in question: biology classes for nonmajors. Active learning and collaborative small group instruction feature prominently

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of this dissertation, therefore decline to employ impractical and unnecessary grammatical changes that—*in this context*—amount to American linguistic imperialism. The dissertation will use the LatinX construction only for those individuals who themselves identify as LatinX.

at this point, since these two instructional innovations have gained in popularity over the past decade, including in science courses for nonmajors. Finally, the chapter concludes with how these learning innovations—steeped as they are in collaborative, discourse-heavy practices—may serve to reinforce, rather than mitigate, the social identity concerns introduced previously. As befits a literature review in the social sciences, theory will be drawn from a wide range of disciplines, from science and social psychology to law and linguistics. Findings from this diverse array of sources will ground this dissertation and validate the methodological approaches chosen therein.

Chapter 3, in turn, describes the educational, biological, and sociological contexts that inform these studies. The researchers collected data in a college biology class for nonmajors that used an evolutionary ecology lens to explore sex-based differences in morphology, physiology, and behavior across a range of species, including humans. The instructor designed the course to be accessible by freshmen with a limited science background, relying on active learning and inclusive teaching strategies to ground and contextualize evolutionary and ecological concepts, theories, and case studies. This chapter (Chapter 3) thus provides an overview of the disciplinary concepts the instructor taught, as well as her curricular and instructional choices. Finally, given the course openly discusses how sex, gender, and society intersect, the chapter also summarizes the sociopolitical movements that permeated the period encompassing data collection (2016) and final publication (2023). This period has been characterized by conflict, with people expressing strong views on everything from (toxic) masculinity and sexual violence to the proper role of science instructors and public health officials in a democracy.

Description of Studies

The dissertation then transitions to two related but ultimately independent research studies (Chapters 4-5). These chapters query a different formulation of the same overarching research question: How does the sex ratio of collaborative groups affect the educational experience of college students in a biology course for nonmajors? Both chapters follow the traditional structure of a primary research paper, from an introduction and research questions to methods, findings, and conclusions.

Chapter 4 contains the first study. It takes a top-down mixed-methods approach to measure how the sex ratio of collaborative groups influences students' engagement. This study quantifies the attendance and perceived engagement of students throughout the semester, and then analyzes whether the percentage of women in student groups affected these variables. The study supplements this quantitative inquiry with semi-structured interviews that allow the researcher to probe the subjective learning experiences of students in the course—especially in relation to collaboration with peers.

Chapter 5 contains the second study. It explores how women in single-sex collaborative groups develop their scientific reasoning skills. It first measures students' volubility and then quantifies the number of times each student proposes a claim, provides evidence, or uses logical reasoning during a lesson on the costs of sex. The study then rates each group’s quality of scientific reasoning and explains how different student behaviors either hindered or encouraged its development. The chapter concludes with a qualitative dive into student discourse, making connections between students’ non-academic discursive roles—including going off-task, socially loafing, or making jokes—and the emergence of scientific reasoning.

Chapter 6 synthesizes the conclusions presented in the two previous studies and inductively weaves them into a cohesive call to action. It argues that instructors must take a critical, gender-focused lens to their instructional practices. The chapter also concludes that gender-based grouping can help address social identity threat under certain conditions. Future research in the field of educational gender equity will hopefully continue to bring clarity to this area and to foster more inclusive learning environments.

Chapter 2: Literature Review

Multiple, interacting variables will determine the academic trajectory of Mercedes and other female-identified students in a college science course for nonmajors. These variables are multifaceted, and include psychological (e.g., gender identity), sociocultural (e.g., patriarchal bias), and behavioral (e.g., women's withdrawal from male-dominated spaces) components. To fully understand how these components interact, one must first evaluate them individually. The following section opens with an interrogation of the preeminent variable guiding this dissertation: gender.

Sex and Gender: An Introduction

To understand how gender impacts learning in the science classroom, one must first address how gender expands on sex assigned at birth[3]. Sex is a biological category based primarily on the reproductive potential of an individual, while gender is a social construct that extends past a person's sex assigned at birth (Bittner & Goodyear-Grant, 2017; Lindqvist, Gustaffson Sendén, & Renström, 2021). "Gender," Eckert and McConnell-Ginet (2013) clarify, "builds on biological sex, it exaggerates biological difference and, indeed, it carries biological difference into domains in which it is completely irrelevant" (p. 10). Evaluating how gender transforms biological sex into a social construct necessitates an understanding of how various sexual species partition

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[3] This dissertation asserts that "sex assigned at birth" is the more equitable and socially conscious terminology. "Biological sex" obscures the fact that sex is assigned using a combination of subjective and socially contestable factors (Winter et al., 2016).

male and female reproductive function within and between organisms. The following section provides said overview.

The Biology of Sex

Simply put, the male-female binary is neither as widespread nor as rigid a classification as popularly conceived (Ahnesjö et al., 2020; Clutton-Brock, 2017). Many species are asexual (Yamamichi & Ichiro, 2020), while others rely on asexual reproduction at certain points during their life cycle (e.g., the parthenogenetic lizard *Darevskia unisexualis,* Vergun et al., 2020; yeast and budding, Fraschini, 2019; and strawberry plants and clonal propagation, Wilk, Kramer, & Ashley, 2017). In sexually reproducing species, sex is nothing more than the functional consequence of anisogamy[4], and its expression varies markedly from species to species (Lively & Morran, 2014). Some sexually reproducing species are hermaphroditic (Christopher, 2019). In these species, organisms produce functional male and female gametes during their lifetimes (Schaerer, Janicke, & Ramm, 2015). Other sexually reproducing species are instead dioecious[5]; male and female function are separated (Bachtrog, 2014). To complicate matters further, many species display complex mating systems that differ markedly from the XY sex-determination system of dioecious mammals (e.g., gynodioecy in the blue

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[4] Anisogamy refers to sexual reproduction by the fusion of gametes of different sizes. By convention, in biology organisms that produce the larger-sized gamete are considered female (Lehtonen, Parker, & Schärer, 2016).

[5] From the Greek words *di-* (“two”) and *oikos* (“houses”). Dioecious organisms are either egg-producing females or sperm-producing males. Humans and *Gingko biloba* trees are examples of dioecious organisms.

cardinal flower *Lobelia siphilitica*, with only female and hermaphroditic individuals present in a population, Eisen, Case, & Caruso, 2017; the ZZ/ZW sex-determination system in cichlid fishes, where females are heterogametic[6], Feller, Ogi, Seehausen, & Meier, 2021; and haplodiploidy in the rusty-patched bumblebee *Bombus affinis*, where unfertilized eggs develop into males, Strange & Tripodi, 2019). Even in those species with recognizably male and female individuals, sex expression emerges from a complex interaction among chromosomal, epigenetic, hormonal, and environmental variables that include pathogen and predator prevalence (Doubleday & Adler, 2017), ambient temperature (Bock et al., 2020), social dominance (Sunobe et al., 2017), and maternal condition (Vega-Trejo, Head, Jennions, & Kruuk, 2018). Some organisms can even switch between sexes within their lifetime; in groupers (Family *Serranidae*) the largest female fish in the colony becomes male through a series of hormone-mediated processes once the previous male dies[7] (Soyano et al., 2022).

Even in human populations, individuals are born with anatomical or hormonal variations that preclude their easy classification as either male or female[8] (Chew et al., 2020; Fausto-Sterling, 2013). 1 in 100 babies begin life with anatomies that differ from

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[6] Denoting the organism with two sex chromosomes that differ in morphology. For example, in many mammal species, male organisms are heterogametic (i.e., they have an X and a Y chromosome).

[7] This and other examples expose the insidious lie at the core of transphobic rhetoric (i.e., that gender-affirming therapy 'isn't natural.' For a review of this and other barriers faced by transgender individuals, see Puckett, Cleary, Rossman, Newcomb, & Mustanski, 2017).

[8] Fausto-Sterling (2013) correctly concludes "labeling someone a man or a woman is a social decision", rather than purely a biological or medical one (p. 3).

the standard male or female archetypes (Jones, 2018), while genetic mutations can result in individuals who are chromosomally male (i.e., with an XY karyotype) yet phenotypically female (e.g., androgen insensitivity syndrome, Fulare, Deshmukh, & Gupta, 2020). Consequently, cataloging someone a man or a woman involves a cultural and subjective judgment, in addition to a scientific and medical one, since societal beliefs about gender influence definitions of sex (Pearse & Connell, 2015; Weber, Cislaghi, Meausoone, & Loftus, 2019).

As the previous examples demonstrate, the contemporaneous male-female binary does not approximate biological reality (Ahnesjö et al., 2020; van Anders, 2013). Said binary leads to gender polarization, defined as the normative legal and cultural structures that differentiate between men and women (Wong, Shi, & Chen, 2018), potentially inhibiting an individual's life choices and personal expression (Bishop, Kiss, Morrison, Rushe, & Specht, 2014; Blair & Hoskin, 2016). The male-female binary proves insufficient (Morgeroth & Ryan, 2021), and should be discounted in favor of a continuum that more accurately reflects—and celebrates—the natural world and human experience. Anything less amounts to a flagrant misrepresentation of the biological record in service of parochial, contestable, and ultimately harmful societal perceptions of sex and gender.

Gender as Performative Classification

Gender arises from an individual's construction of social identity (Butler, 1993; Morgenroth & Ryan, 2018), and is both inherently social and deeply contextual

(Carothers & Reis, 2013; Netchaeva, Kouchaki, & Sheppard, 2015). “Gender,” Eckert and McConnell-Ginet write (2013), “is not something we are born with, and not something we *have,* but something we *do*” (p. 10). Gender can therefore be understood as a performative identity that encompasses sexuality, past lived experiences, and reactions to pervasive social norms (Bishop, Kiss, Morrison, Rushe, & Specht, 2014; Sinnes & Loken, 2012). The concept of performative production of sexual difference is most closely associated with Butler’s work *Gender Trouble* (1999), where she methodically dissects how sexual differences between people become major components of the social fabric that govern contemporaneous norms and behaviors. Butler makes this connection explicit when she argues that society takes as self-evident “the position that there is a natural or biological female who is subsequently transformed into a socially subordinate ‘woman’, with the consequences that ‘sex’ is to nature […] as gender is to culture” (p. 47). The illusory existence of the former justifies the hegemonic systems that brutally police the latter (Dinno, 2017; Levy & Levy, 2017; Chirwa, Jewkes, van der Heijden, & Dunkle, 2020). See Breyer, Sotomayor, & Kagan, J., dissenting in *Dobbs v. Jackson Women’s Health Organization,* 597 U.S. ___ (2022).

Butler (1999) even questions the assumption that gender is the psychological or cultural expression of sex. She argues that providing gender with a “substantive identity category” obscures the epistemological epiphany that gender only exists within "grammatical categories"[9] (Clark, 2012, pp. 32-33). Essentially, language creates—rather than merely describes—gender. Butler maintains "[a]ll psychological categories (the ego, the individual, the person) derive from the illusion of substantial identity" (Haar, 1977, as cited in Butler, 1999, p. 27). These observations compelled Butler (1999) to propose that gender should be understood as performative: a person's gender identity does not dictate their behavior. Rather, a person's gendered behavior creates their identity. Through the enactment of these gendered identities, individuals collectively validate the social regulatory structure that governs their lives, reifying the purported sexual differences that justify the system. Butler (1999) describes these regulatory practices as:

> acts and gestures, articulated and enacted desires [that] create the illusion of an interior and organizing gender core, an illusion discursively maintained for the purposes of the regulation of sexuality within the obligatory frame of reproductive heterosexuality (p. 173).

Gender, then, is the expression of unspoken rules of how men and women (and non-binary individuals) must behave within a heterosexual and patriarchal system (Carter, Croft, Lukas, & Sandstrom, 2018). Children learn about gender through socialization, described by de Beauvoir (1972) as a process of "social discrimination [that] produces in women moral and intellectual effects so profound they appear to be caused by nature" (p. 18). Feminine and masculine behaviors are thus socially acquired,

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[9] Consider the LatinX movement (confined to the United States) and the use of gender-neutral "e" constructions in Latin America, Spain, and other Spanish-speaking countries (e.g., 'Latine' refers to both Latino and Latina individuals). These approaches are consciously trying to extirpate gender from grammar to be more inclusive.

rather than naturally derived from biological sex (Westbrook & Saperstein, 2015). "Gender," Lindqvist and colleagues elaborate, "is a non-essential category […] repeatedly performed on societal norms" (Lindqvist, Gustaffson Sendén, & Renström, 2021, p. 333). And this repeated performance is "culturally and historically specific, internally contradictory, and amenable to change" (Hegarty, Ansara, & Barker, 2018, p. 59). To borrow a metaphor from the law, gender functions like "a demiurge" because it possesses a "generative power of its own, and all that it creates [is] in its own image." Jackson, J., dissenting in *Korematsu v. United States,* 323 U.S. 246 (1944). These observations led Eckert and McConnell-Ginert (2013) to observe, somewhat wryly, "gendered performances are available to everyone, but with them come constraints on who can perform which personae with impunity" (p. 10), since individuals who do not conform to stereotypical enactments of their expressed sex are punished socially[10] (Baumermeister, Connochie, Jadwin-Cakmak, & Meanly, 2017; Miller & Grollman, 2015).

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[10] As evidence for this claim, evaluate the following cases, the former ultimately positive, the latter infinitely tragic. The first case involves Anne Hopkins, a lawyer who was denied partnership at her firm simply because her demeanor and behavior did not conform to traditional gender stereotypes. A senior partner at her law office, Price Waterhouse, admonished her to "walk more femininely, talk more femininely, dress more femininely, wear make-up, have her hair styled, and wear jewelry." *Price Waterhouse v. Hopkins,* 618 F.Supp., at 1117. (1989). Ms. Hopkins sued instead and won a major Title VII case at the Supreme Court of the United States. Now shift your attention to the reality that trans women continue to be murdered for their performance of gender, both in the United States and abroad (Carlisle, 2020).

Social Identity Theory

Having established a working definition of gender as a social construct, the next step is to identify how social categories, such as gender and socioeconomic status, color students' academic experiences in the postsecondary science classroom (Jetten, Iyer, & Zhang, 2017; Skourletos, Murphy, Emerson, & Carter, 2013). Social identity theory facilitates this exploration by explicitly linking the psychosocial processes of individuals with the educational contexts those individuals inhabit (Constantine, 2017; Emerson & Murphy, 2014).

Social identity theory operates under the guiding principle that people express themselves either as individuals or as members of distinct groups (Canning, LaCosse, Kroeper, & Murphy, 2020; Koenig & Eagly, 2014; Tajfel & Turner, 1979), and that this self-definition depends on social context (Reynolds, Subasic, Lee, & Bromhead, 2017). People will emphasize their 'personal identity' and individual self whenever they would like to differentiate themselves from others; they will underscore their 'social identity' and social self whenever membership carries personal and emotional value (Boucher & Murphy, 2017; Emerson & Murphy, 2014). The latter point is vital, for it conveys that within the social identity framework, the term 'group' does not refer merely to demographic or professional categories (Platow, Hunter, Haslam, & Reicher, 2015). Rather, the term refers to *psychological groups* that are self-defining, self-relevant, and self-reinforcing to the individual (Boucher & Murphy, 2017).

Belonging to a psychological group imparts multiple physiological and affective rewards (Miller, Wakefield, & Sani, 2015). In-group members working together will be more motivated to achieve communal goals, will interact more positively with one another, and will be more open to influence and persuasion from other in-group members (Reynolds, Subasic, Lee, & Bromhead, 2017). Heightened cohesion flows directly from the collective need of group members to internalize and conform to the norms that guide the group (Smith, Louis, & Tarrant, 2017).

Group membership, however, can also exact psychosocial costs (Cohen, Purdie-Vaughns, & Garcia, 2012). First, a group-level identity may exist in tension with a person's desire to be judged based on personal characteristics or merit rather than group membership (Frederick, Grineski, Collins, Daniels, & Morales, 2021; Peng & Solheim, 2015). Mercedes, for example, may powerfully and positively self-identify with her gender. Yet that positive association does not mean Mercedes appreciates being evaluated solely on the basis of her sex—in all settings, all the time. She would justifiably bristle if her biology professor dismissed her as simply 'another female student' in the class. Imagine if, during office hours, the hypothetical professor made an offhand comment of how 'women tend to struggle' in the course 'because they lack the self-confidence to participate in science conversations' and thus 'fail to reason scientifically'. Such comments, in that context, erase the unique combination of skills, effort, and challenges that Mercedes brings to the classroom.

Second, society does not value all social groups equally; it extolls some while it disparages others (McGee & Robinson, 2019). Tajfel and Turner (1979), early theorists on identity construction, summarize this interaction when they describe how social identities may lead individuals to be viewed positively (if they belong to a non-stigmatized group) or negatively (if they belong to a stigmatized group) by society. This subjective over- and undervaluation, Ong and colleagues (2018) argue, partly explains why BIPOC women in STEM, for example, remain underrepresented relative to their numbers in the general population (Ong, Smith, & Ko, 2018). Latinas and Black women experience stigma in STEM post-secondary programs on two fronts: first on race, and second on gender—the 'double bind' (McGee & Robinson, 2019). And this stigmatization leads to pernicious psychosocial processes, such as social identity threat (Thomas, McGarty, & Mayor, 2016), a concept elaborated on below.

Social Identity Threat

The need to develop and maintain positive interpersonal relationships forms a foundational aspect of human motivation (Morgenroth & Ryan, 2021; Pietromonaco & Collins, 2017). The value society places on a given psychological group greatly impacts the contextual psychosocial experience of its members (Musto, 2019; Morgenroth & Ryan, 2018; Skourletos, Murphy, & Emerson, 2013). "When society values a group," Justice O'Connor (1984) admonishes, "it sends a message to its [members] that they are insiders, favored participants within the [] community, as well as an accompanying message to non-[members] that they are outsiders, disfavored participants within the [] community". Concurring in *Lynch v. Donnelly*, 465 U.S. 668 (1984). Furthermore, people are especially likely to be concerned about being devalued when negative stereotypes or a history of bias exists for that social group (Winter et al., 2016)—such as female-identified individuals in STEM classes (Good, Rattan, & Dweck, 2012; Grunspan et al., 2016). When an identity is perceived to be degraded, people can experience social identity threat, "the worry and uncertainty that they will be viewed and evaluated through the lens of their group's negative stereotypes" (Boucher & Murphy, 2017, p. 95). The following sections will expand on the concept of social identity threat, using the interaction between gender and postsecondary science classes as contextual background.

The Four Components of Social Identity Threat

Social identity threat can be partitioned into four distinct components: Stereotype threat concerns, belonging concerns, social exclusion concerns, and trust and fairness concerns (Biliuc, Goodyear, & Ellis, 2017). Which components of social identity threat become activated depends both on the individual's unique psychosocial vulnerabilities as well as the sociocultural context occupied by the individual (Smyth, Mayor, Platow, Grace, & Reynolds, 2015). The sociocultural context considers both social interactions among individuals as well as situational cues, which Emerson and Murphy (2014) define as the physical (e.g., high-tech active learning classroom, Cotner, Loper, Walker, & Brooks, 2013), demographic (e.g., female representation, Boucher & Murphy, 2017), and organizational features of a space (e.g., single-sex instruction, Pahlke, Hyde, & Allison, 2014). The gender of a college instructor, for example, functions as a situational cue, and has been linked to changes in student’s motivation in STEM courses (Dasgupta, Scircle, & Hunsinger, 2015; Deemer, Lin, & Soto, 2016; Solanki & Xu, 2018). Situational cues can be overt, such as the high incidence of sexual harassment in Physics departments (Aycock et al., 2019), or covert, such as gendered bias in grading across educational levels (Doornkamp et al., 2022). Covert situational cues in educational settings can be particularly pernicious, in part because they are hard to evaluate consciously, and in part because they affect even the most self-confident of students (Boucher & Murphy, 2017; Smith, Lewis, Hawthorne, & Hodges, 2012). Numeric underrepresentation by race, class, or gender in the STEM classroom, for example, exerts intense and far-reaching effects on students by triggering both objective experiences of social identity threat (e.g., cognitive and psychological vigilance) and subjective experiences of identity threat (e.g., decreased sense of belonging and a dampened desire to engage with classmates) (Carli, Alawa, Lee, Zhao, & Kim, 2016; Frederick, Grineski, Collins, Daniels, & Morales, 2021; Jetten, Iyer, & Zhang, 2017). The following sections first describe each of the four components of social identity threat in general, and then explain how the components become activated when a student’s psychosocial profile collides with situational cues in the biology classroom for majors and nonmajors alike.

Stereotype Threat

Totonchi and colleagues (2022) describe stereotype threat as the "anxiety related to confirming the negative stereotypes about one's group" that engenders temporary cognitive deficits, typically observed during high-stakes performance tasks (p. 1). Often, evaluation in and of itself is enough to trigger social stereotype threat, "especially when the task is difficult and the stakes for success are high" (e.g., a college final exam in the physical sciences, Boucher & Murphy, 2017, p. 97). The psychological vigilance elicited by stereotype threat arises from the burdening perception that one's potential is being evaluated through the jaundiced lens of group stereotypes that favor a group's performance deficits within a domain over individual achievement (Makarova & Herzog, 2015; Smith, Brown, Thoman, & Deemer, 2015). The psychological vigilance associated with stereotype threat engenders emotional suppression and reduces working memory capacity (McGee, 2018; Spencer, Logel, & Davies, 2016), both of which result in stereotyped individuals completing high-stakes tasks at a disadvantage (Makarova, Aeschlimann, & Herzog, 2019; Smith, Brown, Thoman, & Deemer, 2015). Often, being asked to identify one's group membership (e.g., marking "F" in a demographics form, Smith, Lewis, Hawthorne, & Hodges, 2012), or listening to an offhand pejorative comment (e.g., 'men outperform women in mathematical tasks', Spencer, Logel, & Davies, 2016), or being the target of offensive objectification (e.g., 'you're pretty when you smile’, Guizzo & Cadinu, 2016; Kahalon, Shnabel, & Becker, 2018), are enough to elicit stereotype threat (Maloy, Kwapisz, & Hughes, 2022; Olzmann, 2020).

Stereotype Threat in College Biology. Women and girls harbor a subconscious fear of validating society’s low expectations of their gender during high-stakes assessments (Spencer, Logel, & Davies, 2016; Shenouda & Danovitch, 2015). Some researchers have consequently advocated for a shift toward lower-stakes assessments and a more equitable distribution of points across the curriculum (Cotner & Ballen, 2017; Scott, McNair, Lucas, & Land, 2017). “Reliance on high-stakes exams,” Tracy and colleagues (2022) caution, “[…] and large class sizes, particularly in introductory courses […] contribut[e] to students’ perceived struggles” (p. 11) for both majors and nonmajors in college biology courses.

Research further shows that effective study habits (Numan & Hasan, 2017), intrinsic motivation (Dyrberg & Holmegaard, 2019), and self-efficacy (Tracy et al., 2022) can psychologically protect students during high-stakes assessments. Yet nonmajors will have developed these skills in a different educational context that may not easily translate to the STEM classroom (Salehi, Cotner, & Ballen, 2020; Tracy et al., 2022). To illustrate, biology majors employ study strategies that nonmajors do not (e.g., re-working incorrect homework responses, Knight & Smith, 2010), and they likewise spend more time, on average, studying for midterms and exams (Knight & Smith, 2010). In addition, women in STEM programs have different neural connectivity and brain correlates than their nonmajors counterparts (Gonzalez et al., 2019), and these differences impact anxiety and ‘academic grit’ (Tracy et al., 2022) during high-stakes science and math exams. These affective, behavioral, and neurobiological differences suggest female nonmajors are especially vulnerable to stereotype threat, because they did not develop STEM-based resiliency in the K-12 setting (Hall, McGill, Puttick, & Maltby, 2022). Further, while previous exposure to biology lowers the effects of high-stakes exams, nonmajors, by definition, generally enter college with less experience with and a lower emotional connection to the discipline (McFarlane & Richeimer, 2015). They likewise possess, on average, lower mathematical self-confidence, when quantitative skills strongly impact success in undergraduate biology courses (Flanagan & Einarson, 2017).

To summarize: biology courses with exams that count for a disproportionate portion of the final grade invariable disadvantage women by triggering stereotype threat (Totonchi, Perez, Lee, Robinson, & Linnenbrink-Garcia, 2021; Tracy et al., 2022). Thankfully, unlike the other components of social identity threat discussed below, college instructors control the curricular and instructional variables that activate this component of social identity threat (Scott, McNair, Lucas, & Land, 2017). As recent research shows, mixed-methods assessments that value group participation, low-stakes quizzes, and in-class activities ameliorate the effects of stereotype threat by decreasing the importance of final exam, for both majors and nonmajors (Cotner & Ballen, 2017). Likewise, biology curricula that explicitly incorporate skills-building (e.g., effective study skills) can bridge the behavioral and affective gap between majors and nonmajors (Hall, McGill, Puttick, & Maltby, 2022), thus lessening the likelihood and severity of social identity threat.

Belongingness Concerns

When people question their connection to a particular social setting, they may experience belongingness uncertainty (Bloodhart, Balgopal, Casper, Sample McMeeking, & Fischer, 2020). This component of social identity threat can be defined as a lack of fit between the individual and other members in the setting, although that lack of fit also extends to situational cues (Cheryan, Ziegler, Montoya, & Jiang, 2017). For example, Ong and colleagues (2018) demonstrated that Black and Latine STEM students who knew they could access safe spaces reported higher rates of persistence and academic success. Conversely, those students who experienced social ostracism within the major felt a concomitant psychological separation from the major (Ong, Smith, & Ko, 2018). Like stereotype threat, belongingness uncertainty adversely affects academic domain identification, achievement, persistence, and career aspirations of afflicted students (Leaper & Starr, 2019; Pietri et al., 2019). Unlike stereotype threat, however, belongingness concerns are not restricted to specific, high-stakes assessments (Höhne & Zandler, 2019a). These concerns consequently describe a more general psychological phenomenon that arises from the gnawing doubt that a particular educational space shuns certain social identities (Riegle-Crumb & Morton, 2017). Reason through how female students in STEM courses are keenly aware of their peers' and instructors' bigotry of low expectations (McGee, 2020a). Now connect that psychosocial priming with female students' sensitivity to situational cues that signal a lack of fit, from the numerical underrepresentation of their gender (Boucher & Myrphy, 2017), to the male-centric classrooms (Bloodhart, Balgopal, Casper, Sample McMeeking, & Fischer, 2020; Perez, 2019) and sexually antagonistic conversations (Aycock, Hazari, Brewe, Clancy, Hodapp, & Goertzen, 2019; Leaper & Starr, 2019) that sometimes define the STEM educational context (Tao & Gloria, 2019)—especially in physics, computer science, and other disciplines that lag behind in gender parity. Logically, rejection based on group membership lowers students' sense of well-being and stunts their relationships with instructors and peers (Boucher & Murphy, 2017; Höhne & Zandler, 2019a). To learn effectively, a student must first feel like an integral member of the learning environment.

Belongingness Concerns in College Biology. As the previous section clarified, belongingness concerns are more likely to surface in science classrooms where women occupy a distinct minority (Boucher & Murphy, 2017; Perez, 2019). Over the past decade, however, biology education has undergone rapid demographic change, with women accounting for 60% of college graduates in the life sciences (Bailey et al., 2020; Board, 2018). Likewise, while most tenured faculty in biology are men (>60%), younger faculty are roughly 50% women (Charlesworth & Benaji, 2019). This increased gender representation at both the student and instructor level likely neutralizes the belonginess concerns tied to numerical representation previously described (Cheryan et al., 2017).

However, other variables besides numerical underrepresentation can signal a lack of fit, especially if a history of gender bias permeated the field[11] (Boucher & Murphy, 2017; Cheryan et al., 2017). Despite gains in representation, students, teaching assistants, and faculty still display implicit gender biases that signal a lack of fit within educational spaces in the life sciences (McNutt, 2015; Sarson, 2017). Women in biology are less likely to be recognized for their academic productivity and disciplinary contributions, be they students in the classrooms (Bian, Leslie, & Cimpian, 2017; Grunspan et al., 2016) or scholars at the podium (McNutt, 2015; Sarson, 2017). College students also tend to penalize female instructors with course evaluations, judging them less knowledgeable and competent than male instructors (MacNell, Driscoll, & Hunt, 2014). In addition, the biology cannon remains male biased (Simpson, Beatty, & Ballen, 2020; Wood et al., 2020). As Simpson and colleagues (2020) observe, "[u]ndergraduate science textbooks reinforce a dominant language of science that is often white and masculine" (p. 1) by highlighting historical figures and scientists from selective institutions, both of which tend to be male dominated (Córdova, 2016; McNutt, 2015). Finally, a recent study demonstrated that male students consistently underestimate the scientific knowledge of their female peers (Grunspan et al., 2016), while another documented how biology instructors themselves tend to favor male students over female students (Moss-Racusin,

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[11] Biology, like other STEM fields, traditionally discriminated against women (Huang, Gates, Sinatra, & Barabási, 2020).

Dovidio, Brescoll, Graham, & Handelsman, 2012). These examples of bias may elicit belongingness concerns even in gender-balanced STEM classrooms.

Social Exclusion and Trust and Fairness Concerns

These two types of concern have received less attention in the academic literature and are more closely associated with discriminatory behaviors and policies (McGee & Robinson, 2019; Ong, Smith, & Ko, 2018). “Members of stigmatized groups,” Boucher and Murphy (2017) caution, “are vigilant for evidence in the environment as to how they will be treated by others” (p. 97). And members of the dominant social group—often white, often male—are sensitive to accusations of bigotry (Forbes, Stark, Hopkins, & Fireman, 2020; Veldhuis, Gordijn, Veenstra, & Lindenberg, 2014), due in part to a psychological phenomenon called motivated reasoning[12] (Rudert, Sutter, Corrodi, & Greifeneder, 2018). These dynamics create unfortunate educational contexts where some students’ need to trust their educational environment is subordinated to most students’ desire to feel comfortable (Emerson & Murphy, 2015). Dominant groups will “react less negatively when witnessing ingroup members ostracize a disadvantaged group member as compared to a fellow dominant group member” (Petsnik & Vorauer, 2020, p.2). This selective empathy response explains research on bystander apathy and lower physiological responses that dominant group members exhibit when witnessing

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[12] Motivated reasoning is a way of thinking in which people access, construct, and evaluate arguments in a biased fashion to arrive at or endorse a preferred conclusion: In this case, that they are more moral and less prejudiced than the evidence suggests (Boyer, Aaldering, & Lecheler, 2022).

"explicitly racist and homophobic comments directed toward outgroup targets" (Petsnik & Vorauer, 2020, p.3). Additionally, social exclusion concerns and trust and fairness concerns do not require system-wide discriminatory policies (e.g., a color-blind policy, Boucher & Murphy, 2017) or bigoted behavior (Verdhuis, Gordijn, Veenstra, & Lindenberg, 2014). Seemingly neutral situational cues can unwittingly exacerbate these concerns (Emerson & Murphy, 2014). Imagine for a moment an introductory physics course taught by an earnest and well-meaning professor. Her course routinely enrolls ten times as many men as women, making the latter feel numerically underrepresented in the classroom. Under these conditions, outside of the instructor's control, female students will likely experience social exclusion and trust and fairness concerns. The biased sex-ratio signals psychological danger, and the instructor must actively and intentionally incorporate inclusive teaching practices to chip away at the pernicious effects of this seemingly neutral situational cue.

Social Exclusion and Trust and Fairness Concerns in College Biology. If university students perceive that their family or peers would have been excluded from certain disciplines based on their social identity, they will experience these types of concerns (Biliuc, Goodyear, & Ellis, 2017; Moss-Racusin, Pietri, van der Toorn, & Ashburn-Nardo, 2021). The social incompatibility perception (Jetten, Iyer, & Zhang, 2017) that drives trust and fairness concerns becomes activated when students enter unrepresentative programs and disciplines that lack social identity-specific resources (e.g., a multicultural center on campus, DiMaggio, 2012). Students gauge social incompatibility by evaluating who lacks power within the program's social hierarchy (e.g., low-income students in a upper-middle class private college, Jetten, Iyer, & Zhang, 2017; or college women in a STEM department with risible female representation, Boucher & Murphy, 2017). When students conclude these institutional resources do not exist, they experience social exclusion (Raskauskas, Rubiano, Offen, & Wayland, 2015). As Niu and colleagues (2022) note, "[s]ocial exclusion (also defined as ostracism) is not only a common negative interpersonal experience," but also one of the "most alarming and unpleasant experiences" students may face (p. 2). Social exclusion, after all, leads to loneliness and other risk factors that impinge on a student's physical and mental wellbeing (Park et al., 2020; Raskauskas, Rubiano, Offen, & Wayland, 2015) and thus impact their academic development (Biliuc, Goodyear, & Ellis, 2017; Forbes, Stark, Hopkins, & Fireman, 2020).

Biology programs at the undergraduate level must ensure vulnerable students feel both welcome and represented (Boucher & Murphy, 2017; Park et al., 2020). For example, departments may hire a meaningful quorum of female faculty and teaching assistants, since having female-identified role models strongly mitigates against gender-related social identity threat in women and sexual minorities (Linley, Nguyen, Brazelton, Becker, Renn, & Woodford, 2016; Mattheis, de Arellano, & Yoder, 2019).

Likewise, they could enact identity-based educational programs—such as Women in STEM initiatives (Moss-Racusin, Pietri, van der Toorn, & Ashburn-Nardo, 2021)—that mitigate against trust and fairness concerns by visibly reinforcing that students with those identities have well-developed and highly structured pathways to success at those institutions (Bloodhart, Balgopal, Casper, Sample McMeeking, & Fischer, 2020). In short, trust and fairness concerns usually arise from institutional-level variables, and as such, cannot always be rectified by curricular and instructional changes at the classroom level.

The Neurobiological Consequences of Social Identity Threat

The neurobiological and social consequences from the persistent activation of social identity threat are long-lasting and severe (Leaper & Starr, 2019; Riegle-Crumb, 2014; Tao & Gloria, 2019). Humans crave meaningful connections with their peers and their communities of practice (Tarr, Launay, & Dunbar, 2014), and they rely on these relationships to nurture their sense of self and feelings of self-worth (Pietri et al., 2019; Skourletos, Murphy, Emerson, & Carter, 2013). Those individuals with positive relationships feel welcome and valued; those without them feel excluded and undeserving (Murphy & Taylor, 2012; Höhne & Zandler, 2019b).

Social pain theory places any "aversive emotional state of exclusion" (Höhne & Zandler, 2019a, p. 1741) on the same level as physical pain (Kross, Berman, Mischel, Smith, & Wager, 2011). The reason for the connection is simple: physical and social pain share neural underpinnings, as demonstrated by an influential study on social exclusion that relied on FMRIs (Eisenberger, Lieberman, & Williams, 2003). This study showed that the same regions of the brain became activated when a participant experienced physical pain or social exclusion. This shared neurobiology explains why both physical and psychological distress trigger the same somatosensory representations (i.e., the ability to interpret bodily sensations that include breathing, sweating, and increased heart rate, Karayannis, Baumann, Sturgeon, Melloh, Mackey, 2019). Just as physically derived pain serves an important biological function, so too does socially derived pain (Johnson & Dunbar, 2016; Karayannis, Baumann, Sturgeon, Melloh, & Mackey, 2019). As Johnson and Dunbar (2016) note, the "binding of the neuropeptide β-endorphin to μ-opioid receptors in the central nervous system" drives "social bonding, particularly amongst primates" (p. 1). In layman's terms, the pituitary gland releases β-endorphin in response to pain; endorphins in general are associated with a range of social behaviors, including laughter and learning (Tarr, Launay, & Dunbar, 2014). Therefore, physically- and socially derived pain function as immediate warning signs of danger. And the same inimical manifestations of *chronic* pain also emerge with *chronic* social exclusion—including declines in cognitive performance (Sui & Gu, 2017) and increases in morbidity and mortality (Johnson & Dunbar, 2016).

A person who experiences pain and rejection may exhibit antisocial behaviors as they attempt to reassert control and a sense of belonging (Betts & Hinsz, 2013; Maloy, Kwapisz, & Hughes, 2022; Woodcock, Hernandez, & Estrada, 2012). Within the educational context, ‘being antisocial’ could present itself as not participating in classroom discussions, withdrawing from the group or the course, and de-identifying with the academic domain (Frederick, Grineski, Collins, Daniels, & Morales, 2021; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013). A student who experiences social identity threat may take actions that seem counterproductive and in direct conflict with their academic and professional goals—but these behaviors are congruent with the psychosocial harm said student experienced. In these situations, the individuals responsible for structuring the educational environment, including instructors, mentors, and other people in positions of authority, have a moral obligation to change the circumstances on the ground to ensure equitable learning for all.

As the following section will argue, de-identification with the STEM field has implications that extend beyond an individual’s educational and professional trajectory, in part because science permeates every aspect of modern society (Mahmud & Wong, 2022). Having explored the complex world of social identity theory, the educational context for this study can now be explored: college science classes for nonmajors. After a brief overview of science education for nonmajors, the focus will shift to the instructional innovations currently being implemented in these courses, and how these interventions might activate or assuage social identity concerns. While an intersectional lens will be used to evaluate the interaction between active learning, college biology for nonmajors, and psychosocial variables, gender will continue to drive the analysis.

College Instruction for Non-Majors

Why should scientists and STEM educators devote themselves to teaching nonmajors students like Mercedes, Jodi, and Titilayo? Most students who graduate from college are not science majors (Bozzone & Doyle, 2017; Knight & Smith, 2010), yet they will represent a larger percentage of the American voting population than their peers who graduated with STEM degrees. Mercedes, regardless of chosen profession, will directly interact with rapidly evolving technologies, including novel medical devices and genetically modified produce (Chrispeels, Chapman, Gibson, & Muday, 2019). She will vote on governmental funding priorities (Motta, 2018), and demand—or not—policy initiatives designed to protect her health, her privacy, and her general-wellbeing (Cahill & Ojeda, 2021; Gstrein & Beaulieu, 2022; Tribe & Matz, 2014). She will also need to collectively address with fellow citizens the most pressing problems of the 21st century (Kahan, 2017), from the emergence of deadly new diseases (Baker et al., 2022) to the apocalyptic consequences of climate change (Abbas et al., 2022; Flener-Lovitt & Shuyler, 2016). As the unmitigated disaster known as COVID-19 teaches, policy makers, and the voters who elected them, are woefully unequipped to successfully counter these looming crises (Gao & Radford, 2021).

Humanists will therefore argue that nonmajors must primarily master the knowledge and skills that they need to make sense of, and find meaning in, a rapidly changing world (Brickhouse, 2022). Humanists will further contend that science courses for nonmajors should elevate these goals above a conceptual mastery of disciplinary principles (Wright, 2005). A chemistry course for nonmajors, for example, could emphasize the biochemical basis of anatomical processes by explicitly connecting disciplinary concepts with an enticing socio-scientific framework (e.g., college students' health and nutrition, Chen, Michalak, & Agellon, 2018). This "contextualized scientific knowledge learned on a need-to-know basis" (Klopfer & Aikenhead, 2022, p.2) facilitates instruction by pairing abstract and abstruse ideas with practical applications that directly address student interests (Hales, 2020). Consequently, the lived curriculum better serves the educational needs of Mercedes and students like her. The following sections will expand on this claim by narrowing the analytic focus to biology courses for nonmajors. Specifically, these sections will cross-examine a particular socio-scientific context—the biology of sex—previously shown to capture students' attention in science courses for nonmajors (Cotner & Hebert, 2016; Zemenick, Turney, Webster, Jones, & Weber, 2022).

A Contextualized Biology Curriculum

College biology courses for nonmajors should equip Mercedes and her peers with the scientific background they need to make informed, evidence-based decisions affecting their body (Loder et al., 2020), their health (Cassidy, Steenbeek, Langille, Martin-Misener, & Curran, 2019), and their choice to "bear or beget a child." Brennan, J., *Baird v. Eisenstad*, 405 U.S. 438 (1972). Research warns that college students are in dire need of this information, since young Americans remain ignorant of contraception, the spread of sexually transmitted infections, and effective sexual violence prevention interventions (King, Burke, & Gates, 2020; Moore & Smith, 2012; Renfro et al., 2022)—topics that directly impact their daily lives, their families, and their wallets (Downey, & Gómez, 2018). Topics, in fact, that substantially color students' college experiences, often with life-long consequences that disproportionately impact women and gender nonconforming individuals (Hatzenbuehler et al., 2014; Mengesha, 2017).

Furthermore, biology courses for nonmajors that discuss sexual health usually also cover information on gender identity and gender roles, sexual orientation, sexual development, and sex and society (Oswalt, Wagner, Eastman-Mueller, & Nevers, 2015). Research shows that university students benefit by learning about these topics, as they lower the incidence of sexually transmitted diseases and improve attitudes towards marginalized LGBTQQA communities (Oswalt, Wagner, Eastman-Mueller, & Nevers, 2015; Puckett, Cleary, Rossman, Newcomb, & Mustanski, 2017). Likewise, college students who learn about reproductive health and autonomy are statistically more likely to devote themselves to gender-based activism (Martin & Smith, 2020), and to discuss these topics in depth with their children (King, Burke, & Gates, 2020). These courses may likewise reduce the incidence of relationship and sexual violence—or at least encourage victim-survivors to seek support (Oswalt, Wyatt, & Ochoa, 2018). All these learning outcomes are positive and desirable enough, both on an individual and societal level, to justify requiring students like Mercedes to enroll in these courses despite their aversion to science.

Unfortunately, when these topics are taught in other departments—including psychology, public health, and women and gender studies—enrollment drastically shifts in favor of women (e.g., an 8:1 ratio in a psychology course on mental and sexual health, King, Burke, & Gates, 2020). As King and colleagues (2020) note, male teenagers consider themselves experts on sexual health, and therefore see no need to take courses on this topic. Another study identified the cause of this unearned confidence: men not only watch porn obsessively, but also deem it a reliable source of information (Willoughby, Carroll, Nelson, Padilla-Walker, 2014)—a claim that exhausts the credulity of the credulous. Therefore, the same socio-scientific context that may increase engagement in female students could also provoke the opposite effect in men who ascribe to chauvinist ideologies (Horwath & Diabl, 2020). Instructors consequently default to 'hiding' these topics within a biology course, lest they alienate those students who would benefit the most from this instruction. The college biology course for nonmajors analyzed in this dissertation, however, boldly highlights—rather than meekly conceals—the sexual health topics that directly pertain to the evolutionary ecology of sexual reproduction.

To summarize, the research is clear: science classes for nonmajors are vital for students' ability to craft their own future and that of their society. Further, the most successful courses rely on a lived curriculum to contextualize instruction. College biology courses that discuss scientific principles at the intersection of sex, gender, and society, for example, have been shown to meaningfully shift students' behaviors long term. Curriculum design alone does not guarantee success, however, since curriculum implementation plays an equally important role. And yet, as the following section will document, instructional practices at the university level often fail students, especially if they hold social identities traditionally marginalized in higher education.

Instructional Practices at the College Level

Despite continuous research attempting to drive a stake through its heart, the exclusive use of the lecture format continues to haunt the college classroom[13] (Barthelemy, Hedberg, Greenberg, & McKay, 2015; Stains et al., 2015). Like a ghoul slinking around under the cover of darkness, it feasts on students' potential, resulting in compromised learning gains (Freeman et al., 2014; Freeman, Haak, & Wenderoth, 2011) and a desiccated personal connection with the course content (Graham, Frederick, Byars-Winston, Hunter, & Handelsman, 2013). While multiple means of exorcism have been proposed, researchers and instructors continue to advocate for the widespread implementation of structured, active learning activities (Freeman et al., 2014; Neill,

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[13] This dissertation concurs that some teacher talk during class time is necessary, and that the best pedagogy finds a balance between active and passive forms of instruction (Walker, Cotner, Baepler, & Decker, 2017).

Cotner, Driessen, & Ballen, 2018; Theobald et al., 2020fv). The following section will describe these instructional techniques in depth and will emphasize how they rely on the collaborative learning of small groups. Subsequent sections will link these teaching techniques with social identity theory, using gender as the foregrounding identity variable. As this synthesis will make clear, whether active learning and collaborative exercises help or hinder female students depends on their contextual implementation.

Active Learning

Educators, policy makers, and other stakeholders in post-secondary science education have made urgent and far-reaching calls for instructional reform (American Association for the Advancement of Science [AAAS], 2018; National Science Foundation [NSF], 2015; Weir et al., 2019). These reforms advocate the integration of active learning techniques into discourse-driven and socially contextualized curricula—often called the lived curriculum[14] (Wright & Klymkowski, 2005).

Active learning is an elastic concept that encompasses any educational intervention that prompts students to engage with the course content through a diverse set of approaches (Patrick, Howel, & Wischusen, 2016), from group problem-solving to the manipulation of models (Patrick, Duggan, & Dizney, 2023). In practice, most instructors rely on collaborative learning and small group instruction to break away from lecturing

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[14] A lived curriculum "in non[]majors biology focuses on helping students learn to use scientific knowledge to solve relevant problems" (Wright & Klymkowski, 2005, p. 189). This perspective aligns with the humanist ideal for education. It also explains one of the animating principles that structured the college biology course investigated in this dissertation.

(Freeman et al., 2014; Lund & Stains, 2015). And research shows that these instructional techniques improve student outcomes when compared against the traditional lecture format (Theobald et al., 2020; Weir et al., 2019)—if certain conditions are met (Flaherty et al., 2023). Otherwise, active learning will not impart educational gains equitably. Like all social processes, collaborative active learning may trigger social identity threat in vulnerable students. The following sections will expand on the interaction between these instructional techniques, academic outcomes, and students' social identities.

Collaborative Learning

Educators acknowledge that collaborative learning can improve the academic outcomes and affective experiences of students (Scager, Boonstra, Peeters, Vulperhorst, & Wiegant, 2016), even though the concept itself remains overbroad and generic (Wieman, 2014). When students like Mercedes learn in groups, they get to negotiate the problems they would like to address, the procedure they would like to follow, and the explanations they would like to propose (Nokes-Malach & Richey, 2015). They consequently achieve more academically, hold more positive attitudes towards science, and show higher self-efficacy than those students who learn through the traditional lecture format (Khosa & Volet, 2013). Students in collaborative small groups also develop their critical thinking skills and science-process skills at a faster rate than their peers in lecture classrooms (Woolley, Aggarwal, & Malone, 2015), and these gains persist longer post-instruction (Iqbal, Velan, O'Sullivan, & Balasooriya, 2016). These two mechanisms may explain why collaborative learning outcompetes the hoary lecture style. First, students' science talk is usually more memorable than a lecturer's dry recitation of facts (Nokes-Malach & Richey, 2015). Second, talking about science forces students to converge on a common answer. This conceptual convergence requires forging scientific explanations in the fire of public opinion (Jeong, Clyburn, Bhatia, McCourt, & Lemons, 2022; Wertsch & Tulviste, 2013). Claims proposed by Mercedes not only need to be correctly structured, but also rhetorically powerful to persuade her peers.

Collaborative learning also benefits traditionally marginalized college students, such as Mercedes, who are prone to experience social identity threat (Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013). Collaborative learning, when structured properly within a dynamic and inclusive classroom environment, increases the self-efficacy of underrepresented minority (URM[15]) students (Ballen, Wieman, Salehi, Searle, & Zamudio, 2017). As Ballen and colleagues (2017) document, structured collaborative learning exercises "improved knowledge of course material" and benefited "URM students [] disproportionately" (p. 5) substantially narrowing racial and gendered performance gaps. Collaborative learning thus has the potential to deliver significant and positive results (LoPresto, 2020), but only if it occurs within a safety-inducing

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[15] As noted previously, the dissertation relies on the authors' language when describing student populations. URM is the preferred term for BIPOC student populations within the Design-Based Educational Research field.

environment that benefits, rather than hurts, women and other students liable to experience social identity threat.

Potential Pitfalls with Collaborative Learning. The reader would err in idealizing collaborative learning. It can be detrimental, particularly in unstructured learning environments that lack clear group goals and individual roles (Ballen, Wieman, Salehi, Searle, & Zamudio, 2017; Hong, Chang, Chai, 2014). The mis-implementation of group-based learning activities in this context may engender conceptual and interpersonal dysfunction (Iqbal, Velan, O'Sullivan, & Balasooriya, 2016). For the former, consider how groups may coalesce around incorrect explanations for scientific phenomena; for the latter, notice how unstructured conversations about science can easily activate social identity threat (Iqbal, Velan, O'Sullivan, & Balasooriya, 2016). The following sections will explore how these problems emerge and why they systematically target vulnerable learners, using gender and college biology classrooms as context.

Faulty Construction of Scientific Knowledge. Collaborative learning encourages students to "construct their own understanding of scientific concepts through a process of negotiation and consensus building" (Chang & Brickman, 2018, p. 2). By discussing the merits and deficits of scientific information and contextualized problems, students can, as a group, define concepts, employ appropriate methodologies, and solve problems (Haugland, Rosenberg, & Aasekjær, 2022). But research demonstrates that college students generally only grapple with scientific concepts on a surface level and often hit conceptual dead ends without instructor assistance (Halim, Finkenstaedt-Quinn, Olsen, Gere, & Shultz, 2018). Sometimes this resistance to delving deeper stems from a student’s underdeveloped academic self-efficacy and content-specific language proficiency (Rees, Kind, & Newton, 2021). Conversely, students sometimes refuse to engage because previous inimical interactions in K-12 spaces (e.g., social contagion of math anxiety, Ganley, Schoen, LaVenia, & Tazaz, 2019) convinced them they cannot think quantitatively or argue scientifically.

In these situations, instructors can provide explicit scaffolding to prevent students from coalescing around scientifically unfounded conclusions (Scager, Boonstra, Peeters, Vulpefhorst, & Wiegant, 2016). Likewise, they can mitigate the inevitable emergence of preconceptions by following small-group discussions with classroom-wide conversations that specifically root out conceptual mistakes and faulty logic, or with writing-to-learn assignments that require peer review (Halim, Finkenstaedt-Quinn, Olsen, Gere, & Shutlz, 2018). By encouraging students to continuously practice self-reflection, they can be taught to ward against preconceptions on their own. In short, Mercedes and other students benefit from talking about science with peers, but these conversations must be carefully designed and mediated to be conceptually useful.

Unequal Participation by Group Members. Small groups are rarely egalitarian, because the most outspoken and advantaged students generally dominate interactions in group contexts and their opinions tend to prevail (Theobald, Eddy, Grunspan, Wiggins, &

Crowe, 2017). Some instructors and students may hold gendered societal expectations regarding the proper role of men and women that benefit the former at the expenses of the latter (Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012). These subconscious schema about sex differences guide people's expectations and behaviors, so that both men and women begin to overvalue traits and behaviors associated with masculinity (Good, Rattan, & Dweck, 2012). Peers—especially male peers—can similarly prevent Mercedes and other female-identified students from fully participating in group activities by excluding women from leadership roles, making crude sexual remarks, or discrediting their conceptual and procedural contributions (Knight et al., 2012; Lauer et al., 2013). By dominating the group's discourse and validating status differentiation between the sexes, men can exclude women from the learning process.

Lee and Mccabe (2020) expanded on this idea by analyzing how "cultural beliefs about gender that assign more value and competence to men than to women continue to frame social relations" (p. 33), including within the classroom. These socially reinforced messages erect an invisible but unavoidable hierarchy that exalts men at the expense of women, thus replicating and perpetuating social inequalities (King, Burke, & Gates, 2020; Lee & Mccabe, 2020). Further, this exclusion depends on a woman's social identity rather than academic ability. Phrased another way, Mercedes and other female students may be judged as low ranking whenever they attempt to express themselves, and they will be actively silenced, even when they have achieved conceptual mastery[16]. Lithwick (2020; para. 5) calls this tendency to exclude women from critical conversations "the woman-shaped silence," and cautions that it promotes the worldview of the powerful at the expense of the powerless. When meaningful learning depends on active participation in classroom discussions, this gender-mediated exclusion harms women's educational journey. Instructors must therefore consider these discursive inequalities as they devise and revise their curricula. Otherwise, the potential benefits Mercedes would derive from collaborative learning will be radically curtailed by the sexist interactions that chill classroom culture and activate social identity concerns.

Social Loafing. Students enter the college science classroom with a diverse set of academic and social skills (Kwon, Liu, & Johnson, 2014). They likewise differ in their motivations, their work ethic, and their ability to subordinate individual wants for collective needs (Svinicki & Schallert, 2016). And while most students experience stress in college, some students may also need to address physical and mental health concerns that complicate their ability to collaborate (Curşeu, Janssen, & Raab, 2012). When students who differ wildly across these categories must work together, the risk of social loafing increases (Jassawalla, Sashittal, & Maishe, 2009). Social loafing occurs when students expend less effort during collaborative activities than they would have when

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[16] Need further evidence? Consider how STEM instructors hold implicit biases that marginalize women (Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012). Also evaluate how male college students often rate themselves and other men as being academically gifted—even when evidence clearly contradicts that conclusion (Grunspan et al., 2016).

working alone (Takeda & Homberg, 2014). Because this phenomenon arises in all small groups, instructors need to address it proactively (Hall & Buzwell, 2013), especially since the emergence of social loafing will be modulated by students' social identities.

To illustrate, research indicates that the numerical representation of men in an academic space modulates students' social loafing (Hall & Buzwell, 2013; Jassawalla, Sashittal, & Malshe, 2009). In a study that examined the effects of gender on group work process and performance, Takeda and Homberg (2014) perceived that gender balanced groups were the least likely to suffer from men's social loafing. Conversely, all-male groups evinced a higher incidence of social loafing behaviors and a statistically significant decrease in academic performance in relation to the mixed-gender groups. Finally, whenever a lone man worked alongside women, he invariably diminished his contributions to the group—fully expecting his female peers to pick up the slack (Takeda & Homberg, 2014). Female students, sensitive to these gendered dynamics that reward men at the expense of women, disdained social loafers and punished them severely.

To summarize, collaborative learning is a double-edged sword: While it does improve student academic outcomes generally, its promise may not be shared equally among all group members (Theobald et al., 2017) for the reasons discussed above, and group dynamics may serve to reinforce, rather than counter, negative stereotypes about women in STEM courses (Musto, 2019).

Addressing Gendered Participation in a Biology Classroom

One potential solution to men's dominance during classroom discussions would be to create safety-inducing, single-sex educational spaces for women—including within STEM courses for nonmajors. However, as the previous sections on gender and social identity showed, identity-based grouping can be beneficial or harmful depending on the educational context. Placing Mercedes and other female-identified students in single-sex groups may trigger social identity threat if said grouping exacerbates their minority status in the course (Boucher & Murphy, 2017). This scenario is most likely to arise in STEM courses for majors that are highly male-biased (Campbell-Montalvo, 2022; Ganley, Goerge, Cimpian, & Makowski, 2018). The potentially negative effects of gender-based grouping may be weaker or absent in nonmajor courses, since they tend to enroll men and women in roughly equal numbers[17]. The following section will expand on how these safety-inducing spaces can be constructed by first evaluating how single-sex educational spaces have been structured in the past.

Single-Sex Programs

Some STEM departments in co-educational institutions have relied on single-sex programs to foster gender-inclusive academic environments (Park, Behrman, & Choi, 2018). By participating in single-sex spaces, the thinking goes, women derive many of

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[17] After all, these courses target the general student population, and this population is predominantly female (Mead, 2023). Likewise, students majoring in the humanities and social sciences are used to being grouped into female-majority groups, because the majors themselves are female-dominated. These students may be more receptive to this type of grouping, and thus less likely to be harmed by it.

the benefits associated with women’s colleges without risking any of their drawbacks (Pahlke, Hyde, & Allison, 2014; Wong, Shi, Chen, 2018). Rosenthal and colleagues (2011), for example, demonstrated that women enrolled in single-sex STEM programs experience a greater sense of psychosocial identification with their majors—and were thus more likely to persist academically and professionally (Rosenthal et al., 2011). Students in these gender-inclusive programs are also more likely to interact with female faculty and teaching assistants (Moss-Racusin, Pietri, van der Toorn, & Ashburn-Nardo, 2021), and these female-identified role models help students feel represented in their fields (Cotner, Ballen, Brooks, & Moore, 2011). Given these and other benefits, this type of gender-based grouping has gained traction within STEM programs. However, it remains understudied among nonmajors, even though the same safety-inducing psychosocial mechanisms likely apply.

If participation in safety-inducing, single-sex educational programs *at the departmental level* help female students, then participation in similar spaces *at the classroom level* should also yield positive—though likely less robust and persistent—educational benefits. Unlike STEM majors, nonmajors only interact with scientific disciplines in the classroom, so any gender-based grouping would have to develop within those spaces. Instructors could provide students, for example, with the opportunity to opt into single-sex learning groups in their lecture sections. By entering these spaces, students like Mercedes can avoid some of the affective and behavioral barriers they would encounter in mixed-gender groups (e.g., sexist conversations in mixed-gender student groups, Clark, Dyar, Inman, Maung, & London, 2021; Kapitanoff & Pandey, 2017). Without these barriers, Mercedes and other female students are more likely to fully immerse themselves in the curriculum and fully interact with their peers. And that increased engagement, both curricular and social, will stimulate higher cognitive investment, higher self-efficacy, a better acquisition of discipline-specific skills, and a closer connection with science (Chi & Wylie, 2014; Johnson, Pelzel, & Mantina, 2022; Wester, Walsh, Arango-Caro, & Callis-Duehl, 2021)—all laudable educational goals for female nonmajors enrolled in a biology college course.

Conclusion

Research extensively documents how and why women experience social identity threat in college science classrooms (Emerson & Murphy, 2014; Vooren, Haelermans, Groot, & Maassen van den Brink, 2022). Research likewise shows that already-developed instructional interventions, including the use of a lived curriculum and active learning activities, may ameliorate this psychological threat (Ballen et al., 2019; Theobald et al., 2020). Small group learning, for example, has the potential to foster women’s interest in science content by incentivizing them to actively participate in the co-construction of knowledge (Khosa & Volet, 2013; Nokes-Malach & Richey, 2015). However, small group interactions heavy in discursive practices have the potential to magnify, rather than attenuate, the social identity concerns that arise from exposure to persistent and pervasive sexist interactions present in mixed-identity groups (McGee, 2020b; Neill, Cotner, Driessen, & Ballen, 2018). Instructors should therefore ensure that their instructional choices signal safety, rather than threat, to ensure their teaching follows gender-inclusive teaching practices (Boucher & Murphy, 2017).

Having completed a bare-bones review of the literature, the dissertation will now transition to describing the educational, biological, and sociopolitical contexts that inform it. An exploration of these contexts will bring concreteness and specificity to the general descriptions of gender, social identity threat, and college biology classrooms presented in this chapter. By thus narrowing the reader's focus, the dissertation can then sequentially introduce the two research articles that compose it.

Chapter 3: Context for the Research Project

This chapter provides a detailed description of the educational context, biological context, and sociological context needed to understand the research studies presented in this dissertation.

Educational Context

The *Evolution and Biology of Sex,* a course for non-majors at a public university in the Midwest, showcases scientific stories at the intersection of biology and society. The course makes upper-level evolutionary and ecological concepts accessible to non-experts by exploring them within the context of human sexuality (Cotner & Hebert, 2016). The instructor balances lectures with student-centered pedagogy (Walker, Cotner, Baepler, & Decker, 2008), devoting between 20-40% of instructional time to active-learning activities. Students work together in pre-assigned lecture groups (see Cotner, Driessen, & Ballen, 2018) on a wide range of collaborative exercises, including guided exploration of scientific articles and the elaboration of concept maps. The course therefore relies on student discourse to construct and disseminate content-specific information. The curriculum assigns points to classroom discussions in the form of attendance and clicker questions; the instructor increases accountability by ending every small-group discussion with a classroom-wide conversation, where she randomly cold-calls on student groups to share their thoughts (Waugh & Andrews, 2020).

Classroom discourse therefore functions both as a means and as an end (Felton, Garcia-Mila, Villaroel, & Gilabert, 2015), since the course aims to provide students with opportunities for argument-driven inquiry (Paine & Knight, 2020; Walker, Van Duzor, & Lower, 2019). The instructor begins the course by underscoring how the skills valued by scientists, including data analysis and logical reasoning, can also empower nonmajors in their daily lives and professions. She then proceeds to scaffold the process of science throughout the curriculum, providing students with opportunities to form hypotheses, analyze figures, and craft scientific explanations. To assist in this endeavor, she includes data from the primary literature and guides student groups through the theoretical assumptions and complex methodologies of persuasive peer-reviewed studies that address questions on sex, gender, and human biology. As an example of this approach, students read about sperm competition in mammals (delBarco-Trillo & Ferkin, 2004), before they tackle the variable morphology of mammalian bacula[18] (Simmons & Firman, 2013). They then connect these morphologies with the biological processes that shaped them: promiscuity and sexual selection (Simmons & Firman, 2013). Finally, students discuss the biological and sociocultural implications of the data: in this case, why a sexually derived trait that signals evidence of promiscuity is absent in human populations. Students quickly internalize the data-driven, constant-comparison approach

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[18] Bacula (sing. baculum) refers to the bone within the penis of certain mammals, including shrews, rodents, bats, and all primates except humans.

explicitly favored by the instructor, and are eventually primed to make connections between wild populations and humans on their own.

Biological Context

Anisogamy (from Greek *anisos*, “unequal” and *gamos*, “marriage”; see Bateman, 1948) is the guiding principle that animates the course’s biological narrative. Colloquially understood as sexual reproduction or the fusion of an egg with sperm, anisogamy explains, in part, the gendered dynamics that structure society and dictate human behavior (Borgerhoff Mulder & Ross, 2019; Tang-Martinez, 2016). A person’s conception of themselves and their world so depends on anisogamy, that people assume its emergence inevitable and its consequences desirable. The course challenges those assumptions by posing a question that has bedeviled biologists for over a century: why should species favor anisogamy when its evolution and maintenance entail steep biological costs (Darwin, 1871; Parker & Scharer, 2016)?

The Costs of Sexual Reproduction

To answer the question, the course foregrounds some of the costs associated with sexual reproduction: genetic reshuffling during meiosis and fertilization; ecological risks of sex; and sexual conflict. Each of these costs, described sequentially in the following section, explains some of the evolutionary and ecological constraints associated with sexual reproduction.

Genetic Costs

Sexually reproducing organisms merge the genetic information present in egg and sperm. Their offspring, by design, will share only a percentage of each parent's genetic information (Ridley, 2012; 2016). Further, the process of making sperm and eggs, known as meiosis, re-shuffles genetic combinations through independent assortment and crossing over[19] (Latrille, Duret, & Lartillot, 2017). Since these molecular processes are random, sexually reproducing organisms could potentially handicap their offspring with novel and dangerous genetic combinations that lower their fitness (Wilk, Kramer, & Ashley, 2017). Sexual reproduction is, by definition, a genetic gamble.

In contrast, clones made by an asexual organism are identical to their progenitor, barring mutations (Ågren, 2016). A successful asexual organism can thus propagate clones that will be equally successful in the same environment (Wilk, Kramer, & Ashley, 2017). The selfish gene theory popularized by Richard Dawkins (1989) therefore predicts asexual organisms will easily outcompete their sexual counterparts within a few generations. This genetic penalty incurs even for sexual organisms with the ability to self-fertilize (e.g., apomixis[20] in the notoriously self-loving *Taraxacum* dandelions, Hojsgaard

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[19] For those who dread genetics, a simple analogy suffices: If a person's genes are akin to playing cards, then meiosis reshuffles the deck. Whether the offspring ends up with a full house or a 2-7 off-suit hand is both random and contextual.

[20] Apomixis refers to organisms that can mate with themselves (i.e., 'selfing' organisms). Apomixis is an extreme form of inbreeding; Van Dijk, Op den Camp, & Schaurer, 2020.

& Hörandl, 2019), strengthening the conclusion that sexually reproducing organisms encounter biological challenges that their asexual counterparts avoid.

Ecological Costs

Searching for and copulating with sexual partners carries ecological risks. For instance, sexual organisms risk exposure to venereal diseases (McLeod & Day, 2014), whether the *pas de deux* occurs in the bedroom (Ashenhurst, Wilhite, Harden, & Fromme, 2017), a lake in New Zealand (e.g., the snail species *Potamopyrgus antipodarum*, Lively, 1996), or a spring meadow in the United States (e.g., the White Campion weed *Silene latifolia,* Toh et al., 2018). Anther smut (*Basidiomycota*—Order *Ustilaginales*) forces its plant host to manufacture spores instead of pollen (Bruns, Pierce, Antonovics, & Hood, 2021), and is transmitted from flower to flower by pollinators (Toh et al., 2018). Likewise, sexual signals across species also have the unfortunate tendency of exposing suitors to cheaters, predators, and castrating parasites (Janoušková & Berec, 2020). Consider the plight of the male Pacific field crickets (*Teleogryllus oceanicus*): known to seduce females with their song, they have lately been attracting a parasitoid fly (*Ormia ochracea*) instead of lovers (Tanner, Swanger, & Zuk, 2019). Much simpler—much safer—to reproduce asexually.

Sexual Conflict

Finally, anisogamy may generate sexual conflict between the two predominant sexual morphs, male and female (Perry & Rowe, 2018). When organisms partition their sexual function, male and female individuals can follow divergent, specialized reproductive strategies (Duryea, Bergeron, Clare-Salzler, & Calsbeek, 2016; Reedy, Evans, & Cox, 2019). Unfortunately, sometimes these gendered strategies clash at the molecular, organismal, and ecological level (Delph et al., 2011; Sayadi et al., 2019). Mate guarding in amphibians, for example, can result in the asphyxiation of female frogs (Rueda-Solano et al., 2022), while sexually antagonistic selection favors males in the invasive ant species *Nylanderia fulva* at the expense of their female conspecifics (Eyer, Blumenfeld, & Vargo, 2019). And lest an anthropocentric reader assume these hostile interactions remain confined to wild animal populations, remember that in human societies, public figures have consistently been credibly accused of sexual assault (Bazelon & Thompson, 2018; Diaigle, 2021; Relman, 2020).

The Red Queen Hypothesis

While multiple scientific explanations have been proposed to explain why species repeatedly rely on sexual reproduction, the course favors the *Red Queen Hypothesis* (Anzia & Rabajante, 2018). Based on the eponymous character from *Through the Looking Glass* (Carroll, 1900), this explanation theorizes that the genetic reshuffling inherent in sexual reproduction allows populations to temporarily escape their parasites[21].

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[21] The Red Queen admonishes Alice, "[n]ow, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that" (p. 33). Biologists have used this quote as a metaphor for the coevolutionary dynamics between parasites and their hosts. Genetic recombination through meiosis allows organisms to remain barely one step ahead of their predators and parasites.

It re-conceptualizes the all-bad, no-good genetic penalty mentioned previously as something of a mixed blessing: the same process that dilutes the genetic resemblance of parents and offspring also allows organisms to better evade the most common biological dangers in their environment (Gibson, Drown, & Lively, 2015; Ridley, 2012). And this ability to escape these dangers by doing “all the running you can do” (Carrol, 1900, p.33) trumps all the other costs associated with sexual reproduction (Lively & Morran, 2014). Otto, 2021; Smith, 1978). Anisogamy might be problematic, but the alternative strategy is worse. Asexual reproduction is a dead end in rapidly changing environments; sooner or later, cheaters, predators, and parasites overwhelm clonal populations (Ridley, 2012).

In sum, sexual reproduction may be necessary, perhaps even desirable in context, but beneath the siren song of seduction lurks a relentless threat: sex can maim, sex can traumatize, sex can kill—a conclusion students in college biology must eventually grapple with. Hundreds of college-aged students register for the *Evolution and Biology of Sex* every year, and every year they must talk about the costs of sex. And unlike experts—who use the language and conventions of the field to detach themselves from their lived experiences—novices are left to grapple with the biographical, cultural, and sociological implications of each biological principle. After all, reasoning from the familiar to decipher the unknown is a common and effective learning strategy. Further, precisely because the course foregrounds gender, gender-mediated social identity threat in students may increase as a function of increased knowledge (Wong, Shi, & Chen, 2018). For these reasons, the following section will now address the sociopolitical context informing these studies.

Sociopolitical Context

Data for this dissertation was collected in 2016, but the writing process continued to the present. Therefore, while the students' perspectives are frozen in time, the authors' positionality has shifted drastically in response to major events at the intersection of sex, sexuality, and society that developed over the past decade. The following section provides but two examples of how sociopolitical movements shifted societal perspectives on intercourse and reproduction: The #MeToo movement in 2018 and the United States Supreme Court's overruling of Roe *v.* Wade in 2022.

First, in 2018, the #MeToo movement confronted gender-based violence and gained international recognition (Daigle, 2020). By "justly commending publicity as the remedy for social diseases," the #MeToo advocates proved that "sunlight is said to be the best of disinfectants; electric light the most efficient police[]" (Brandeis, 1914, p. 139). Yet the movement concurrently confirmed that shining a floodlight on sexual conflict may activate vicarious trauma (Crivatu, Horvath, & Massey, 2023). Further, the cultural background (e.g., religiosity; Krull, Pearce, & Jennings, 2021), medical history (e.g., gender nonconformity or sterility, Hales, 2020), and lived experiences (e.g., sexual trauma; Molstad, Weinhardt, & Jones, 2023) of some people may impair their ability to fully engage in conversations about intercourse and pregnancy. Thus, while these topics generally increase student engagement in the classroom (Cotner & Hebert, 2016), the #MeToo movement cautioned that the same topics might also distress vulnerable students.

Second, the Supreme Court of the United States recently declared open season on women and sexual minorities when they eviscerated a woman's right to choose (Ziegler, 2022). Some Justices hungered for more, salivating at the possibility of completely carving up "all of this Court's substantive due process precedents, including *Griswold*[22], *Lawrence*[23], and *Obergefell*[24]." Thomas, J., concurring in *Dobbs v. Jackson Women's Health Organization,* 597 U.S. ___ (2022). This context makes the author's marginalized identities salient, subconsciously prompting him to varnish the interpretative research process with the gloss of his lived experiences. While all research in the social sciences must consider author positionality (Holmes, 2020), here the temporal gap between data collection and analysis necessarily distorts the research process, precisely because the local and national sociopolitical context shifted dramatically during this time. The dissertation will consequently be clear when it transitions between what students said then and what the data implies now. More importantly, the dissertation will now transition to an author positionality statement.

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[22] Protecting a married couple's rights to use contraceptives.
[23] Protecting an individual's right to sexual autonomy.
[24] Protecting an individual's right to marry.

Author Positionality

Before presenting the first study enclosed in this dissertation, the author would like to share, in the spirit of self-reflection and transparency, his viewpoint as an educated Hispanic Basque-Czech gay Jew, born and raised in Guatemala. As a gay man raised within a matriarchal and Orthodox household in a patriarchal society, the author understands how societal expectations of gender color all interpersonal relationships. Further, while the author was treated as white by Guatemalan communities, his instructors and peers in the United States considered him a Latino immigrant in college and beyond. He thus learned how to operate as a person of color as a teenager in Massachusetts, and consequently experienced many of the social identity threat components described in the literature review for the first time as a college freshman. Thankfully, he encountered female-identified faculty and peer mentors who supported his grow, academically and personally. With this support, the author majored in biology and earned a master's degree in evolutionary ecology, before entering a doctoral program in science education.

During the doctoral program, the author became a state-certified sexual assault crisis counselor in 2014 and volunteered as a Violence Prevention Educator at his research university. He also taught biology courses to first-generation, low income, BIPOC, and immigrant student communities through a federally funded program called TRIO Student Support Services (SSS). Having experienced significant and persistent identity-mediated antagonistic interactions with certain faculty and graduate students in Curriculum and Instruction and Biology Teaching and Learning, he thus considers TRIO SSS his true home at the University of Minnesota. The author acknowledges that his positionality and lived experiences influenced his doctoral trajectory and the dissertation it ultimately produced.

Having considered the three concentric contexts that inform this dissertation, two related but ultimately independent studies will be presented in turn. The first study uses thematic analysis to tease apart how students' previous STEM experiences shaped their objective and subjective perceptions of the biology course for nonmajors they enrolled in.

Chapter 4: Impact of Small Group Gender Ratios on Sense of Belonging in a College Biology Course for Nonmajors

Student engagement drives the learning process in college classrooms (Patrick, Duggan, & Dizney, 2023), but student engagement remains low and male biased (Aguillon et al., 2020). In most introductory science courses, for example, men answer a disproportionately high percentage of instructor-posed questions (Eddy, Brownell, & Wenderoth, 2014; Opie, Livingston, Greenberg, & Murphy, 2019). They likewise dominate conversations during collaborative learning, and often relegate women to secretarial group roles, such as recording information during group activities (Doucette, Clark, & Singh, 2020). Further, this gendered gap substantially widens for students who hold additional marginalized identities (e.g., BIPOC women in STEM, Boucher & Murphy, 2017; Ong, Smith, & Ko, 2018). Since student engagement increases self-efficacy (Hewapathirana & Almasri, 2022; McGee, 2020a), facilitates the long-term retention of information (Wester, Walsh, Arango-Caro, & Callis-Duehl, 2021), and promotes identification with the discipline (Hewapathirana & Almasri, 2022; McGee & Robinson, 2019), disengaged female students suffer academic and social tribulations that extend beyond low course grades (Makarova, Aeschlimann, & Herzog, 2019).

While the actual mechanisms driving these disengagement behaviors remain complex, researchers agree that a frosty classroom ecology accounts for a significant amount of the observed variation (Ainsworth, 2015; Maloy, Kwapsiz, & Hughes, 2022).

This chilly climate consists of all the overt and subtle forms of gender discrimination that women face in male-dominated spaces (Simon, Wagner, & Brooke, 2017). These gendered biases include instructors' subconscious prejudices that favor men (Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012), as well as the chauvinist behaviors and sexist commentary that unfold in academic and professional spaces (Aycock et al., 2019; Biggs, Hawley, & Biernat, 2018). When confronted with these antagonistic interactions, some female students withdraw emotionally and behaviorally from these spaces, a response explained by social identity theory (Emerson & Murphy, 2014). This theory presupposes individuals yearn to present their social identities in the best possible light (Hildebrand, Monteith, Carter, & Burns, 2022; Tajfel & Tatel, 1979). However, when peers and mentors devalue a group, such as women in science courses, members of that group experience social identity threat (Chen et al., 2021)—the dispiriting perception one is being judged based on negative stereotypes rather than individual effort (Boucher & Murphy, 2017; Kahalon, Shnabel, & Becker, 2018).

To mitigate the activation of social identity threat, instructors can modify the course's situational cues that control students' sense of belonging (Ng, 2018). For example, previous research has shown that numerical representation within student groups operates as a powerful situational cue that can trigger threat or signal safety depending on the educational context (Boucher & Murphy, 2017). In male-biased science courses, numerical representation invariably functions as a negative situational cue, because it exacerbates women's minority status in the discipline (Bloodhart et al., 2020; Moss-Racusin, Pietri, van der Toorn, & Ashburn-Nardo, 2021). In gender-balanced science courses, however, numerical representation may be used to signal safety: by creating educational spaces where women occupy the majority, instructors can foster female students' sense of belonging (Pahlke, Hyde, & Allison, 2014; Wong, Shi, Chen, 2018).

Instructors in gender-balanced courses could potentially use single-sex collaborative groups to ward against social identity threat. By working in single-sex small groups, female students can avoid some of the affective and behavioral barriers they could otherwise encounter in mixed-gender groups (Cokley et al., 2013; Ong, Smith, & Ko, 2018). Without these barriers, they are more likely to engage with the course content and their peers, partially addressing the low and male-biased college engagement gap. Yet research on this topic remains relatively understudied, especially in nonmajors college science courses.

Research Questions

The numerical representation of women in small groups substantially influences student engagement, as previous work on female science majors has shown. However, its effects in nonmajors science courses remain relatively unexplored. This study addresses this gap in the literature by probing the interaction between the sex ratio of student groups and the engagement of its members, both male and female, within an introductory college biology course for nonmajors. The specific research questions addressed include:

1. *Does single-sex grouping ameliorate social identity threat in women with previous harmful STEM educational experiences?*
2. *How do men and women evaluate their educational experiences in single-sex and mixed-sex groups?*

Theoretical Framework

Multiple educational theories acknowledge that learning is an inherently social process (Lantolf, Thorne, & Poehner, 2015; Vygotsky, 1978), but they disagree on which social parameters matter. Social constructivism remains agnostic about society and culture, while socio-cultural learning theory spotlights these variables, including race (Carbado, Crenshaw, Mays, & Tomlinson, 2013), gender (Boucher & Murphy, 2017), and country of origin (Qadeer, Javed, Manzoor, Wu, & Zaman, 2021). This study ascribes to the latter framework, precisely because psychosocial variables color and constrain all interpersonal relationships in the classroom (Jeong, Clyburn, Bhatia, McCourt, & Lemons, 2022), since learning occurs when students interact repeatedly within a specific sociocultural context (Lantolf, Thorne, & Poehner, 2015).

The process of learning is neither invariable across contexts, nor autonomously derived (Lantolf, Thorne, & Poehner, 2015). As Jeong and colleagues (2022) observe, "learning is a mediated action. Learners construct knowledge while interacting socially with others and artifacts" (p. 2). Sociocultural learning theory lends itself to educational and research interventions that seek to change the local situational cues that structure a student's learning ecology. An instructor could, for instance, group students based on their demographic characteristics, including gender. This identity-based grouping will create a new sociocultural context unique to that group that will guide its members' classroom experience by influencing their psychology.

Social Identity Theory

The need to develop and maintain positive interpersonal relationships forms a foundational aspect of human motivation, including in educational settings (Morgenroth & Ryan, 2021; Pietromonaco & Collins, 2017). The value society places on a given psychological group greatly impacts the contextual psychosocial and academic experience of its members (Musto, 2019; Morgenroth & Ryan, 2018; Skourletos, Murphy, & Emerson, 2013). Students are particularly apprehensive about being denigrated when negative stereotypes or a history of bias permeate their social context (Winter et al., 2016): when female-identified individuals, for example, enroll in STEM courses that traditionally coddle men and shun women (Good, Rattan, & Dweck, 2012; Grunspan et al., 2016). When an identity is perceived to be degraded, people can experience social identity threat, "the worry and uncertainty that they will be viewed and evaluated through the lens of their group's negative stereotypes" (Boucher & Murphy, 2017, p. 95). As the next section will explain, social identity threat invariably compromises a student’s cognitive and behavioral engagement by inducing belongingness concerns (Cheryan, Ziegler, Montoya, & Jiang, 2017; McGee, 2020a).

Belongingness Concerns

When people question their connection to a particular social setting, they may experience belongingness uncertainty (Bloodhart, Balgopal, Casper, Sample McMeeking, & Fischer, 2020). This component of social identity threat can be defined as a lack of fit between the individual and other members in the setting, although that lack of fit also extends to situational cues (Cheryan, Ziegler, Montoya, & Jiang, 2017). For example, Ong and colleagues (2018) demonstrated that Black and Latine STEM students who knew they could access safe spaces reported higher rates of persistence and academic success. Conversely, those students who experienced social ostracism within the major felt a concomitant psychological separation from the major (Ong, Smith, & Ko, 2018).

Belongingness uncertainty adversely affects academic domain identification, achievement, persistence, and career aspirations of afflicted students (Leaper & Starr, 2019; Pietri et al., 2019). These concerns describe a general psychological phenomenon that emerges from students’ gnawing doubt that they are being excluded based on their social identities (Riegle-Crumb & Morton, 2017). Reason through how female students in STEM courses are keenly aware of their peers’ and instructors’ bigotry of low expectations (McGee, 2020a). This psychological priming renders them vulnerable to situational cues that signal a lack of fit, from the numerical underrepresentation of their gender (Boucher & Myrphy, 2017), to the male-centric classrooms (Bloodhart, Balgopal, Casper, Sample McMeeking, & Fischer, 2020; Perez, 2019), and sexually antagonistic conversations (Aycock, Hazari, Brewe, Clancy, Hodapp, & Goertzen, 2019; Leaper & Starr, 2019) that sometimes define the STEM educational context (Tao & Gloria, 2019). Logically, rejection based on group membership lowers students' sense of well-being and stunts their relationships with instructors and peers (Boucher & Murphy, 2017; Höhne & Zandler, 2019a). To learn effectively, a student must first feel like an integral member of the learning environment—and the courses' situational cues will either hinder or facilitate this goal.

Situational Cues

The sociocultural context considers both social interactions among individuals as well as situational cues, which Emerson and Murphy (2014) define as the physical (e.g., high-tech active learning classroom, Cotner, Loper, Walker, & Brooks, 2013), demographic (e.g., female representation, Boucher & Murphy, 2017), and organizational features of a space (e.g., single-sex instruction, Pahlke, Hyde, & Allison, 2014). The gender of a college instructor, for example, functions as a situational cue, and has been linked to changes in student's motivation in STEM courses (Dasgupta, Scircle, & Hunsinger, 2015; Deemer, Lin, & Soto, 2016; Solanki & Xu, 2018).

Situational cues can be overt, such as the high incidence of sexual harassment in Physics departments (Aycock et al., 2019), or covert, such as gendered bias in grading

(Doornkamp et al, 2022). Covert situational cues in educational settings can be particularly pernicious, in part because they are hard to evaluate consciously, and in part because they affect even the most self-confident of students (Boucher & Murphy, 2017; Smith, Lewis, Hawthorne, & Hodges, 2012). Think through the previous point by reasoning how numeric underrepresentation by race or gender in the STEM classroom exerts powerful and far-reaching effects on students by triggering both objective experiences of social identity threat (e.g., cognitive and psychological vigilance) and subjective experiences of identity threat (e.g., decreased sense of belonging and a dampened desire to engage with classmates) (Carli, Alawa, Lee, Zhao, & Kim, 2016; Frederick, Grineski, Collins, Daniels, & Morales, 2021). The following sections expand on the social identity component most important to this study: a sense of belonging.

Literature Review

Most students who graduate from college are not science majors (Bozzone & Doyle, 2017), yet they will represent a larger percentage of the American voting population than their peers who graduated with STEM degrees. Unfortunately, nonmajors tend to enter the science classroom at a disadvantage. They are more likely to hold preconceptions about the nature of science (Coley & Tanner, 2015) and less likely to find the subject matter personally relevant (Cotner, Thompson, & Wright, 2018). They also collectively display a wider range of academic skills, with some nonmajors evincing low motivation, self-efficacy, and confidence in expertise (Knight & Smith, 2010; Whitcomb, Maries, & Singh, 2023). And given their low self-identification with the subject matter, they are more likely to experience social identity threat (Boucher & Murphy, 2017). Research shows that the best way to counter these disadvantages is to integrate active learning and collaborative activities into the nonmajors science curriculum (Weasel & Finkel, 2016).

Collaborative Learning

College students who learn collaboratively with their peers tend to achieve more academically, hold more positive attitudes towards science, and gain more self-efficacy than those students who learn through the traditional lecture format (Adkins, Rock, & Morris, 2018; Scager, Boonstra, Peeters, Vulperhorst, & Wiegan, 2016). These students also develop academic skills—including critical thinking and problem solving—at a faster rate than their peers tortured by the lecture format (Johnson, Pelzel, & Mantina, 2022; Wester, Walsh, Arango-Caro, & Callis-Duehl, 2021). Further, these gains persist long after instruction ends (Foster-Hartnett, Mwakalundwa, Bofenkamp, Patton, & Nguyen, 2022), allowing nonmajors to apply them in other contexts (Mello & Wattret, 2021). Collaborative learning succeeds because it forces students to converge on a common answer through science talk (Lombardo & Shipley, 2021), and these conversations often prove more memorable and personally relevant than a lecturer's soporific presentation of facts (Smith et al., 2009; Terson de Paleville, 2022). Lastly, collaborative learning also benefits historically marginalized students vulnerable to social identity threat (Ballen, Wieman, Salehi, Searle, & Zamudio, 2017; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013). The additional instructional scaffolding can level the playing field, in part because it explicitly teaches students how to work together to discover explanations for scientific phenomena (LoPresto, 2020). As the next session will expound, small groups sometimes struggle to collaborate for multiple reasons.

Unequal Participation by Group Members

Small groups are rarely egalitarian, because the most outspoken and advantaged students generally dominate interactions in group contexts and their opinions tend to prevail (Theobald, Eddy, Grunspan, Wiggins, & Crowe, 2017). Additionally, some instructors and students may hold gendered societal expectations regarding the proper role of men and women that benefit the former at the expenses of the latter (Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012). These subconscious schema about sex differences guide people's expectations and behaviors, so that both men and women begin to overvalue traits and behaviors associated with masculinity (Good, Rattan, & Dweck, 2012). Peers—especially male peers—can similarly prevent female students from fully participating in group activities by excluding women from leadership roles, making crude sexual remarks, or discrediting their actual contributions of female peers (Knight et al., 2012; Lauer et al., 2013). By dominating the group's discourse, men validate status differentiation between the sexes, thus making women's relatively low participation rates in the classroom appear both innocuous and natural (Lindqvist, Gustafsson, Sendén, Renström, & 2021; Minjung & Sikorski, 2019). Lithwick (2020, para. 5) calls this tendency to exclude women from critical conversations "the woman-shaped silence," and cautions that it promotes the worldview of the powerful at the expense of the powerless.

Lee and Mccabe (2020) expanded on this idea by reminding readers that "cultural beliefs about gender that assign more value and competence to men than to women continue to frame social relations" (p. 33), including within the classroom. These socially reinforced messages erect an invisible but unavoidable hierarchy that exalts men at the expense of women, thus replicating and perpetuating social inequalities (King, Burke, & Gates, 2020; Lee & Mccabe, 2020). Further, this exclusion depends on a woman's social identity rather than academic ability (Emerson & Murphy, 2014; Boucher & Murphy, 2017). In introductory physics courses, for example, gender identity depresses students' self-confidence: female students with As exhibit the same self-efficacy as male students with much lower exam scores (Marshman, Kalender, Nokes-Malach, Schunn, & Singh, 2018). In equitable learning environments, self-efficacy should mirror academic performance, since students integrate knowledge and refine their academic skills through practice and reflection (Ainscough, 2016; Bandura, 1977). Only the existence of gender-mediated barriers explains the disconnect between learning and self-efficacy seen in Marshman and colleagues' (2018) female students.

When meaningful learning depends on active participation in classroom discussions, this gender-mediated exclusion harms the educational journey of female students (Aguillon et al., 2020; Boucher & Murphy, 2017; Learper & Starr, 2019). Instructors must therefore consider these participatory inequalities when designing an equitable biology course (Killpack & Popolizio, 2023). Otherwise, the potential benefits women would derive from collaborative learning will be dramatically curtailed by sexist interactions that chill classroom culture and inflame social identity concerns (Boucher & Murphy, 2017). To summarize, collaborative learning is a double-edged sword: its promise may not be shared equally among all group members (Theobald et al., 2017), and group dynamics may serve to reinforce, rather than counter, negative stereotypes about women in STEM courses (Musto, 2019).

Student (Dis)Engagement

As predicted by social identity theory, a student who experiences continuous and negative interactions in the classroom develop antisocial behaviors as they attempt to reassert control and a sense of belonging (Betts & Hinsz, 2013; Maloy, Kwapisz, & Hughes, 2022; Woodcock, Hernandez, & Estrada, 2012). Within the educational context, ‘being antisocial’ could present itself as not participating in classroom discussions, withdrawing from the group or the course, and de-identifying with the academic domain (Frederick, Grineski, Collins, Daniels, & Morales, 2021; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013). Because these disengagement behaviors directly impact academic performance, students may protect their psychological profile at the expense of their studies (Totonchi et al., 2022). The following section will discuss two metrics that assess student involvement with course content and peers: attendance and perceived engagement during lessons.

Attendance

Studies suggest that class attendance remains a powerful, positive predictor of student success in college (Kassarnig, Bjerre-Nielsen, Mones, Lehman, & Dreyer Lassen, 2017; Westerman, Perez-Batres, Coffey, & Pouder, 2011). As a meta-analysis by Crede and colleagues demonstrated (2010), consistent attendance is a more accurate forecast of academic achievement than previous high school GPA or standardized exam scores. In another study, involving 1,602 first-year undergraduate students, researchers discerned that students who regularly attended class at the start of the semester were more likely to earn the highest grades at the end (Summers, Higson, & Moores, 2021). Admittedly, investigations at the graduate level have not detected a correlation between attendance and student attainment (Doggrell, 2020), suggesting the value of attendance may decrease as students grow academically and become more self-reliant. Therefore, at the undergraduate level, attendance should matter most for freshman and nonmajors (Doggrell, 2023; Kassarnig, Bjerre-Nielsen, Mones, Lehman, & Dreyer Lassen, 2017), as they tend to evince lower self-efficacy than seniors and STEM majors (Hebet & Cotner, 2019). To complicate matters further, Büchele (2021) proposed that it does not matter *whether* students attend lectures, but rather *how* they show up. By explicitly linking attendance rates and student engagement in the classroom, Büchele (2021) and other researchers (e.g., Moores, Birdi, & Higson, 2019) consistently found a stronger relationship between attendance and different metrics of student success.

Perceived Engagement Behaviors

Students can engage passively or actively with course content, the instructor, and their peers (Hodges, 2018; Weasel & Finkel, 2016). Passive modes of engagement include making eye contact with the instructor and listening to group discussions, while active modes of engagement include answering instructional prompts, generating concept maps, and contributing to group discussions (Doggrell, 2023). Naturally, actively engaged students outperform passively engaged students, since the former will interact with concepts at a deeper cognitive level (Chi and Wylie, 2014). Conversely, students who fall asleep, peruse social media, or stop attending class have emotionally and behaviorally disengaged from the course, leading to poor scholastic outcomes (Wester, Walsh, Arango-Caro, & Callis-Duehl, 2021).

Methods

This study utilizes thematic analysis, a type of qualitative methodological approach, to interrogate students' objective and subjective experiences in a college biology class for nonmajors. Underpinned by constructivist epistemology, thematic analysis allows for both inductive and deductive theme development, where the researchers take an active role in the process (Xu & Zammit, 2020). A rigorous thematic analysis can produce trustworthy and insightful findings, especially for educational research with an applied focus (Guest, MacQueen, & Namey, 2011) or investigations with deductive and inductive sources of coding (Fereday & Muir-Cochrane, 2006).

Study Context

This study focused on two lecture sections of an introductory biology course for nonmajors, BIOL 1003 (*The Evolution and Biology of Sex*). The course addresses general biological principles, including scientific inquiry, history of evolutionary thought, behavioral ecology, and human evolution (Sullivan, Ballen, & Cotner, 2018). In addition to exams (midterms and a final) and laboratory activities, in-class lecture assignments completed in small groups accounted for almost one-fifth of students' grades. A substantial portion of the course grade thus depended on student collaborations.

The same female-identified instructor taught both lecture sections in the same high-tech, active learning classroom at the University of Minnesota (Cotner, Loper, Walker, & Brooks, 2013). She incorporated inclusive teaching practices that increased student participation and weakened identity-driven achievement gaps (Neill, Cotner, Driessen, & Ballen, 2018). These practices included structured group assignments where students created different learning artifacts (e.g., concept maps and graphical representations of data). The instructor also required students to answer multiple-choice questions using their personal response systems colloquially known as “clickers”. In short, the instructor afforded students with ample opportunities to reconcile information from multiple sources—including the course textbook *The Red Queen* (Ridley, 2016), articles from the primary literature, popular science videos, and their own lived experiences—by discussing these sources in depth in small groups.

Data Collection

Data collection occurred in two lecture sections taught by the same female-identified instructor (N=230) in fall 2016 (Table 4.1). Both sections were taught on the same weekdays: (S1) at 9:45AM and (S2) at 11:45AM. Prior to the start of the semester, the instructor divided students in each section into fourteen groups composed of 8-9 students. A third of the groups were single sex (e.g., all-female). The remaining groups were mixed, from a low of 17% female to a high of 86% female (Figure 4.1). By varying the sex-ratio of groups, researchers could evaluate the objective and subjective educational experiences of men and women as they engaged in collaborative activities at the intersection of sex, gender, and society.

Table 4.1

Demographic Breakdown of Each Lecture Section

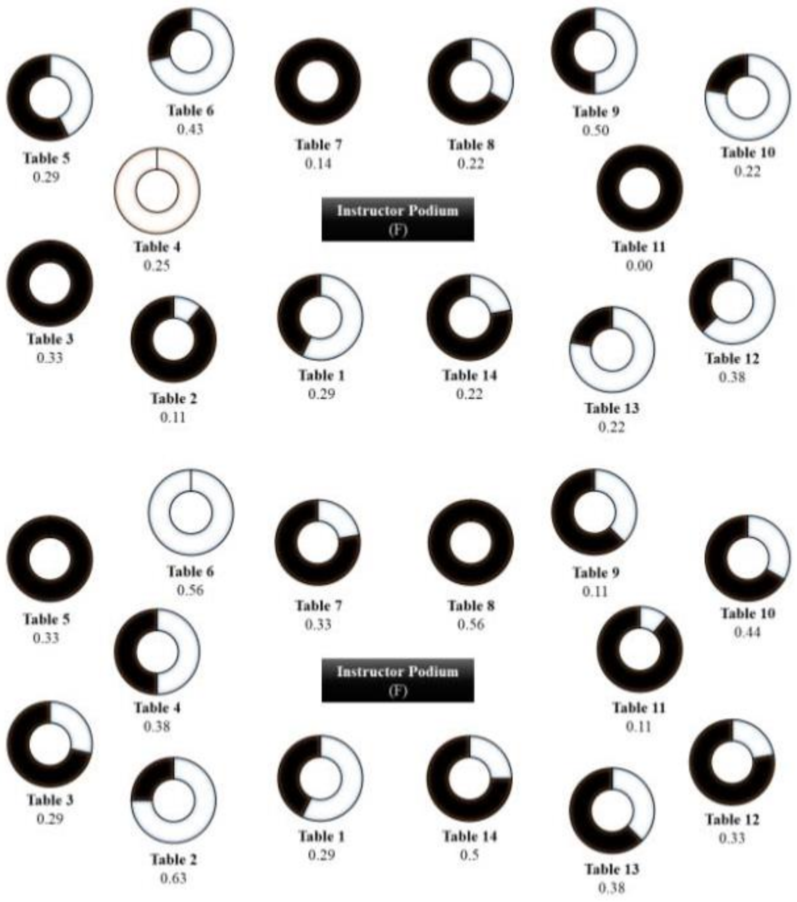
Ethnicity			Academic Year			Gender		
	S1	S2		S1	S2		S1	S2
White	75	77	Freshman	29	6	Male	44	55
Asian	9	13	Sophomore	50	55	Female	70	61
Hispanic	4	5	Junior	8	31			
Black	7	5	Senior	27	24			
Indigenous	1	0						
International	18	16						
Total (N)	114	116		114	116		114	116

Note: Student demographic data were collected from administrative profiles of students. S1 and S2 refer to the first and second lecture sections, respectively, that started at 9:45AM and 11:15AM on the same weekdays.

At the beginning of the semester, the instructor introduced the first author, a male-identified researcher, to students. He attended every class section and interacted with students as the course's unofficial teaching assistant, answering conceptual questions and facilitating group discussions. During class he also kept an ethnographic journal where he collected field observations, reflected on classroom dynamics, and recorded student data, including attendance and perceived engagement.

Figure 4.1

Group Composition



Note: Each circle represents one student group. Black shading denotes female students, while white shading denotes male students. The relative ratio of black to white approximates the female to male ratio of that group. The percentage under each group describes the proportion of students in the group that does not identify as White/Caucasian. (*Top*) Section 1 (S1). (*Bottom*) Section 2 (S2).

Qualitative Data Collection

After the conclusion of the fall semester, the first author conducted semi-structured interviews with eleven students to qualitatively explore the interaction between group gender ratio and students’ sense of belonging. Recruitment occurred two weeks before the last day of class; the instructor invited students to participate through classroom announcements and email reminders, and incentivized participation with $10 gift cards. Fourteen students initially agreed to be interviewed in early December, but only twelve scheduled interview appointments—though one student cancelled hers without an explanation at the last minute. All remaining interested students were interviewed during winter break (January 2017) and are included in this publication.

A researcher followed up via email a week before finals. Interviewed students included members from single- and mixed-sex groups and approximated the demographic diversity of the lecture sections. Interviews lasted approximately 45 minutes and covered a wide range of topics, including student expectations at the start of the semester, group dynamics, and their personal experience working in their assigned group. Audio-recordings of these interviews were subsequently transcribed and all identifying personal information removed.

Thematic Analysis. To understand the impact of a group’s gender ratio on the students’ sense of belonging, researchers explored the interview transcripts using thematic analysis (Belotto, 2020). Underpinned by constructivist epistemology, thematic analysis encourages researchers to take an active role in the development of codes through deductive and inductive approaches (Xu & Zammit, 2020). Deductive coding is theory-driven and relies on models discussed in the literature (Roberts, Dowell, & Nie, 2019). Inductive coding, conversely, requires intimate familiarity with the transcripts, since generated codes must capture large-scale patterns observed in the data (Saldana, 2016). Here, the authors perused educational and psychological research studies that explained why women experience social identity threat in STEM college courses (e.g., Boucher & Murphy, 2017; Cheryan et al., 2017) to generate deductive codes. They likewise created a list of pertinent inductive codes, which they then contracted by removing codes that either did not align with the deductive codes or else had low explanatory power (Roberts, Dowell, & Nie, 2019). All remaining inductive codes were grouped by commonality, resulting in more capacious codes (Xu & Sammit, 2020). By integrating inductive and deductive coding in blended approach (Roberts, Dowell, & Nie, 2019), the researchers then developed themes that addressed the research questions (Nowell, Norris, White, & Moules, 2017). Effective themes formed a coherent analytic story that described how they interacted (Clarke & Braun, 2014; Saldana, 2016).

Table 4.2

Group and Major of Interviewed Students

Name	Race	Age	Sex[a]	Grade	Section	Group ID	Group Treatment	Major
Elena	White	42	F	A	S1	2	Mixed (78%)	FSOS
Laura	White	19	F	A	S1	3	F (100%)	Public Health
Anne	White	21	F	A	S1	3	F (100%)	Arabic Studies
Mercedes	White	19	F	A	S1	11	F (100%)	Psychology
José	AAPI	18	M	B	S2	4	Mixed (56%)	Journalism
Julia	White	20	F	B	S2	5	F (100%)	Marketing
Tahir	ME	20	M	Pass[b]	S2	6	M (0%)	Engineering
Devon	Black	21	M	A-	S2	6	M (0%)	Theater
Titilayo	Black	19	F	B	S2	8	F (100%)	Business

Note: Information of students who participated in semi-structured interviews. S1 and S2 refer to the first and second lecture sections, respectively. [a] Researchers used information found in student's academic profile unless students self-identified otherwise. [b]Tahir took the class pass/fail and he earned enough to pass the course.

Findings

The following sections will discuss the findings of this study. The description of the qualitative results will include student cases that highlight individual experiences as well as the qualitative themes that collectively address students' experiences.

Qualitative Findings

In the next section, the qualitative results will be presented. To start, student-level cases will be introduced to provide the reader with a rich understanding of students' motivations and experiences in the course. The focus will then shift to the qualitative generation of themes that will highlight how students' collective experiences either converged or diverged.

Student-Level Cases

Anne (All-Female Group). Anne began the interview by disclosing "I had never felt like I belonged in a science class." She rated her high school experience as "very negative" due to interactions with her teachers and peers, leading her to "dread science courses since." Though initially "worried about sounding dumb" to her group members, "the relaxed conversations" around human biology prompted her to participate "more than I originally expected." She would often take the lead in conversations, guiding her group through the discussions of the evolutionary and ecological costs of sex described in the course text, *The Red Queen* (Ridley, 2016). "To be honest," Anne admitted, "I led discussions probably because I was the only student [at the table] who consistently read [the book].” Despite her peers’ occasional social loafing, she “really liked” being in an all-female group, because “we were able to talk about a lot of things, like female reproductive things” and “the menstrual cycle, biologically, without being uncomfortable.” More importantly, her group members “never made me feel dumb” to the point that now “I can talk to people about [biology], especially in relation to sex and gender, including my roommate’s pre-med boyfriend. I think that’s really important.” For Anne, her constructive experiences with her single-sex group superseded her previous inimical experiences in the K-12 science classroom.

Mercedes (Single-Sex Group). Mercedes came into the class with a strong academic record. Nonetheless, she started the course “worried about not knowing enough, about sounding dumb.” But her fears disappeared quickly, in part because she bonded with her group. Group chemistry helped her overcome her initial “stress and anxiety, since I didn’t always feel like I was the only one behind.” She could therefore share her academic insecurities, letting her classmates know she “was not happy with [her] grades so far,” and they tended to be supportive. In fact, they often shared that they, too, felt stressed or confused; the group normalized making mistakes and asking for help. After about a month, they started staying after class “to go over all the answers we got wrong” and asking the instructor for clarification. “It was actually nice,” Mercedes reminisced, “because we could have conversations where we could try to figure stuff out

[…] instead of one person knowing all the answers.” And that safety-inducing dynamic gave her confidence.

Tahir (Single-Sex Group). Tahir thought being in an all-male group helped him “bond early on with all my group members.” Tahir attributed his strong connection to two reasons. First, as a chemical engineering major and a student athlete, he is “surrounded by dudes” so an all-male group “did not feel out of the ordinary.” Second, he described his group’s conversations as “lacking a filter” because “we were not worried about being charming [or] embarrassing ourselves. The filter normally used in school was toned down.” This rapport allowed Tahir and others in his group to learn the course content with explicit humor, often expressed through a “GroupMe thread” where “we coordinated homework assignments, wished each other happy birthday, and shared memes about sex.” Tahir also noted that two of his group members self-identified at the start of the semester as gay and bisexual, respectively, “and we were cool with that. We could jokingly flirt with them about stuff in ways we wouldn’t with girls.” The men in the group could use humor to dissect human reproduction without fearing their teasing would alienate a female student.

Devon (All-Male Group). Devon, a black freshman majoring in theater, also appreciated the dynamics of all-male groups. He initially felt apprehensive about enrolling in the course, because “I am not a science major, and I hate labs.” He found sterile technique and the science process “tedious,” especially because he “learned by talking." Thankfully, his team members ensured he had a positive experience. "I really liked them; the whole table was hysterical." They so thoroughly enjoyed the science talk around sex that they often wished the instructor would cold call on their group. In Devon's words: "we lived for the magic 8 ball questions". When asked to elaborate on the group dynamics that bred success, he emphasized that the boys in his team were "chill" and "funny." "I am a theater major and performer," he elaborated. "I don't mind being put on the spot." He therefore found the banter helpful, rather than offensive.

José (Mixed-Gender Group). Not all men, however, appreciated learning in -hyper-masculine spaces. A gay freshman of Filipino descent, José shared his experience in the course was "pretty average." His group members did not go out of their way to establish rapport with each other, and they usually relied on a divide-and-conquer approach to shared tasks. Those observations, in addition to poor group attendance, meant he did not get to know his peers. He also shared he was a trained sexual assault crisis counselor who worked with victim-survivors on campus. "Conversations around sex are easy for me," José continued, "so I was disappointed we didn't have more interesting conversations." He felt his classmates' laconicism resulted in missed opportunities. When asked whether he would appreciate being grouped only with men, he vehemently replied, "I don't like the dynamics that occur when only guys are present." In his mind, men tend to "boast" in mixed-gender groups and "act immaturely" in all-male groups. And being confronted with those behaviors would have made him behaviorally withdraw from the course.

Elena (Mixed-Gender Group). As a non-traditional older student, Elena approached her small group discussions with a clear goal in mind: to show her fellow students that "there's no shame in talking about sex." During the interview, she laughed as she remembered how during "the first or second week of class, I told everyone how I'm in my forties, and I still love sex." Building on her background as a mother and Family and Social Science major, Elena took it upon herself to ensure all members of the group felt "comfortable" and willing to participate. Specifically, when Elena noticed that the two men in her group rarely spoke, "I would turn to them and ask them, 'what's your opinion on this study?'" When prompted to elaborate why she assumed a leadership position, Elena reflected she felt "uncomfortable with sex when I was their age" and she wanted them to "transcend that barrier." Elena consequently married multiple identities (i.e., female, a mother, an older student) to great effect, supporting and motivating her team.

Titilayo (All-Female Group). A female student athlete of Nigerian descent, Titilayo initially "dreaded" the conversations around sexuality and intercourse: "I don't talk about [these topics], because I know I will never understand what it means to be gay or sexually active. Those are different from my choices, or how I was raised" in her socially conservative household. However, both her group members and the instructors eased her into these conversations, so that she came to believe “these conversations were really cool.” She especially appreciated how the instructor “would bring science-y facts to show students the hidden biology behind societal rules and opinions. Now *that* was incredibly interesting” (emphasis in the original). Through “open dialogue” with her group members and with the help of “a judgement free zone,” Titilayo came to “absolutely love” these discussions. She especially enjoyed seeing “how some students’ viewpoints changed after hearing these science facts, and I thought that was cool.” When asked to describe her group, she stated: “I really liked them; they were funny, too. I would hang out with them” now the course has ended. She further elaborated that “it was nice having other girls—other group members carry the load and the burden. I really enjoyed that part, feeling like you had people who had your back.” For Titilayo, those safety-inducing personal relationships allowed her to overcome her fear that she “would never understand” the lived experiences of gender minorities and sexually active college students.

Laura (All-Female Group). A student athlete and sophomore majoring in Public Health, Laura felt ambivalent about her group. She emphasized she felt the course was “a very exciting class. Stressful, but you know what? It was exciting and that’s something.” When asked to reflect on the group’s interactions, Laura openly hungered for more talkative partners. “I wake up at 5:30 every day for practice,” she explained. “I’m already tired” by the start of class, and felt she was doing most of the work to initiate and sustain non-academic conversations. She acknowledged that the group did discuss biological concepts, but not consistently. “I think a lot of the time we would talk a lot in the beginning,” she mused, “but then [the conversation] would quickly die out over time pretty fast.” She therefore tended to converse with students in the adjacent group more often. With them, she could talk about music, movies, and her college experience. Laura felt these non-academic conversations were important because they helped her connect with her classmates.

Julia (Mixed-Gender Group). Not all students appreciated being grouped based on their gender. Julia felt “women, especially when surrounded by other women, will tend to be quieter but more judgmental, so your guard is inevitably up.” Julia elaborated further by stating she did not particularly enjoy discussing course topics with her group. “The two [women] immediately next to me rarely talked. It was frustrating.” One of these students was “an international student from China,” and Julia attributed her lack of participation to “a partial language barrier” and “cultural differences.” As an example, a conversation on abortion ended abruptly once the international student translated the term to her native language. “I can talk to boys about sex,” Julia concluded, “but I couldn’t talk to her about anything, really—especially after that happened.” That same student allegedly did not participate during subsequent socio-scientific discussions, and Julia “did not know how to engage her in conversation.” She also disliked the implication that “women will always get along with women. That has not been my experience. In fact, most of my friends are men, because I can't stand catty women." Race, country of origin, and culture, Julia felt, mattered more than gender identity; lacking kinship in these categories with her peers, she withdrew.

Generation of Themes

Theme 1: Women and Gender Minorities Already Experienced Social Identity Threat in STEM Spaces. Most students recalled being "worried," "nervous," or even "terrified," at the start of the semester, and they invariably related this apprehension to "unpleasant," "demeaning," and "stressful" experiences in their K-12 setting. Consider how Titilayo felt uneasiness "because science courses are hard," and she worried the discussion-heavy lectures would expose "how far behind I was from everyone else." Laura likewise fretted about "quickly falling behind others." And when Anne admitted "I have never felt like I belonged in a science class," she unintentionally voiced a common fear among interviewed students. The sole student, Tahir, who felt confident going into the course still stated he "thought biology was incredibly boring," particularly because high school teachers "never actually taught the interesting things."

Many students also interpreted their negative STEM experiences as personal failings. Titilayo hypothesized she struggled with science courses because she had "never been good at remembering things." Anne lamented she was not a "science-minded person" which engendered "hard times in high school." Laura disclosed that "science has always been really difficult for me" because "I am unable to remember [the] sequences and cause-effect relationships" that define science. For most of these students, previous and unpleasant educational experiences severed their connection with science, as predicted by social identity theory. By only enrolling in science courses when forced, these students ensured they could avoid combustible educational spaces known to internally ignite worry, anxiety, and pure terror.

Theme 2: Shared Experiences and Explicit Humor Increased Sense of Belonging in Single-Sex Groups. Interviewed students from single-sex groups, both male and female, generally appreciated discussing biology and sexuality concepts with members of the same sex. They felt their single-sex groups allowed for laid-back discussion, which female students said allowed them to address their academic self-doubt by contributing to the conversation more often. "All the women in my group," Titilayo recalled, "were very appreciative of each other, and gave each other the opportunity to contribute to the conversation." Being able to engage in the co-construction of scientific knowledge "felt nice," according to Anne, since "I could participate in the conversations where we figured stuff out together". Mercedes agreed: she enjoyed being in "a science class where we could have conversations and figure things out together" without feeling others were judging her performance. Additionally, most interviewed students agreed they felt more comfortable discussing highly gendered topics—such as masturbation, dating in college, and intercourse—with members of the same sex, and they attributed their increased comfort to shared lived experiences and the ability to rely on humor.

Shared Experiences. Consider how Mercedes appreciated working in her group, precisely because “we could talk and laugh about the things our bodies do.” She felt at ease discussing “gender discrepancies” because of the “shared experiences” of group members. She also stated that she “always liked learning about your body; it’s unique to you. And talking about pregnancy and birth” with only women “was really comfortable.” Titilayo added:

> Even though we had different views on social issues, we could all still personally understand menstruation, cramps, and what estrogen does. We have all been there, we could all relate, so we could all talk.

This capacity to relate on a personal level allowed most students in single-sex groups to feel connected, both with group members and with the course content. This connection in turn helped students talk openly about socio-scientific topics, including sexual orientation and gender identity, often with the use of humor.

Humor. Students in single-sex groups, particularly male students, shared how they quickly created coalesced around humor as a learning strategy. Tahir and others in his group could use jokes to emphasize biological concepts, and this relaxed environment allowed them “to build friendships with the group over time.” As an example, Tahir referenced a study (Apicella, Feinberg, & Marlowe, 2007) that compared the attractiveness of two male voices that differed on their pitch. When asked to discuss the article within their groups,

> We turned to Devon, who’s gay,” said Tahir, “and told him: ‘Ok, big guy, who[m] do you like?’ And he replied ‘well, the first one [high-pitched] seems nice, but the other one [low-pitched] sounds like he could wrap me in his arms and make me feel safe.’ We laughed about it.

Similarly, Devon felt his group was “more interactive,” and he appreciated being able to “throw pins at the wall to see what sticks” without the worry of “saying something offensive.” As Devon noted, the electronic conversation supplemented the in-class discussion, but he “would not share those [text messages] with students outside of the group” given their explicit humor.

Female students’ repeated references to “having fun” and “laughing” during group conversations suggest they also relied on humor in their co-construction of knowledge. Mercedes and her team members, for example, gently ribbed the instructor for claiming tardigrades (*Tardigrada* sp.) “were cute.” After Mercedes shared images of the organism with her group, one of her team members deadpanned: “it’s like when a mother asks you if her baby is cute, but it looks like someone sat on it.” These and other jokes helped them bond—and learn. Anne also shared two particularly “funny conversations” where explicit humor was used. The first was a class exercise where students had to list words “for hyper-sexually active men and women.” The discussion was “funny” because “while there were words that the whole class didn’t agree on, our group all agreed on the words used to describe men.” She also recalled another in-class exercise where students were asked to evaluate the language used in personal dating apps and personal ads. “That was really funny,” Anne recounted, “because some of the men’s ads were pretty pathetic.” And Anne felt the safety-inducing effect of being in a single-sex group allowed them to joke about men’s seduction attempts without fearing repercussions.

Theme 3: Students Unanimously Rejected Single-Sex Collaborative Groups. Despite acknowledging the educational benefits of single-sex groups, all interviewed students stated they would not join a single-sex group in a future class. They justified their position by either addressing their own weak identification with their expressed sex, or else by evincing a commitment to having difficult conversations with members of the opposite sex. Titilayo, for example, explained she “would be fine with either [option], I guess? I don’t know. I do like diversity in all senses, and I do think it’s important to have a man’s perspective, especially on all of this,” broadly referencing course concepts. These two types of justifications will be elaborated on in the sections below.

Weak or Negative Identification with Expressed Sex. Julia and José each mentioned how they are more likely to interact with men and women, respectively, both in the classroom and in their social circles. José argued that being in a single-sex group would have made him less likely to attend classes and engage with the course content, given earlier distasteful encounters with all-male groups. “As a gay man,” he disclosed, “I would have felt intimidated. Would I join an all-male group? No, no, no, absolutely not!” Julia, as discussed previously, expressed a deep dislike of all-female groups, describing their social interactions as insincere and overly critical. Both students hold negative perceptions of their own identities, and this self-rejection can be explained by their lived experiences.

Another student in an all-female group, Laura, shared some of Julia's negative perceptions. Although student participation within her group was "fine" and the interactions were "pleasant," Laura noted, "for me it's not important to be surrounded by women. It's just something I don't think about." When asked to elaborate, Laura suggested that the women in her group lacked shared interests. "I got along with the girls in my lab group. On the first day [of lab] I started talking to one of them and realized that she was from a town close to where I grew up. We connected." But in her lecture group, the lack of small talk during lessons meant she "never got to know them individually." She tried using pre-class time to talk to her group members, but they did not always engage; she therefore spoke more frequently with members from Group 2.

The interviews with Julia, José, and Laura validate assumptions posited by social identity theory: group membership is a psychological rather than demographic factor. Individuals need to self-identify with the group in question, and none of these students did so in this specific context. While Julia and José categorically rejected any single-sex group, regardless of composition, Laura acknowledged she may have connected with a different set of female students. For these and other students, other identities—including age, culture, and country of origin—played a stronger mediating role than gender.

Titilayo emphasized her athleticism and her conservative religious background as often as she mentioned gender. Conversely, Elena leaned into her identities as an older, returning student, and as a mother, to guide how she connected with her classmates and the course content. An intersectional lens is therefore crucial to tease apart how gender regulates learning, since everyone's relationship to their expressed sex depends on contextual factors, including lived experiences.

Loss of Educational Experience. All interviewed students argued that single-gender groups prevented their members from encountering and addressing opposing perspectives. They deemed this deficiency to be highly detrimental to their learning and their growth as students and individuals. As Tahir pointed out, the anatomy of men and women differs drastically. Being in an all-male group meant he and his teammates, for example, "overdrew the ovaries and forgot some tubes" during a human anatomy activity, and "needed to be rescued by [the instructor]." His group was also relatively silent during "the female topics," such as pregnancy and birth. Likewise, Julia argued, "I feel that I did not learn as much as I could in this class, because I only discussed these concepts with girls. I wanted to know what guys thought." She therefore felt her group conversations could only reveal, at best, half of the story.

The problem of single-sex grouping, students conjectured, extended beyond the gendered course content. Elena stated she preferred having both men and women in her groups, because then she encountered "different perspectives, different ideas, different experiences.” She would consequently “highly value having both sexes” in her groups, because it allowed her to see how men and women “viewed masturbation or pregnancy.” Anne felt similarly conflicted, since “being in an all-female group makes it easier to have those discussions about shared experiences. But I also feel it’s very important for men to participate in those topics and be included in the conversation.” Or as Mercedes reflected, if college students must encounter opposing points of view “to learn how to argue critically and persuasively, then we [women] should feel comfortable talking about reproductive biology with men, even if it’s awkward.” All students felt that their academic experience was, or would have been, diminished by being assigned to single-sex groups, even if they acquiesced that their academic performance benefited from the grouping.

Discussion

While further research should be carried out to identify other educational interventions that address gender-driven barriers in college STEM courses for nonmajors, this study nonetheless highlights one important conclusion. Single sex grouping may benefit female students in specific educational contexts (Pahlke, Hyde, & Allison, 2014). Specifically, this grouping succeeds when it does not magnify women’s numerical underrepresentation in the classroom (Boucher & Murphy, 2017; Bloohart et al., 2020). Previous studies, focused on college women majoring in STEM, discerned that sex-based grouping often precipitated social identity threat by making female students feel tokenized (Emerson & Murphy, 2014; Pietri et al., 2019). Social identity theory predicts students will withdraw—physically or emotionally—from educational spaces they find psychologically threatening (Chen et al., 2021; Skourletos, Murphy, Emerson, & Carter, 2013). Women who identify strongly with their gender and weakly with the discipline will display lower attendance and engagement when gender-based grouping activates social identity threat (Boucher & Murphy, 2017; Emerson & Murphy, 2014). The following section will contextualize these findings with research from the primary literature and discuss the educational variables that convert gender-based grouping from a threat-activating instructional choice into a safety-inducing one.

All-Female Grouping Alleviates Social Belonging Concerns

Previous research cautioned against this type of grouping, for it could precipitate trust and fairness concerns by exacerbating women's numerical deficit (Boucher & Murphy, 2017). This admonition may not apply to science courses where men and women register in equal proportions. Biology continues to be one of the more gender-equitable science majors in colleges and universities (Charlesworth & Banaji, 2019; Ganley, George, Cimpian, & Makowski, 2019), suggesting that single-sex grouping in biology classes for majors and nonmajors could impart the benefits of gender-specific spaces (Park, Behrman, & Choi, 2020; Rosenthal, London, Levy, & Lobel, 2011) without triggering social identity concerns (Boucher & Murphy, 2017).

Yet students also failed to unambiguously endorse the creation of single-sex collaborative groups. They unanimously stated they would rather learn with a diverse group of peers, even if that entails encountering the sexist interactions that typify mixed-gender conversations (Biggs, Hawley, & Biernat, 2018; Kahalon, Shnabel, & Becker, 2018). Educators and researchers would err in dismissing these responses as students parroting back the liberal ideals of their social context. Much better to take students at their word: they value encountering a diverse set of opinions and behaviors, even when these may trigger social identity threat. This perspective aligns with previous research on gender salience and single-sex schooling (Park, Behrman, & Choi, 2018; Wong, Shi, & Chen, 2018). Graduates from single-sex institutions generally experience heightened gender salience when they enter the workplace, and consequently may struggle in relation to their female peers who have developed cognitive and affective strategies to deal with gender-mediated antagonism (Bigs, Hawley, & Biernat, 2018). This rejection suggests that instructors will need to persuade students that this gender-based grouping has merit, and that evaluating the pros and cons of any situation is a life skill worth developing.

Conclusion

This study demonstrated that the sex ratio of student groups can influence attendance and engagement in a college biology class for non-majors. At a practical level, this work on situational cues and gender ratios provides instructors with a simple yet effective intervention that may help ameliorate the psychological barriers that female students encounter in STEM courses. Specifically, instructors in nonmajors biology courses can increase female students’ sense of belonging by creating safe spaces within the classroom. These safe spaces will in turn protect these students’ attendance and engagement, leading to more positive STEM educational experiences for these students than what they experienced prior to enrolling in college.

Chapter 5: “Fat Lady Spiders are Sexy”—Scientific Reasoning in a College Biology Course for Nonmajors

College biology courses for nonmajors aim to teach students to think like scientists, even when students in the course are not majoring in STEM (Guang & Bierna, 2013; Lammers, Goedhart, & Avraamidou, 2019; Walker & Sampson, 2013). Defined as problem-solving and critical thinking in relation to conceptual and procedural disciplinary knowledge (Milkova, Crossman, Wiles, & Allen, 2013), scientific reasoning allows practitioners to test hypotheses, collect data, and propose novel explanations for observed phenomena (Fischer et al, 2014). Yet, since problem-solving and critical thinking are not domain-specific, students who practice scientific reasoning gain skills they can apply in other contexts (Woolley et al., 2018). Nonmajors who practice scientific reasoning learn how to make detailed observations (Klemm, Flores, Sodian, & Neuhaus, 2020), evaluate claims (Fischer et al., 2014), and develop an intrinsic curiosity for natural and societal phenomena (Klijnstra, Stoel, Ruijs, Savenije, & van Boxtel, 2022).

An effective science course for non-majors therefore helps students master the cognitive tools scientists use to make sense of the world (Walker, Van Duzor, & Lower, 2019). When students practice using scientific reasoning, they question prior beliefs, reject implausible explanations, and formulate evidence-based solutions (Milkova, Crossman, Wiles, & Allen, 2013). Nonmajors benefit from developing these sense-making skills because they can help students navigate their academic, professional, and personal experiences (Grooms, Enderle, & Sampson, 2015). They can then apply these behaviors throughout their lives, especially when the context benefits from critical thinking and problem solving (e.g., parents navigating health care for a late preterm infant, Rajabi, Maleki, Dadashi, & Tahna, 2021; or women planning pregnancies after *Dobbs*, Casas, Horvath, Schwarz, Bachorik, & Chuang, 2022). By prioritizing the acquisition of scientific reasoning, science courses for nonmajors can encourage students to become "courageous, self-reliant [citizens], with confidence in the power of free and fearless reasoning" (Brandeis, J., concurring in *Whitney v. California*, 274 U.S. 357).

To help students practice these skills, college biology courses for nonmajors explicitly scaffold systems thinking, quantitative thinking, and the process of science into the curriculum (Momsen, Speth, Wyse, & Long, 2022). However, despite a renewed emphasis in helping students develop these skills, research shows that students' learning has been compromised, as many students struggle to solve problems, explain their reasoning, and apply their knowledge to new situations (Dowd, Thompson, Schiff, & Reynolds, 2018; Krontiris-Litowiz, 2009). Most researchers and practitioners agree that instructional choices, rather than student aptitude, likely explains this deficiency (Haugland, Rosenberg, & Aasekjær, 2022).

Learning biology in a college course for nonmajors is an inherently social process, heavily influenced by the physical (e.g., high-tech active learning classroom, Cotner, Loper, Walker, & Brooks, 203) and sociocultural components (Dasgupta, Scircle, & Hunsinger, 2015; Sullivan, Ballen, & Cotner, 2018) of the classroom ecology. Students engage with one another and the course instructor as they jointly construct scientific explanations for natural phenomena. This type of collaborative, discursive activity pushes students to apply disciplinary theories to novel contexts (Leupen, Kephart, & Hodges, 2020). The roles and behaviors that emerge as students jointly practice scientific reasoning are valuable to interrogate, as they directly address how scientific reasoning emerges in groups (Klemm, Flores, Sodian, & Neuhaus, 2020). While scientific reasoning has been explored extensively in K-12 and undergraduate settings (Jirout, 2020), studies exploring scientific reasoning for nonmajors remain rare (Alberst, 2013; Gormally, & Heil, 2022; Quay, Bleazby, Stolz, Toscano, & Webster, 2018).

Research Questions

This study addresses a gap in the literature by interrogating how female, nonmajor students in single-sex small groups learn to reason from evidence in a college biology class for nonmajors focused on sex, gender, and society. By removing gender as a potential barrier, this study could identify differences in discursive patterns among female, nonmajor students in the absence of their male peers. Further, it could then identify the academic and social behaviors that may arise in all-female student groups. The specific research questions addressed include:

(1) *How do female students in single-sex small groups differ in their rates of participation during scientific reasoning?*

(2) *How do female students in single-sex small groups differ in their scientific reasoning?*

(3) *How do female students' behaviors in single-sex small groups influence the emergence of scientific reasoning?*

Theoretical Framework

Multiple educational theories acknowledge that learning is an inherently social process (Lantolf, Thorne, & Poehner, 2015; Vygotsky, 1978). Socio-cultural learning theory, as the name suggests, prioritizes the socio-cultural variables that color all interpersonal interactions, both in the classroom and beyond (Jeong, Clyburn, Bhatia, McCourt, & Lemons, 2022). These variables include gender (Boucher & Murphy, 2017), race (McGee, & Robinson, 2019), and language (Minjung, & Sikorski, 2019). Since learning occurs when students interact repeatedly within a specific sociocultural context, research that relies on this theoretical framework must describe how students interact with the physical, curricular, and social components of the classroom ecology (Lantolf, Thorne, & Poehner, 2015).

As Jeong and colleagues (2022) note, "learning is a mediated action. Learners construct knowledge while interacting socially with others and artifacts" (p. 2). The nature of these social interactions will necessarily depend on the demographic breakdown of small groups (Doucette, Clark, & Singh, 2020; Minjung, & Sikorski, 2019). The numerical representation of women in small groups, for example, will mediate how students in that group interact socially; when said numerical representation changes, the learning process necessarily changes as well. When women learn in co-educational small groups, they are more likely to encounter sexually antagonistic conversations (e.g., sexist humor and deprecating notions of women's role in society). Conversely, when women work in single-sex groups, they are more likely to punish social loafers (Chang & Brickman, 2018), in part because academic sanction-reward systems operate differently in single-sex educational spaces (Fang, Bennett, & Casadevall, 2013; Witmer & Johansson, 2015). Therefore, a woman's educational experience in a college biology course will certainly depend on the classroom space, the instructor, and the curriculum—but it will be equally tempered by the identity, personality, and academic background of her classmates. The literature review in the following section expands on these claims.

Literature Review

The literature review enclosed in this study will clarify how instructional choices at the curricular and instructional level influence the emergence of scientific reasoning in college nonmajors. The section begins with an academic description of scientific reasoning, and then documents the curricular choices college instructors may employ to effectively integrate its practice in their classrooms. Since collaborative, discursive practices remain the gold standard for scientific reasoning instruction (Alkhouri et al., 2021; Kontiris-Litowitz, 2009), this section will also explore the variables of student groups that may hinder or facilitate students learning how to reason with science in this context.

Scientific Reasoning

Scientific reasoning is a defining characteristic of scientific practice (Milkova, Crossman, Wiles, & Allen, 2013). It helps researchers carry out experiments, collect data, and form explanations for natural phenomena (Anwar, Susanti, & Ermayanti, 2019). In addition to incorporating the skills necessary for inquiry, scientific reasoning also influences the culture of science (Dewey, Roehrig, Schuchardt, 2021). For example, scientific reasoning confines practitioners to proposing claims that fit within the general contours of the disciplinary canon (Lammers, Goedhart, & Ayraamidou, 2019). Likewise, scientific reasoning encourages scientists to trust the expertise of others when their own professional background precludes them from proposing their own scientific explanations (Nichols, 2017).

When students practice scientific reasoning, they learn how science, as a discipline, both refines prior knowledge and formulates new understanding (Bradshaw, Nelson, Adams, & Bell, 2017; Fischer et al., 2014). Reasoning logically from evidence to propose novel claims helps practitioners—be they scientists or nonmajor college students—internalize the primacy of empiricism within science (Dowd, Thompson, & Schiff, 2018), as well as its value in other contexts (e.g., evidence-based policy, Weasel

& Finkel, 2016; public health initiatives, Smith, Olimpo, Santillan, & McLaughlin, 2022). Only through experience and experimentation, and the coordination between evidence and logical reasoning, can novel yet plausible explanations be proposed (Woolley et al., 2018). Though this process fails to produce universal truths (Chen, Benus, & Hernandez, 2019), it nonetheless succeeds in advancing society's understanding of the human experience and its place within the natural world (Woolley et al., 2018). Hence, to truly comprehend how science as a discipline relies on scientific reasoning to refine prior knowledge and formulate new ideas, students must first practice using it in the college classroom (Yang, Bhagat, & Cheng, 2019). However, as the next sections document, many college courses for nonmajors fail to deliver on this promise.

Teaching Scientific Reasoning

As Alberts (2013) notes, most college science courses suffer from "superficial 'comprehensive coverage' [that] leav[es] little room for in-depth learning" (p. 1263), including the development of scientific reasoning. When instructors rely on the lecture format to deliver information to a large group of students, they invariably prevent students from meaningfully practicing how to think methodically, argue scientifically, and speak persuasively (Freeman et al., 2014; LoPresto, 2020; Waldrop et al., 2015). Students cannot be expected to master these skills while sitting passively in a lecture hall (Chi & Wylie, 2014). In addition, these lecture-based courses tend to eschew a strand of scientific reasoning called pragmatism, which accentuates how science has transformed the way people interact with one another and the natural world (Quay, Bleazby, Stolz, Toscano, & Webster, 2018). Pragmatism follows Bronowski's (1973) admonition that "there is no absolute knowledge. And those who claim it, whether they are scientists or dogmatists, open the door to tragedy. All information is imperfect. We have to treat it with humility" (p. 353). This author understood that scientific reasoning and other sense-making behaviors are necessarily contextual works in progress where proficiency, rather than perfection, carries the day.

Science courses that rely on lecturing also suffer from few "quality assessments that measure student learning" in relation to their ability to "to interpret scientific explanations of the natural world" and "to evaluate scientific evidence" (Alberts, 2009, p. 79). Conversely, courses that employ reflective, discursive activities help students refine their ideas and gauge their understanding in relation to their peers (Kelly, 2016; Repice et al., 2016). They further help students appreciate that, contrary to historical descriptions of science, scientific knowledge and skills do not create timeless truths (Quay, Bleazby, Stolz, Toscano, & Webster, 2018). This (mis)perception of the process of science is especially strong in nonmajors (Johnson & Willoughby, 2018), who tend to view scientific disciplines as unassailable dogma and scientists as mystical oracles, endowed with knowledge forbidden to the uninitiated (Lin, Liang, & Tsai, 2012; Cruz, Bruhis, Kellam, & Jayasuriya, 2021). Only by participating in scientific reasoning and practicing other scientific behaviors can they understand how knowledge is constructed—and that they themselves can be active participants in the process. By refining their use of scientific reasoning and other scientific behaviors, nonmajors demystify the process of science for themselves. The discursive nature of science practice, therefore, helps students gain scientific expertise via experiential learning (Alkhouri et al, 2021; Waldrop et al, 2015).

Only courses that intentionally incorporate opportunities to engage in science talk will fix the problem of superficial comprehensive coverage (Alberts, 2013). As Alkhouri and colleagues (2021) observe, students learn best when courses challenge them "to analyze and challenge questions, and work collaboratively in small groups to answer" problems posed by the instructor or their peers (p. 1063). Instructors facilitate this process by implementing conversational strategies that induce students to incorporate scientific reasoning roles and behaviors into their group conversations (Felton, Garcia-Mila, Villaroel, & Gilabert, 2015; Tanner, 2009). The instructor can use instructor talk to introduce and justify discursive practices, as well as to model how experts use evidence and logical reasoning to propose falsifiable claims (Kelly, 2016). Student groups, in turn, practice these skills in a collaborative setting by engaging in science talk (Alkhouri et al., 2021). Over time—and with practice—students participating in collaborative learning will jointly internalize and eventually master the conceptual, procedural, and linguistic conventions of science (Repice et al., 2016). The following section describes how collaborative learning may facilitate the development of scientific literacy.

Developing Scientific Reasoning through Collaborative Learning

College students who learn collaboratively with their peers tend to achieve more academically, hold more positive attitudes towards science, and show higher self-efficacy than those students who learn through the traditional lecture format (Adkins, Rock, & Morris, 2018; Scager, Boonstra, Peeters, Vulperhorst, & Wiegan, 2016). These students also develop better academic skills, including critical thinking and self-efficacy, than their peers trapped in a lecture format (Johnson, Pelzel, & Mantina, 2022; Wester, Walsh, Arango-Caro, & Callis-Duehl, 2021). Further, these gains persist long after instruction ends (Foster-Hartnett, Mwakalundwa, Bofenkamp, Patton, & Nguyen, 2022). Collaborative learning succeeds because it forces students to converge on a common answer through science talk (Lombardo & Shipley, 2021), and these conversations often prove more memorable and personally relevant than facts delivered through the traditional lecture format (Smith et al., 2009; Terson de Paleville, 2022).

Potential Pitfalls with Collaborative Learning

While talking about science with peers has been shown to deliver measurable academic and social gains (Olander & Ingerman, 2011; Tanner, 2009), group work sometimes fails for a variety of reasons. The following section discussed three potential barriers: unequal rates of student participation, differences in academic and science-process skills, and social loafing. First, sometimes students are unable to participate equally in classroom activities—especially when other students dominate discussions.

Second, students in the group might have different academic abilities, and choose a mode of expression that conflicts with course aims and group expectations. To illustrate, humor functions as a double-edged sword: on the one hand, it can memorably ground abstract concepts; on the other hand, it may alienate students who consider the jokes offensive and disruptive (Cooper, Nadile, & Brownell, 2020). Third, group members could disagree on what constitutes good quality work (Kwon, Liu, & Johnson, 2014), or they may differ in the prosocial behaviors they exhibit (Chang & Brinkman, 2018; Johnson & Johnson, 2009). Since effective communication is a vital component of learning in science (Bautista et al., 2022), socio-emotional variables will necessarily color the process. A rude, lazy, or disruptive classmate will hamper the groups' ability to reason scientifically for non-academic reasons (Jassawalla, Sashittal, & Maishe, 2009). The following section will elaborate on these three potential barriers in turn.

Unequal Rates of Participation. Researchers interested in conversational rates often begin their analysis with volubility. Defined as how often people speak in a group setting (Brescoll, 2011), volubility is modulated by identity (Boucher & Murphy, 2017). When a student holds multiple privileged identities, they are more likely to dominate classroom discussions (Repice et al., 2016). Since conversational volubility depends on status, measures of volubility can indirectly clarify the relative social status of conversational groups (Lithwick, 2020; Minjung & Sikorski, 2019). To illustrate, volubility research has traditionally focused on gender (Grunspan et al., 2016; Owens et al., 2017), demonstrating women tend to speak less often when men are present (Knight et al., 2012; Paine & Knight, 2020). Volubility also interacts with other identity variables, including race and nationality (Alkhouri et al., 2021; Liu, 2015; McGee & Robinson, 2019; Skourletos, Murphy, Emerson, & Carter, 2013). Even invisible identity variables, such as socioeconomic status (Vanormelingen & Gillis, 2016) and sexual orientation (Henning, Ballen, Molina, & Cotner, 2019; Vanormelingen & Gillis, 2016), influence who speaks in group settings. Individual and group identities, therefore, must be considered whenever instructors assign collaborative learning tasks—especially those focused on science talk—given the strong correlation between how often students participate and how frequently they get to practice using scientific reasoning. A student excluded from the conversation will, by definition, be excluded from the vital process of jointly constructing scientific knowledge.

Humor and Other Unconventional Discourse. Research shows that students do not always internalize the linguistic conventions of scientific reasoning (Anwar, Susanti, & Ermayanti, 2019). Nonmajors in a science classroom instead "draw on 'nonacademic' discourse structures to present, critique, and defend ideas" (Minjung & Sikorski, 2019, p. 563), by using memes (Anton-Sancho, Nieto-Sobrino, Fernandez-Arias, & Vergara-Rodriguez, 2022) and humor (Poirer & Wilhelm, 2014). Other students may leverage their artistry and lived experiences, using "passionate [and personal] explorations" instead of "words and equations" to explain natural phenomena (Gurnon, Voss-Andreae,

& Stanley, 2013, p. 2). These innovative representations of biological information can be efficient and effective, but they exist in tension with the conventional discursive patterns of expert practitioners that students are expected to internalize. “One [person’s] vulgarity is another’s lyric” (Harlan II, J., *Cohen v. California*, 403 U.S. 15), and if the offended party happens to be aggrieved peers, emergent science talk based on humor and anecdotes may be snuffed out prematurely[25].

Yet students should not stray too far from the linguistic conventions that define scientific reasoning, for they serve to reinforce the epistemological norms that distinguish the process of science (Alberts, 2009; Waldrop et al, 2015). By framing conversations about science around testable claims, students learn that—to be persuasive—claims must be harmonized with logic and evidence (Lammers, Goedhart, & Avraamidou, 2019). Scientific reasoning likewise constrains meaning-making processes to the realm of acceptable domains of disciplinary knowledge (Acar & Patton, 2012): valid claims in science necessary build upon the existing scientific cannon (Anwar, Susanti, & Ermayanti, 2019; Walker, Van Duzor, & Lower, 2019). These constraints discipline the mind and help nonmajors develop their critical thinking and problem-solving skills. For these reasons, while students may innovate how they employ scientific reasoning, they should nonetheless ensure their original and personalized delivery does not hamper the

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[25] Research also suggests that identity will modulate what topics students consider funny in the classroom. Female and queer-identified students are statistically less likely to appreciate jokes that make fun of women and body size, for example (Cooper, Nadile, & Brownell, 2020).

goal of science instruction for nonmajors: helping students develop skills for lifelong learning and engaged citizenship (Olander & Ingerman, 2011).

Social Loafing. When students work in groups, they must ensure labor is distributed equitably (Chang & Brickman, 2018; Hall & Buzwell, 2013). This process not only requires clear communication regarding task assignments, but also mechanisms to promote reflection and accountability (Kwon, Liu, & Johnson, 2014). Students sometimes fail to contribute for a variety of reasons, including poor time management, stress, different priorities, and peer acceptance of social loafing (Curşeu, Janssen, & Raab, 2012; Svinicki & Schallert, 2016). As Chang and Brickman (2018) note, “five major variables […] mediate the effects of cooperation, including motivational, social, and cognitive aspects” (p. 2). These variables, derived from social interdependence theory (Johnson & Johnson, 2009), include positive interdependence, individual accountability, prosocial interactions, well-developed social skills, and opportunities to reflect on collaborative work. When groups develop these behaviors, they work harmoniously and cohesively—not because conflict fails to emerge, but rather because they share a common purpose and strategy. Conversely, when students fail to employ these prosocial behaviors (e.g., because of poor communication skills), collaboration collapses (Hall & Buzwell, 2013; Jassawalla, Sashittal, & Maishe, 2009).

Further, research suggests that the prevalence and acceptability of social loafing and other antisocial academic behaviors contain a gendered component. In a study that anonymously surveyed graduate students in the life sciences, researchers revealed that male students were significantly more likely to self-report not contributing their fair share in group work (Mol & van den Hoven, 2022). Yet these students also bragged that they eluded academic or professional sanctions, even when the behavior in question clearly breached ethical norms (e.g., adding their names to research papers they did not meaningfully contribute to, Mol & van den Hoven, 2022) The researchers argued that situational cues, including the existence of a gendered sanction/reward infrastructure in academia (Fang, Bennett, & Casadevall, 2013; Witmer & Johansson, 2015), incentivized male students to sidestep academic and research integrity, caused women to judge these violations more harshly than men (Takeda & Homberg, 2014).

Women's understandably low tolerance for cheaters can also be observed in the college classroom—especially when the social loafing affects the quality of group work (Chang & Brickman, 2018). As Chang & Brickman note (2018), "students in lower-performance groups assigned harsh ratings to their low-scoring members, while students in higher-performance groups were more generous in their ratings for low-scoring members" (p. 1). The researchers argued that female students in low-performing groups were especially likely to punish social loafing when the poor performance was "linked uniquely with distracting behaviors" (Chang & Brickman, 2018, p. 2), because they resented having to "reallocate their attention and energies" (p. 2) to compensate. Women in all female-groups, therefore, are only tolerant of disruptive behaviors when these do not affect the group's performance.

Methods

To discern differences in conversational behaviors within and between groups of all-female groups, this study employed a convergent parallel mixed methods approach (Creswell & Clark, 2011). Mixed methods research acknowledges the strengths and weaknesses inherent in purely quantitative and qualitative investigations. Sometimes described as a pluralistic methodology, mixed methods assume some level of commensurability—an appreciation that investigative goals can be met by synchronizing different research paradigms (Kimmons, 2022). Effective mixed methods research aligns investigative procedures with the research question, and they abide by both quantitative and qualitative standards of rigor. The following sections will expand on these observations by detailing the mixed methods framework used in this study.

This study carried out a concurrent triangulation design, with qualitative and quantitative sources of data collected simultaneously (Tashakkori & Teddlie, 2010). A concurrent triangulation design provides two measurable benefits: complex understanding and high predictive power (Kimmons, 2022). This approach ultimately merges results, prompting the researcher to look for data convergence, divergence, and contradictions—both within and between the two types of data (Bishop, 2015). The relationship between different data sources in turn help researchers construct robust and contextual explanations for observed patterns during the interpretation phase (Kimmons, 2022)—leading to a more holistic and therefore accurate understanding of the educational ecology in question.

Course Description

This study collected data in one lecture section of an introductory biology course for nonmajors, BIOL 1003 (*The Evolution and Biology of Sex*). The course addresses general biological principles, including scientific inquiry and evolutionary thinking, using sexual reproduction as context (Sullivan, Ballen, & Cotner, 2018). A female-identified instructor taught all lessons, relying on inclusive teaching practices to increase student participation (Neill, Cotner, Driessen, & Ballen, 2018). She afforded students with frequent opportunities to discuss data and theories from various sources, including the course textbook *The Red Queen* (Ridley, 2016), articles from the primary literature (e.g., Fowler & Partridge, 1989; Chapman, 1992; and Long, Pischedda, Stewart, & Rice, 2009), and popular science videos. She further encouraged students to assimilate how scientists presented claims based on evidence using the claim-evidence-reasoning framework commonly deployed in science courses (Walker, Van Duzor, & Lower, 2019).

Prior to the start of the semester, the instructor divided students into collaborative groups, each composed of 4-5 students. A third of the groups were single sex, either all-female or all-male, while the remaining were mixed gender. Students completed classroom activities, homework, and course projects throughout the semester in these smaller groups. These activities included conversations around clicker questions based on *The Red Queen* (Ridley, 2012), the revision of previously generated concept maps, and guided discussions around data from the primary literature. The following section introduces the specific lesson where data was collected by first describing the flow of instruction, and then elaborating on the different learning tasks students completed in their small groups.

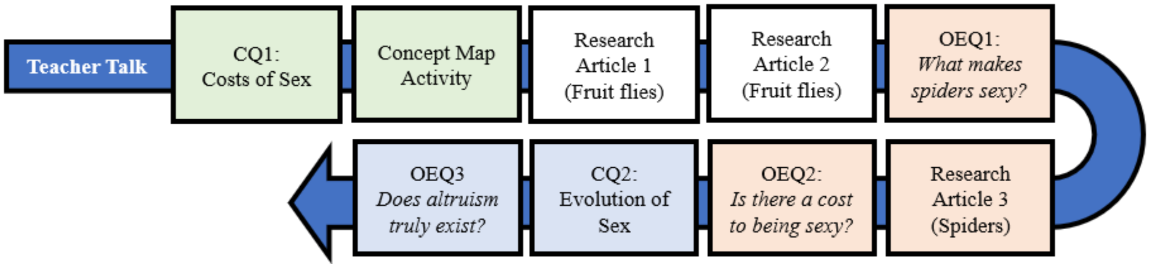
Lesson: The Cost of Sex

The Cost of Sex lesson took place five weeks into the semester. This lesson included a mix of instructor talk and instructional activities students completed in groups (Figure 5.1). Regarding the former, the instructor spoke throughout the lesson to present new conceptual and procedural knowledge, to guide students through instructional activities, and to provide feedback for student collaborative work. Regarding the latter, students throughout the lesson worked in their small groups to complete different learning tasks. These activities included constructing concept maps, analyzing data from the primary literature, and generating student artifacts to explain biological phenomena. Student groups then shared their work with their peers through classroom-level conversations moderated by the instructor. To increase accountability, the instructor relied on a random number generator to cold call on groups, tasking them to share their explanations with the rest of the class. The next section will discuss in-depth the nine[26] collaborative activities students completed in small groups during this lesson on the costs of sex.

Learning Tasks. The following section describes the different learning tasks small groups completed during this lesson. These learning tasks addressed the conceptual and procedural scientific knowledge students needed to understand biological theories that explain the evolution and maintenance of sexual reproduction—and thus function as useful proxies for the development of scientific reasoning. All of the learning tasks described in the following section were collaborative in nature.

Figure 5.1

Lesson Progression



Note: The blue arrow not only shows the sequence of classroom activities, but also represents the teacher talk that guided student groups from one activity to the next. All activities enclosed by the color-coded squares denote instances where student groups were explicitly asked to solve biological problems by engaging in science talk. Clicker questions (CQ) and open-ended questions (OEQ) were based on the course textbook,

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[26] This lesson contained eleven collaborative activities. However, the final two focused on mutations and their effects on an organism's phenotype. These concepts, presented at the end of the lesson, were meant to foreshadow theory introduced in the following lesson, on the evolution of sex. These activities were therefore dropped from the analysis.

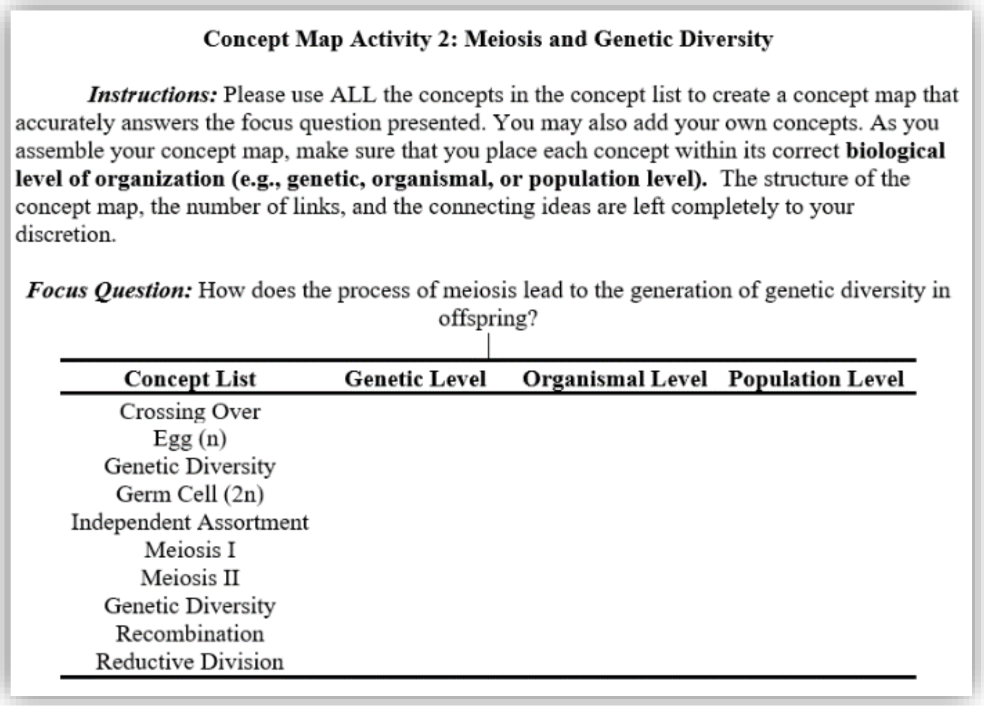
discipline-specific knowledge introduced by the instructor, and the research articles discussed in class. The color-coding scheme aggregates episodes of science talk that were conceptually related (e.g., OEQ1 asked a conceptual question that students needed to answer before they could analyze the data presented in Research Article 2).

Concept Maps. Students worked on a biology-specific concept map called a Knowledge Integration Map (KIM) (Schwendimann & Linn, 2016). At the start of the semester, students watched a training video that not only provided an in-depth guide on how to construct KIMs, but also justified their use in science classrooms by explicitly underscoring how concept maps help students integrate knowledge across different levels of biological organization. Since previous research suggested that students who revise KIMs with peers learn more than students who do not (Schwendimann & Linn, 2016), student groups were instructed to jointly revise the KIMs they completed individually as homework. The concept map activity described in this lesson constitutes the second time student groups worked on this type of knowledge integration activity in class.

The KIM exercise included the following central question: How does the process of meiosis lead to genetic variation in offspring? (Figure 5.2). While the instructor provided students with a word bank they were required to use, she also encouraged them to add their own concepts to the list. She further reminded students to place concepts under the correct level of biological organization—genetic, organismal, or population—to better visualize how the different biological concepts interact. Students revised their concept maps first with a partner, and then with the rest of the small group members. Each group then submitted a jointly revised KIM.

Figure 5.2

Description of Knowledge Integration Map



Concept Map Activity 2: Meiosis and Genetic Diversity

Instructions: Please use ALL the concepts in the concept list to create a concept map that accurately answers the focus question presented. You may also add your own concepts. As you assemble your concept map, make sure that you place each concept within its correct **biological level of organization (e.g., genetic, organismal, or population level).** The structure of the concept map, the number of links, and the connecting ideas are left completely to your discretion.

Focus Question: How does the process of meiosis lead to the generation of genetic diversity in offspring?

Concept List	Genetic Level	Organismal Level	Population Level
Crossing Over			
Egg (n)			
Genetic Diversity			
Germ Cell (2n)			
Independent Assortment			
Meiosis I			
Meiosis II			
Genetic Diversity			
Recombination			
Reductive Division			

Note: A copy of the concept map activity students completed prior to this lesson. Some of these concepts can reasonably operate at more than one level of organization. Links between levels of biological organization describe emergent properties that drive evolutionary processes, including the evolution of sexual reproduction.

Clicker Questions. The instructor also required students to answer multiple-choice questions using their personal response systems colloquially known as “clickers”. These questions usually functioned as summative assessments that gauged their mastery of conceptual and procedural knowledge. But they also often served as opportunities to engage in science talk with their small groups—especially when results from the clicker questions revealed lack of understanding or the presence of robust preconceptions in the student population (Table 5.1). The clicker questions that led to substantial student talk centered around evolutionary concepts presented in *The Red Queen* textbook (CQ1 and 3) and the procedural knowledge necessary to understand the research articles (CQ2) (Figure 5.1).

Open-Ended Questions. In addition to using clicker questions to prompt discussion, the instructor also frequently asked open-ended questions. Sometimes, these open-ended questions arose organically whenever the instructor identified conceptual and procedural gaps in student understanding. Prior to analyzing a research article on sexual selection in spiders, for example, the instructor asked students to brainstorm the physical characteristics that made female spiders sexually attractive (OEQ1) (Figure 5.1). Other times, the instructor paired open-ended questions with instructions to generate student artifacts—usually in the form of lists, tables, and figures.

Table 5.1

Examples of Clicker Questions that Preceded Small Group Discussions

Type	Example	Clicker Questions with Instructor Talk
No answer received majority support	CQ1	*“We humans are only related to our offspring 50%; that’s a huge cost. Asexual organisms, on the other hand, maximize their fitness by producing identical clones. Let’s start with an easy question:”* Which of the following options BEST describes this cost of sexual reproduction?” a) Mueller’s Ratchet b) Genetic costs of meiosis c) Red Queen Hypothesis d) Ecological costs *“We do not have a majority. Help your group members. Also read the course textbook, y’all.”*
Most students coalesced around a preconception	RA2	*“A researcher used a hot wire to burn the skin of little dude flies so they would shoot blanks.”* Which of the following costs of sex did the researchers in this study control for by cauterizing male fruit flies? a) Cost of pregnancy b) Cost of meiosis c) Cost of mating d) All are correct *“Ok, so D is not right. Or phrased another way, what prevents D from being a valid explanation? Discuss in your groups.”*

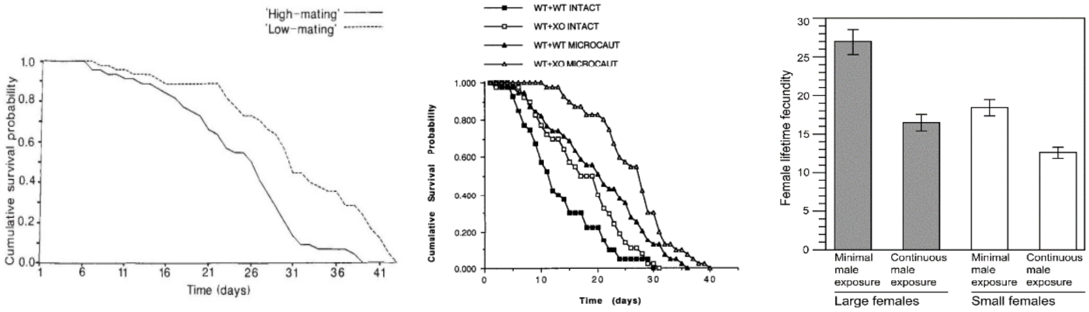
Note: Clicker questions that preceded small group conversations fell into one of two categories: either no answer received majority support (*top*), or else most students coalesced around a preconception (*bottom*). In the table above, italics denote the instructor talk.

Research Articles. Halfway through the lesson, the instructor guided students through three primary research articles: the first two on the cost of mating (Fowler & Partridge, 1989; Chapman, 1992), and the third on the cost of being an attractive female (Long, Pischedda, Stewart, & Rice, 2009) (Figure 5.3). Copulation can be traumatic and physiologically taxing, even when it does not lead to reproduction (Bazelon & Thompson, 2018; Reedy, Evans, & Cox, 2019). Likewise, male-on-female violence during courtship is common across species, including humans (Burn, 2019), and it invariably reduces the fitness of females (Dadda, 2015).

As Fowler & Partridge (1989) demonstrated, female flies in high-mating treatments die more quickly than female flies in low-mating treatments. Chapman (1992) in turn demonstrated that this physiological cost exists even when female flies mate with infertile males. Finally, as Long and colleagues showed (2009), male harassment during courtship explained why female flies and spiders were prone to die sooner. Together, these articles highlight the ecological risks female organisms encounter when they seek mates.

Figure 5.3

Data from the Primary Literature



Note: (*Left*) The instructor first asked students to think about the cost of mating independent of reproduction (Fowler & Partridge, 1989). (*Center*) The instructors then asked students to think about a methodological choice that rendered male flies infertile (Chapman, 1992). The researcher in this study exposed female fruit flies (*D. melanogaster*) to three different types of males: WT+WT INTACT, able to produce sperm and seminal fluid; WT+XO INTACT, unable to produce sperm but able to produce seminal fluid; WT+WT MICROCAUT, able to produce sperm but no seminal fluid; and WT+XO MICROCAUT, unable to produce sperm or seminal fluid. [INTACT males are, well… intact, while MICROCAUT males have been cauterized to render them infertile]. The researcher then exposed females to one of these treatments and quantified their cumulative survival probability. The instructor specifically asked students to compare the WT+WT INTACT and WT+XO MICROCAUT groups (filled squares and open triangles, respectively). (*Right*) The instructor then asked students to carry out a cost-benefit analysis of female sexual attraction (Long, Pischedda, Stewart, & Rice, 2009). In many species, including fruit flies (*Drosophila melanogaster*) and spiders (e.g., the autumn spider *Metellina segmentata*), males preferentially court larger females; the latter also tend to have more offspring.

Participants

This study specifically addressed how two all-female collaborative groups used scientific reasoning during one lesson on the costs of sexual reproduction. In advance of the lesson, the researchers randomly selected the two all-female groups from a larger pool of single-sex groups. Table 5.2 describes the demographics of the two groups.

Data Collection

Data collection occurred in one lecture section (N=114) in fall 2016. Five minutes before class started, a researcher placed a tape recorder at each group's table, and explained it was meant to capture how students talked about science. Student groups were used to being audio-recorded by this point in the semester, as the researchers collected discourse data from student groups during each lesson. Audio-recordings were subsequently transcribed for analysis and students' information altered to protect their privacy. All student names used in this study are pseudonyms.[27]

Data Analysis

The transcripts were subsequently analyzed both quantitatively and qualitatively to address three related behaviors: student participation in small group conversations, student use of scientific reasoning roles, and student use of additional conversational roles associated with scientific reasoning. The following sections describe how these measures of participation and scientific reasoning were evaluated.

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[27] Pseudonyms have been kept consistent in this dissertation to facilitate comparison between studies.

Table 5.2

Student Demographics by Group

Name	Group	Sex	Year	Age	Ethnicity	Major	Grade
Noelle	7	F	Freshman	19	White	Math	C-
Clara	7	F	Freshman	20	White	Business and Marketing	B+
Grace	7	F	Sophomore	20	AAPI	Journalism	A-
Penny[a]	7	F	Sophomore	19	White	N/A	C+
Amber	11	F	Sophomore	19	White	Business	A
Eunice	11	F	Junior	21	AAPI	Dance	A-
Jodi	11	F	Senior	22	White	Apparel Design	B-
Mercedes	11	F	Sophomore	19	White	Psychology	A
Ruth	11	F	Sophomore	19	White	Finance	B+

Note: Students' sex and ethnicity presented in this table reflect how students self-identified during registration as freshmen. [a]Penny did not declare a major, because she left the University at the end of the semester. All other students graduated from the University of Minnesota.

Measures of Conversational Dominance

To address how often students participated in classroom conversations within their small groups, three measures of conversational dominance were used: volubility, floor time, and conversational rates. The following sections describe each of these measures in turn.

Volubility. Each student's volubility was determined by counting the total number of words spoken by each student during the lesson. Since volubility alone fails to truly capture conversational differences among students and between groups, the researchers additionally derived two variables based on volubility: floor time and conversational rates.

Floor Time. Volubility values were divided by the total number of words spoken by the entire group during that lesson, thus deriving the percentage of time each student spoke. While volubility values are absolute, floor time values are relative and contextual to the group, allowing for easier within- and between-group comparisons of students' verbal participation.

Conversational Rates. Researchers further divided the number of words spoken by the group by the total number of minutes in the lesson, producing the average conversational rate per minute for the group. Because the groups differed in the number of students present, researchers subsequently divided the previous rate by the number of students to obtain an average conversational rate per minute per student. This last value allowed researchers to make comparisons between groups.

Codes for Scientific Reasoning Roles and Behaviors

This study partly relies on a previously generated coding schema for student roles and behaviors that frequently arise when students collaborate in a college laboratory course (Paine & Knight, 2020). These researchers aimed to probe all the interpersonal dynamics that emerge when students jointly carry out laboratory procedures, collect and interpret data, and propose explanations for their results. Vitally, the researchers did not limit their unit of analysis to purely scientific—or even purely academic—roles and behaviors. Instead, they wanted to capture all the student interactions that organically arose during their study. From their analysis, they generated fifteen unique codes that explained the student behaviors. Of these codes, this study employed eleven (Table 5.3).

The authors did not distinguish between academic and non-academic behaviors, yet their codes can be broadly separated into three general categories. Some of these codes captured specific student behaviors normally associated with scientific argumentation (e.g., stating a falsifiable claim (C) and using logical reasoning (L); see Table 5.3). Other codes were broader, as they described student behaviors related to effective science-process and academic skills (e.g., solving problems (S) and extending conclusions to new contexts (E); see Table 5.3). A final set of codes addressed roles and behaviors that arise in all conversations, including those that occur outside the classroom (e.g., disagreeing with statements (DE), agreeing with a conversational partner (AF), and posing questions (QQ); see table 5.3).

Table 5.3

Codes Evaluating Individual Student Behaviors or Roles

Role	Definition	Code
	Codes for Scientific Reasoning Behaviors	
Observe	Notices a fact or pattern	O
Recall [a]	Remembers and shares information previously presented in lecture or readings	R
Solve [a]	States the correct answer to a question, but not as a claim or explanation	S
Claim [a]	Frames answer as a falsifiable claim without evidence or reasoning	C
Analyze [a]	Interprets tables and graphs; uses mathematical thinking; references data from a study	A
Provide Warrant	Specifically provides evidence for a claim presented	W
Reason [a]	Justifies the final answer by providing logical link between claim and evidence	L
Extend [a]	Suggest further analysis; provides a new scientific context for interpretation	E
	Codes for Behaviors Associated with Scientific Reasoning	
Question [a]	Asks clarifying questions, requests assistance, or states a lack of understanding	QQ

Agree [a]	Makes statements of agreement, or re-states statement in own words	AF
Disagree [a]	States disagreement with a claim or comment	DE
Conceptual Mentor [b]	Drives conceptual development by teaching others content-specific information	CM
Procedural Mentor [b]	Helps classmates with process-related questions	PM
Drive Discussion [a]	Promotes conversation by focusing attention of group members	DD
Contextualize	Supports discussions with personal anecdotes	CX
Disrupt (Divert) [a]	Off-task comments during science talk that do not pertain to the discussion at hand	OF
Chat	Making social connections with others outside of science talk episodes	CT
Mediate	Attempting to repair social relationship with others or among others	MD
Hold Accountable	Addressing individual responsibility for collaborative work	HA
Joke	Sharing a joke about biology that elicits laughter from team members	JO
Disparage	Negative, disparaging, and unnecessary comments that attack others	DP

Note: The codes differentiate between discursive moves specific to scientific reasoning, and discursive moves that are broader and more commonly found during classroom conversations. [a] These codes were originally used by Paine and Knight (2020). [b] These codes were expanded from Paine and Knight's (2020) "teaching" code. Finally, their code of "off-task" was expanded to better capture student behaviors: chat, mediate, hold accountable, joke, and disparage.

As mentioned previously, the researchers eventually incorporated eleven of the fifteen codes. Another code, teach (T), was expanded into conceptual mentoring (CM) and procedural mentoring (PM) to distinguish peer support around biological concepts (CM) and peer support around procedures (PM), both academic and non-academic. A student would engage in conceptual mentoring whenever she clarified course concepts for the group. For example, a student could share her definition of altruism when a classmate asked for help. A student would conversely engage in procedural mentoring when she explained how to construct a concept map or when she shared her study strategies with a peer who was struggling academically.

Taken together, the student behaviors described above impact not only the flow of conversation and rapport between students, but also the development and eventual success of the group’s co-construction of scientific knowledge. Unfortunately, these codes alone did not capture all the behaviors observed in this study, so the researchers generated additional codes to better reflect the diversity of student roles during the lesson. The following section describes the procedure used to generate these codes, as well as a description of their use in this study.

Generation of Social-Emotional Codes

Codes for the unexplained behaviors were generated through an open-coding approach that relies on iterative content analysis (Saldana, 2015) (Table 5.3). All the student transcripts were read and important themes in the students’ conversations analyzed. These novel codes were then integrated within the coding schema described in Paine and Knight (2020). These emergent codes were necessary for two reasons.

First, Paine and Knight (2020) ignored or only tacitly acknowledged certain academic and scientific behaviors. For example, while the authors included codes for stating claims (C) and providing logical reasoning (L), they did not have a separate code for the use of evidence (W)[28]. The authors likewise did not account for students merely observing information (O); this behavior occurred frequently in the present dataset, especially when students compared their answers with those by other groups. Finally, because the course and the instructor explicitly prompted students to make comparisons between wild populations and human societies, students frequently contextualized (CX) the theory and research studies included in the lesson with their own lived experiences. Paine and Knight (2020), conversely, collected their data in chemistry laboratories—academic spaces where students rarely use their lived experiences to make sense of scientific phenomena. Given the context of the course, these personal connections are both meaningful and conceptually relevant.

Second, the authors of this study deemed Paine and Knight's (2020) off-task code as overly capacious, for it conflated a wide range of distinct and relevant student behaviors that directly informed group interpersonal dynamics. Some students, for example, regularly supported each other, and sometimes this support extended into the

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[28] In their study, the code for logical reasoning naturally included the use of evidence.

non-academic realm. Other students tended to answer science questions with humor and anecdotes from their college experience. And some students spent most of their time holding each other accountable—and when that failed, disparaging each other. Because group cohesion, prosocial/antisocial behaviors, and student rapport explained significant differences between the two groups studied, the authors expanded the original off-task code to include: chat (CT), mediate (MD), hold accountable (HA), joke (JO), and disparage (DP). These behaviors were broadly categorized as social-emotional roles.

Whether these behaviors were considered disruptive (OF) depended on the context. Students who talked during downtime about their workout routine (e.g., Jodi sharing her approach to weightlifting) or their boyfriend (e.g., Mercedes disclosing her partner is a biology major) were only coded as chatting (CT). But if the same conversations unfurled during one of the nine discursive activities, they were additionally coded as disruptive. Likewise, conceptually relevant jokes that elicited laugher were not coded as being disruptive, even when they occurred during group work, since the jokes contextualized or expanded the ideas students were discussing. As the previous observations suggest, each turn at talk could be categorized using more than one code.

Once a final list of codes was generated, the author of the dissertation discussed the codes and their application with his faculty adviser. They then jointly adjudicated differences in their coding through multiple virtual review sessions. More details about these codes can be found in Table 5.3.

Exchange of Quality of Reasoning. To subsequently rate the quality of reasoning exhibited by student groups during each of the nine classroom activities, researchers relied on a previous framework (Knight et al., 2013) (see Table 5.4). The researchers that developed this scale merged Toulmin's components of argumentation (Toulmin, 1958) with more recent work (Erduran et al., 2004). As shown in Table 5.4, a group's discussion will earn a zero when all students fail to provide reasoning for their claims. Conversely, a group's discussion will earn a three when at least two students connect evidence to a claim using logical reasoning. In this scale, each successive level represents a more sophisticated collective use of scientific reasoning (Table 5.4).

Table 5.4

Exchange of Quality Reasoning

Level	Definition
0	Students did not engage in elaborating scientific explanations. They merely shared observations (O), recalled information (R), or shared answers (S) during the activity.
1	Students only crafted claims (C) that lacked evidence (W) and logical reasoning (L).
2	Students only crafted claims (C) that either lacked evidence (W) or logical reasoning (L)
3	Students crafted claims (C) with evidence (W) and logical reasoning (L)

Note: A warrant is a reasoning statement that directly connects evidence to a claim. A non-warrant explanation is typically a “because” statement if it lacks a connection to evidence (see Knight et al., 2013).

Findings

The following sections contain the findings for this study. The quantitative results appear first. These include individual and group differences in verbal participation rates and student behaviors or roles during small group discussions. The findings section then transitions to a qualitative description of small groups’ discussions, making connections between students’ roles and behaviors and the group’s overall quality of scientific reasoning. It then provides examples of how student roles and behaviors during small group discussions substantially colored the group's ability to co-construct scientific knowledge together.

Group-Level Cases

The following section describes and analyzes each student group separately, before expanding the unit of analysis to allow for between-group comparisons.

Group 7: The Chaos Muppets

Analysis of student behaviors in Group 7 revealed that students encountered significant barriers as they attempted to engage each other in conversation, both social and scientific. These barriers partly explain why the students in this group floundered academically, with an average course grade of 2.75 (B-), even though a couple of students majored in quantitative disciplines (Table 5.2). The following sections clarify how the group's inability to collaborate depressed the frequency and effectiveness of their scientific reasoning behaviors.

Verbal Participation. In this group, Clara occupied the floor the longest (31%), followed by Noelle (28%), Penny (23%), and Grace (19%), respectively (Table 5.5). Group 7 spoke a total of 1725 words during the lesson. The average conversational rate for students was 4 words per minute, while the average conversational rate for the group was 16 words per minute (Table 5.5).

Table 5.5

Individual and Group Volubility

Student Names	Volubility	Floor Time	Conversational Rate [a]
Grace	323	0.19	
Clara	529	0.31	
Penny	397	0.23	
Noelle	476	0.28	
Totals	*1725*	*1.0*	*16 words/minute*

Note: Students varied in how long they occupied the floor during the lesson on the costs of sex, with a high of 31% and a low of 19%. [a] The conversational rate displayed in the table represents the groups' conversational rate.

Scientific Reasoning Behaviors. Students in this group rarely assumed scientific reasoning roles and behaviors (Table 5.6). Penny made two observations and solved a problem four times (without providing a claim, evidence, or reasoning). Noelle solved a biological problem one time and stated answers as falsifiable claims two times. Grace recalled information four times, solved a problem one time, and stated a claim two times. Finally, Clara observed, recalled, solved, and stated a complete claim once. Because she distributed her discursive roles equally across multiple categories, she acted as a generalist (i.e., without a particular preference for a specific role or behavior).

Table 5.6

Scientific Reasoning Roles

Scientific Reasoning Behaviors	Group 7			
	Grace	Clara	Penny	Noelle
Observation		1	2	
Recall	4	1		1
Solution	1	1	4	2
Claim	2	1		
Analysis				
Warrant				
Logical Reasoning		1		
Totals	*7*	*5*	*6*	*3*

Note: A summary of the logical reasoning moves carried out by Group 7 during one lesson on the costs of sexual reproduction. This lesson consisted of instructor talk interspersed with active learning activities that emphasized group collaboration.

Quality of Scientific Reasoning. Students in this group only conversed during five of the nine scientific reasoning learning tasks, and the quality of their reasoning was overall poor (Table 5.7). Assessment of the group's quality of reasoning across learning tasks revealed a high of two and a low of zero, for an average reasoning level of 0.44. This value suggests that, on average, this group struggled to even state claims that lacked warrants and logical reasoning (i.e., Level 1). This reticence to engage with the course content and each other flowed from two distinct sources: their lack of conceptual and procedural knowledge, and their inability to collectively address problematic behaviors within the group. The following sections discuss these observations.

Table 5.7

Level of Reasoning by Group for All Discussion Activities

Instructor Prompts for Small Group Discussions	Group 7
Clicker Question 1: Costs of sexual reproduction	-- [a]
Concept Map: *"How does meiosis lead to genetic diversity?"*	1
Research Article 1: Partridge & Fowler (1989)	1
Research Article 2: Chapman (1992)	0
Open-Ended Question 1: *"What makes lady spiders sexy?"*	--
Research Article 3: Long, Pischedda, Stewart, & Rice (2009)	--
Open-Ended Question 2: *"Is there a cost to being sexy?"*	--
Clicker Question 2: The evolution of sex	2
Open-Ended Question 3: *"Does altruism truly exist?"*	0
Average	*0.44*

Note: Clicker and open-ended questions and guided explorations of primary research articles prompted students to discuss concepts, procedures, and implications in their small groups. The color-coding scheme aggregates episodes of science talk that were conceptually related (e.g., OEQ1 asked a conceptual question that students needed to answer before they could analyze the data presented in Research Article 3). [a] Students in Group 7 did not always follow the instructor's advice to discuss solutions to prompts with peers—instead they either remained silent or else laced their comments with acid.

A lack of conceptual and procedural understanding particularly affected two students, Penny and Noelle, who did not evince the requisite skills to participate in scientific reasoning. For example, during the concept map exercise (Concept Map: *"How* *does meiosis lead to genetic diversity?”)*, this dyad strained to think hierarchically, in large part because they did not understand the structure and function of concept maps:

Penny	I’m so lost. So—	(QQ)
Noelle	Yeah?	(QQ)
Penny	—those lines in the concept maps—	
Noelle	Yeah?	(QQ)
Penny	What are they for?	(QQ)
Noelle	I actually don’t really know.	(QQ)

They also received scant help from their teammates, Grace and Clara, although they seemed to have an easier time thinking across levels of biological organization. Unlike Penny and Noelle, this dyad understood how to create concept maps, and used their time to ensure they placed concepts under the right level of biological organization:

Clara	What about fertilization?	(QQ)
Grace	It goes under ‘organismal.’	(S)
Clara	So… here?	(QQ)
Grace	Yeah.	(AF)
	Pregnancy happens to people, not genes or populations.	(C)

In theory, Clara and Grace could have engaged in conceptual and procedural mentoring. By answering their peers’ questions and modeling how to engage in the learning tasks, they may have helped their classmates develop their scientific reasoning skills. However, as the following section will show, this group became undone by the palpable antagonism of its members.

A lack of rapport also affected students’ quality of reasoning. Members of this group spent a not insignificant portion of their conversation disparaging each other, especially after it became evident group members disagreed about how much effort to expend in collaborative tasks. During the concept map activity, for example, Clara reminded the team that they needed to coalesce around one concept map prior to submission:

Clara	Per the concept map, all of us can look at it tonight, and if any new ideas come up, we can share them with Grace before she submits it.	(HA)
Penny	When is it due?	(QQ)
Grace	Monday, but I am submitting it tomorrow morning.	(HA)
Penny	Why rush?	(QQ)
	We have time.	(DE)
Grace	No. This isn’t my only class, so—	(DE)
Noelle	It sounds like you’re upset.	(O)

Grace then denied she was upset, instead claimed she was “in get-it-done mode.” When Noelle sarcastically responded, “right, right,” an awkward and prolonged silence descended on the group. By choosing to address social loafing—and then falling silent—the group missed a critical opportunity to work together in deciphering how meiosis leads to genetic diversity.

Further, students in this group often made negative comments about each other. Grace and Clara directed their antagonism toward Penny and Noelle—and vice versa. For example, later in the lesson, Grace told Clara, “I really don’t think we need to include those two [Penny and Noelle].” Clara replied with “rude” and laugh. Hearing these comments, Noelle shared with her partner: “I don’t think they like us much.” These hostile interactions, and the breakdown of collaboration during classroom activities, imply that this group functioned as two warring dyads. A lack of conceptual and procedural proficiency and students' enmity toward each other depressed this group's ability to engage in meaningful academic talk. The following section expands on this claim by analyzing other roles and behaviors these students employed during the lesson.

Social Emotional Roles and Behaviors. Students in this group tended to display antisocial behaviors (e.g., disrupt and disparage) more frequently than prosocial behaviors (e.g., mentor) (Table 5.8). Penny and Noelle spent most of their time asking questions or stating a lack of understanding (29 and 18 times, respectively), followed by chatting with each other about non-academic topics during downtime (12 and 15 times, respectively). They also engaged in disruptive behaviors 7 and 11 times, respectively—mostly during the collaborative elaboration of a concept map. They pleaded ignorance to excuse themselves from most group activities. These three behaviors accounted for 60% and 63% of their total contributions.

Table 5.8

Roles Associated with Scientific Reasoning

Scientific Reasoning Behaviors	Group 7			
	Grace	Clara	Penny	Noelle
Question	7	18	29	18
Affirm	8	13	10	8
Disagree	4	4	3	6
Mentor		3		
Drive Discussion				
Contextualize				
Disrupt			7	11
Chat	13	13	12	15
Mediate	1	10	1	2
Joke			1	
Hold Accountable	11	2		
Disparage	6	3	6	4
Totals	*50*	*66*	*68*	*64*

Note: A summary of the logical reasoning moves carried out by Groups 7 and 11 during one lesson on the costs of sexual reproduction. This lesson consisted of instructor talk interspersed with active learning activities that emphasized group collaboration.

While Clara also spent a similar amount of time asking for clarification or conversing in between group activities (18 and 13 times, respectively), she never disrupted collaborative work. In fact, she regularly attempted to mediate between her fractious teammates (10 times)—though the frequency noticeably dropped mid-lesson. As her willingness to mediate evaporated, the number of times she attempted to hold others accountable increased (2 times). Finally, Grace engaged her teammates the least often. When she did engage others, she had a clear goal in mind: snuff out social loafing. Her second most common behavior was holding others accountable (11 times or 19% of her verbal roles).

Overall, the thrust of their turns at talk were inimical for the reasons discussed above. The subsequent conversation, which occurred toward the end of the lesson, serves as a representative example (Open Ended Question 3: *"Does altruism truly exist?"*). After the instructor asked students whether any trait could evolve for the good of the species, the students veered into unhelpful behaviors. When Clara attempted to frame the discussion by sharing her definition for group selection, Grace interrupted with a snide question for Penny:

Grace	First, do you understand the question?	(QQ)
Penny	No.	(QQ)
Grace	Right.	(DP)
Clara	We are choosing an answer for why altruism doesn't exist.	(ME)
Penny	I don't really know.	(QQ)
Noelle	Well, aren't there some adaptions [sic] or mutations	
	that affect how you reproduce?	(QQ)
Grace	Is that relevant?	(QQ/DD/DP)
Noelle	I opened the book last night and I know I read it.	
	Something about it being for the good of the species,	(R)
	if, like, I don't know,	(QQ)
	an animal passes his genes on.	(C)
	[3 Second Pause]	
Noelle	Right?	(QQ)
Penny	Right.	(AF)
Grace	No, that still doesn't answer the question.	(DP)
Noelle	Well, I tried.	(CT)
Penny	You did.	(AF)

Immediately after Penny's last comment, the instructor moved on, asking student groups to share the ideas and examples they discussed. Yet Group 7 never got to dissect whether altruism truly exists. They also failed to understand the instructor’s point that selection acts on individuals, not species, and that no trait can evolve for the greater good.

As the previous sections reveal, collaboration in Group 7 collapsed for a variety of reasons. But the most significant was an interpersonal barrier that precluded the group from discussing biological concepts and practicing scientific reasoning. Conversely, as the ensuing sections will argue, Group 11 succeeded where Group 7 failed.

Group 11: The Order Muppets

Analysis of student behaviors in Group 11 revealed that students worked harmoniously to answer biological problems using scientific reasoning. Students in this group were overall academically successful in the course, earning an average course grade of 3.54 (B+) (Table 5.2). The following sections describe how student behaviors fostered camaraderie, which in turn encouraged students to fully participate in the scientific reasoning activities developed by the instructor. However, students in this group still noticeably differed in their verbal participation and scientific reasoning roles and behaviors; these patterns will be discussed in the following sections.

Verbal Participation. Group 11 exhibited a clear pattern where Amber occupied the floor the longest (33%). Mercedes and Jodi spoke at similar rates (23% and 22%, respectively), while Ruth (15%) and Eunice (8%) spoke noticeably less often. Group 11 spoke a total of 3037 words during the lesson. The average conversational rate for students was 5.4 words per minute, while the average conversational rate for the group was 27 words per minute (Table 5.9).

Table 5.9

Individual and Group Volubility

Student Names	Volubility	Floor Time	Conversational Rate [a]
Mercedes	673	0.23	
Jodi	701	0.22	
Amber	977	0.32	
Ruth	442	0.15	
Eunice	244	0.08	
Totals	*3037*	*1.0*	*27 words/minute*

Note: Students varied in how long they occupied the floor during the lesson on the costs of sex, with a high of 31% and a low of 8%. [a] The conversational rate displayed in the table represents the groups' conversational rate.

Scientific Reasoning Behaviors. This group consistently attempted to assimilate both the structure and style of scientific discourse, though individual students varied in their comfort with these conventions (Table 5.10). Ruth shared four observations, recalled information one time, solved clicker questions two times, and provided a claim two times. Jodi likewise limited herself to providing observations (two times), recalling information (three times), and pointing out solutions to clicker questions (five times), though she also shared three falsifiable claims. Eunice, on the other hand, tended to use different moves at roughly the same rates: she provided one observation, two recalls, three solutions, and four claims. Finally, Mercedes and Amber engaged in the most sophisticated scientific reasoning and were the only students to evince all the scientific reasoning behaviors during this lesson. Both provided solutions to clicker questions at noticeably high rates (eighteen for Mercedes and thirteen for Amber). Further, they each favored a specific approach to making sense of biological problems: Mercedes was the student most likely to provide logical reasoning for explanations (nine total), while Amber was the most likely to think quantitatively, especially when analyzing graphs (seven total) (Table 5.10). In fact, they followed a team-tagging pattern where Mercedes put into words what Amber described through numbers.

Table 5.10

Scientific Reasoning Roles

Scientific Reasoning Behaviors	Group 11				
	Mercedes	Jodi	Amber	Ruth	Eunice
Observation	5	2	4	4	1
Recall	4	3	4	1	2
Solution	18	5	13	2	3
Claim	8	3	5	2	4
Analysis	5		7		
Warrant	2		2		2
Logical Reasoning	9	1	2		
Totals	*51*	*15*	*42*	*9*	*12*

Note: A summary of the logical reasoning moves carried out by Group 11 during one lesson on the costs of sexual reproduction. This lesson consisted of instructor talk interspersed with active learning activities that emphasized group collaboration.

Quality of Scientific Reasoning. Students in this group participated in science talk for all the scientific reasoning learning tasks (Table 5.11), and most of their conversations were of high quality. Assessment of the group's quality of reasoning across learning tasks showed a high of two and a low of zero, for an average reasoning level of 2.00 (Table 5.11). This value suggests that this group consistently engaged in scientific reasoning (i.e., Level 2). Further, some of their lower scientific reasoning scores were for discussions where students in the group correctly answered the clicker question (e.g., “the answer is B”). Because their answer turned out to be correct, the group declined to keep discussing the topic when the instructor told the class that they either coalesced around a preconception or else the class lacked a majority (Table 5.1). As predicted by social interdependence theory (Johnson & Johnson, 2009), Group 11 thrived because they exhibited many prosocial behaviors, including open communication and the ability to empathize with one another. Their well-developed social skills and willingness to help each other aided the emergence of positive interdependence (e.g., students worked collectively toward a common goal), as evidenced in the examples that follow.

Table 5.11

Level of Reasoning by Group for All Discussion Activities

Instructor Prompts for Small Group Discussions	Group 11
Clicker Question 1: Costs of sexual reproduction	0
Concept Map*: “How does meiosis lead to genetic diversity?”*	3
Research Article 1: Fowler & Partridge (1989)	2
Research Article 2: Chapman (1992)	2
Open-Ended Question 1: *“What makes lady spiders sexy?”*	3
Research Article 3: Long, Pischedda, Stewart, & Rice (2009)	1
Open-Ended Question 2: *“Is there a cost to being sexy?”*	1
Clicker Question 2: The evolution of sex	3
Open-Ended Question 3: *“Does altruism truly exist?”*	3
Average	*2.00*

Note: Clicker and open-ended questions and guided explorations of primary research articles prompted students to discuss concepts, procedures, and implications in their small groups. The color-coding scheme aggregates episodes of science talk that were conceptually related (e.g., OEQ1 asked a conceptual question that students needed to answer before they could analyze the data presented in Research Article 3).

First, students in this group were happy to help one another when they encountered conceptual and procedural problems. In this group, Jodi displayed a certain discomfort with science, but her team addressed her insecurities in a proactive and inclusive manner. To illustrate, during the concept map activity (Concept Map*: “How* *does meiosis lead to genetic diversity?”)*, Mercedes, Jodi, and Eunice worked together to revise their individual concept maps:

Jodi	I am sorry, I only have a very rough map. I was lost.	(QQ)
Mercedes	That’s ok.	(AF)
	That’s what this is for.	(PM)
Jodi	Thanks. I love how you use colors.	(CT)
Mercedes	Thank you! Color coding helps me learn.	(PM)
Eunice	What concepts did you put under “population”?	(QQ/DD)
Mercedes	Oh, I wondered about that.	(QQ)
	I just assumed that individuals make sperm and egg.	
	And the population only exists because of fertilization.	(L)
	I put the “fertilization” concept under population.	(S)
Jodi	I was like, I don’t know	(QQ)
Eunice	I see.	(AF)
	I put the concept in between the columns,	
	when they could apply to both.	
Mercedes	That sounds right to me.	(AF)

Meanwhile, Ruth and Amber revised their concept maps as a separate dyad. Their own conversation also displayed multiple instances of productive academic and social behaviors that encouraged the co-construction of scientific knowledge:

Ruth	Why make us discuss and revise if we submit one draft?	(QQ)
Amber	It helps us to revise our work together?	(QQ/PM)
	But my question is what goes under genotypic	
	and what goes under organismal?	(QQ/DD)
Ruth	Yeah,	(AF)
	I found that part hard	(QQ)
	but everything in your map seems super accurate	(AF/O)
Amber	I don’t know	(QQ/DE)
	What did you put down for your own categories?	(QQ)
Ruth	Oh, I didn’t	(DE)
Amber	Because I found that part confusing	(QQ)
Ruth	You could add your own concepts,	
	But it wasn’t required	(PM)

	[5 second pause]	
Ruth	Hey! That table put zygote under population	(O)
	but everything else is the same as ours!	

When Amber voiced incredulity over the other group's contestable choice ("Really? That's surprising"), Mercedes and Jodi joined their conversation:

Mercedes	Oh, that's interesting.	(O)
	Because a zygote to me is an individual	(CM)
	It's a fertilized egg.	(R)
	Jodi and I decided to put it under individual	(PM)
Jodi	Sure did!	(AF)

By this point, the two sub-groups had merged back into the original five-person team. When Mercedes again voiced how some concepts arguably fit under more than one level of biological organization, the discussion shifted to the purpose of the assignment:

Amber	That's what I thought.	(AF)
Mercedes	We also didn't really know what goes under population,	
	except for fertilization,	(QQ)
	because you need two individuals for that.	(L)
	But I don't know…	(QQ)
Amber	Right. It's ambiguous.	(AF)
Jodi	So what's the point?	(QQ)
Mercedes	She wants us to think about it, right?	(PM/QQ)
	Instead of memorizing facts?	(QQ)
Amber	She does do that, making things conceptual	(AF)

As this example shows, this group worked well together. While some students, such as Amber and Mercedes, dominated the discussion, all students had meaningful opportunities to engage in the elaboration and revision of a shared concept map. And these behaviors promoted conceptual and procedural proficiency, allowing students in this group to exhibit sophisticated scientific reasoning in later discursive learning tasks. The subsequent section expands on these claims by analyzing other roles and behaviors that emerged during this lesson.

Social Emotional Roles and Behaviors. Members of Group 11 not only succeeded academically but also seemed to bond socially. They enjoyed each other’s company and often conversed during downtime about topics ranging far afield from biology: from stress in college and graduate school applications, to weightlifting regimens, their dating experiences, and their admiration of the instructor. These general observations are supported by the following patterns in the dataset. First, the group collectively engaged in mentoring, both conceptual and procedural. Mercedes herself employed these strategies most often at fourteen (three conceptual, and eleven procedural), but most of her peers attempted to help their teammates at least once (Table 5.12). Some of this mentoring involved peer-peer instruction, especially when a student voiced a lack of understanding. But the mentoring often extended beyond the course content and into the development of academic skills.

Table 5.12

Roles Associated with Scientific Reasoning

Scientific Reasoning Behaviors	Group 11				
	Mercedes	Jodi	Amber	Ruth	Eunice
Question	8	30	16	16	15
Affirm	23	24	22	28	16
Disagree	4	2	3	3	1
Mentor	14		1	2	1
Drive Discussion	4	2	3	1	1
Contextualize		2			
Disrupt		2			
Chat	11	23	13	9	5
Mediate					
Joke	1	6	2	2	
Hold Accountable	2			1	
Disparage		3		1	
Totals	*67*	*94*	*60*	*63*	*39*

Note: A summary conversational roles and behaviors students in Group 11 exhibited during the lesson on the costs of sex.

Second, while the group engaged in seemingly off-task moments, two disruptive comments and eleven jokes, these never occurred during collaborative exercises. These behaviors took a variety of forms, from having a running commentary on the instructor’s biological examples and personal stories, to making off-color jokes about sex, pregnancy, and men. Vitally, these off-task moments were followed by laughter rather than attempts to hold each other accountable. Further, all the discursive moves related to accountability were forward-facing (i.e., division of labor for an upcoming group task), and mostly involved planning around students’ schedules.

Third, while this group did engage in some disparaging commentary (four times total), the negative comments were never directed at each other, but rather at obtuse characters in the instructor's anecdotes and frustrating Microsoft Office platforms. This group affirmed each other, both academically and socially, a total of 113 times during the lesson. Fourth, the group engaged in a fair amount of non-academic chatting (e.g., on graduate school applications, on weightlifting, and on campus social life). Jodi led the way, engaging with her peers 23 times. Notably, Eunice and Ruth rarely participated in side conversations (at nine and five).

Overall, the thrust of their turns at talk were positive for the reasons discussed above. The following conversation, which occurred toward the end of the lesson, serves as a representative example (Open Ended Question 3: *"Does altruism truly exist?"*). After the instructor facetiously asked students whether any trait can evolve for the good of the species, the students in this group coalesced around robust and persuasive explanations and examples. Amber opened the conversation by re-framing the instructor's question. "We," Amber reminded the group, "need to answer when we would sacrifice ourselves for others," which Eunice affirmed and re-stated as "the altruism question." Amber then suggested they could answer the questions whether "any act is truly altruistic," by using police, firefighters, and other professionals who risk their lives for strangers as context:

Amber	It might not affect them either way, reproductively,	
	to be doing their jobs.	(C)
	Like the firefighters.	(CX)
Ruth	Right	(AF)
Amber	They are saving people who they have no relation to,	
	they share no genes.	(L)
	But they might die, which would prevent them from, from—	(C)
Eunice	Reproducing?	(QQ/S)
Ruth	Yes, absolutely.	(AF)

At this point, Mercedes reminded the group that the instructor may argue these examples “are never selfless” because firefighters, “get paid […] to save lives.” This counterargument prompted Eunice to muse whether all altruistic acts are inherently selfish. While the group pondered this question, Jodi shared “an obvious answer”:

Jodi	See, I thought […] of adoption.	(S)
Amber	That’s true	(AF)
Eunice	Yes, I see.	(AF)
	It doesn’t increase your fitness.	(L)
Jodi	You do it because you want to give them a better life.	
	Not because you are related.	(EX)
Ruth	Absolutely.	(AF)
Amber	That’s a really good point.	(AF)

The students in this group internalized the instructor’s main message: since natural selection acts on individuals, traits cannot evolve for the good of the species. This understanding, reinforced by the hierarchical thinking imposed by the concept map, ensured these students evaluated seemingly altruistic behaviors from a selfish gene perspective (Ridley, 2016). Jodi’s contribution at the end proved invaluable, precisely because it directly contradicted the selfish gene theory. While the instructor gleefully shot down other groups’ contributions (e.g., “you’re saying that getting vaccinated is altruistic because people do it to achieve herd immunity?”), she acknowledged that the adoption claim had some merit.

As the previous sections reveal, Group 11 worked harmoniously to complete common tasks in the classroom. Their noticeable rapport ensured they all practiced developing scientific reasoning. The next section will transition to making cross-case comparisons. First, it will directly contrast how often each group engaged in scientific reasoning behaviors, before analyzing the different levels of scientific reasoning exhibited by each group. Next, it will analyze how both groups approached the three remaining collaborative activities included in this lesson: an instructor prompt on the evolution of sex (Clicker-Question 3: The evolution of sex), and the guided discussions around the three research papers, the first two on flies (*Drosophila melanogaster*, Fowler & Partridge, 1989; Chapman, 1992) and the second one on spiders (Long, Pischedda, Stewart, & Rice, 2009). The discussion around the third research article also included two open-ended questions (Open-Ended Question 1: *“What makes a spider sexy?”*; Open-Ended Question 2: *“Is there a cost to being sexy?”*).

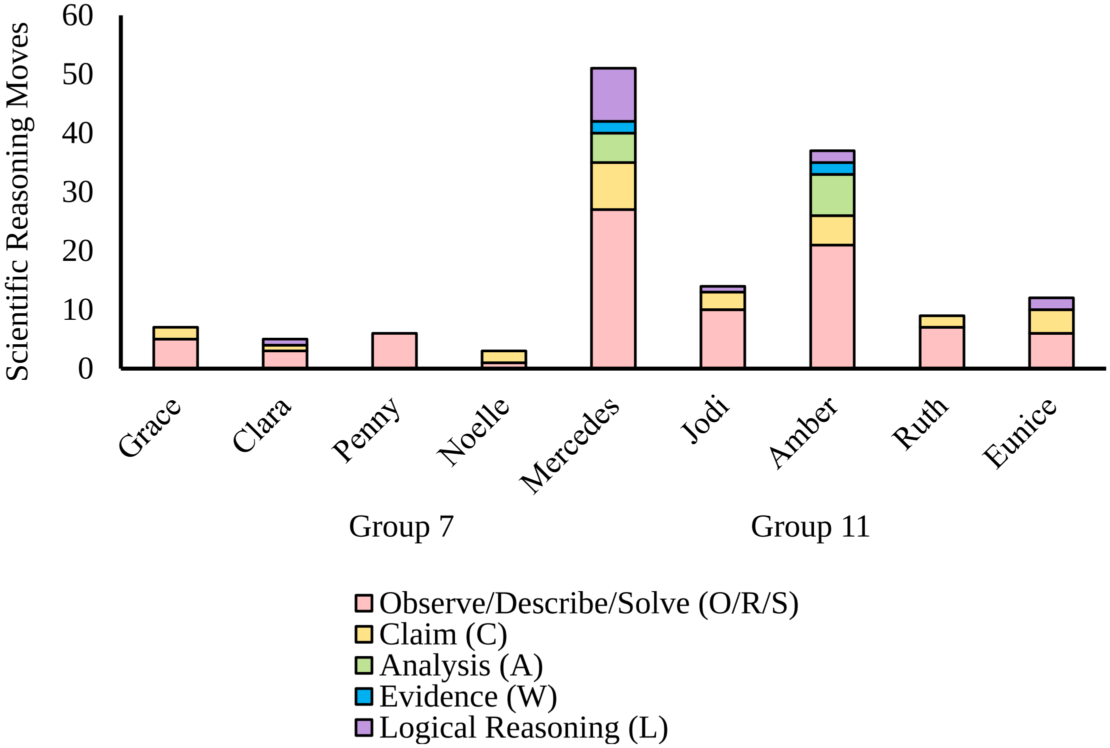
Cross-Case Comparisons: Scientific Reasoning

Evaluation of how students engaged in scientific reasoning exposed large differences in their preference for and comfort in using different moves and behaviors, and these differences were meaningful both within and between groups. While some students routinely engaged in higher-order reasoning moves, such as using quantitative thinking (A), few students consistently practiced them—and many did not utilize them at all (Figure 5.4). Amber and Mercedes, for example, were the only students who applied every reasoning move during the lesson. As Figure 5.4 reveals, most students rarely ventured beyond observing, solving, and recalling (O/S/R), and many students who proposed claims (C) failed to buttress them with evidence (W) and reasoning (L).

This noticeable variation in the frequency of scientific reasoning moves in turn explains the differences in the quality of scientific reasoning (Figure 5.5). Group 7 never engaged in sophisticated science talk, where multiple students proposed claims backed by evidence and logical reasoning (i.e., Level 3). This level required students to coalesce around shared explanations—a tall order for a socially dysfunctional group. Conversely, Group 11 engaged in the most advanced science talk at least half of the time (Figure 5.4). Further, some of their conversations that scored lower on the scale lacked complexity because the students in the group agreed on the right answer from the get-go (e.g., “The answer is B, right?” “Yeah, it’s B”). They consequently did not feel a need to further discuss the topic after the instructor revealed the class as a whole did not converge on the correct answer.

Figure 5.4

Individual Student Behaviors Reasoning Moves

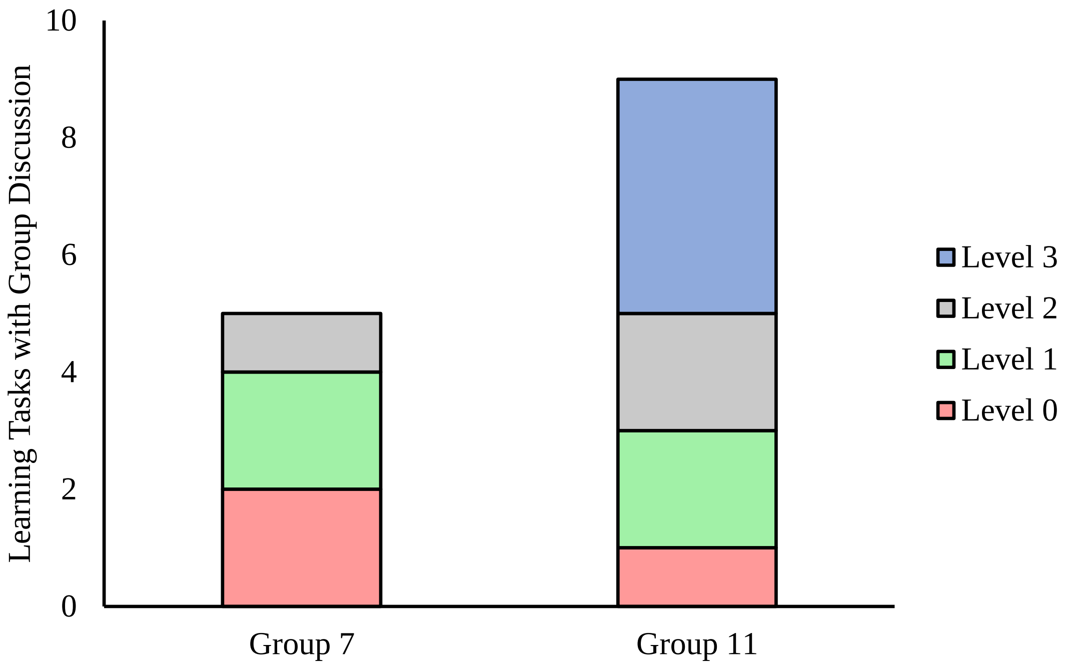


Note: Scientific reasoning moves for Groups 7 and 11 during the lesson. The codes in the legend correspond to the following scientific reasoning behaviors: O/R/S (observing, recalling, and solving (without a claim), respectively); C (providing a claim without reasoning or warrants); A (analysis of quantitative sources of data); W (supporting claim with evidence); and L (stating the logical reasoning that links the claim and its evidence).

As the previous paragraphs foreshadowed, whether students practiced scientific reasoning roles and behaviors depended on what additional roles and behaviors the students engaged in. Collaborative learning, by definition, requires students to work together. It demands students to employ prosocial behaviors, including open communication, interdependence, and personal accountability. As the next section illustrates, the two groups differed markedly in their ability to work cohesively to meet group goals.

Figure 5.5

Scientific Reasoning in All-Female Student Groups



Note: The levels of logical reasoning for all female groups across two lessons: *Lesson 9* (*The Costs of Sex*). Levels 0-3 represent the hierarchical components of collaborative scientific reasoning, from a group only providing observations and recall (Level 0), to positing claims (Level 1), validating them with evidence (Level 2), and logical reasoning (Level 3). (See Table 5.4).

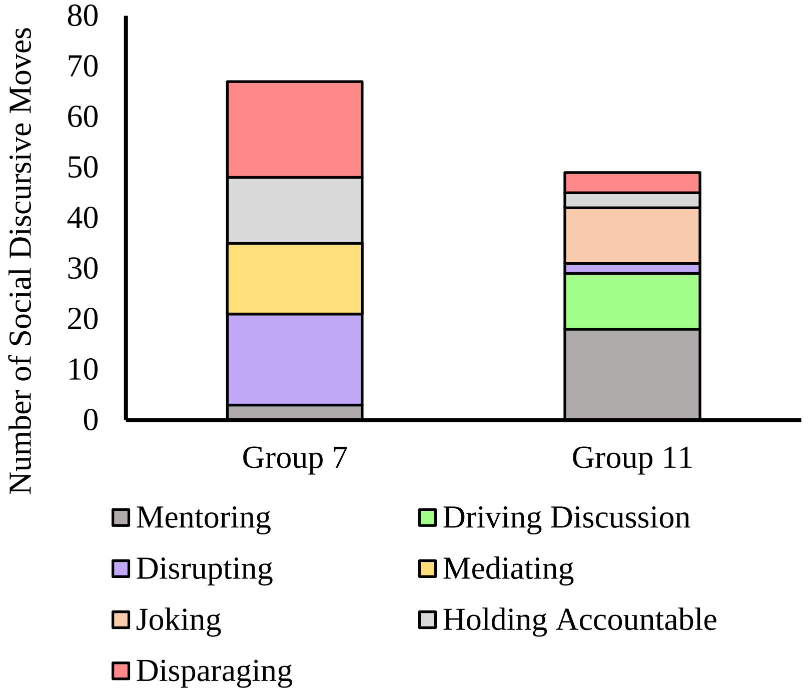
Cross-Case Comparisons: Social Emotional Roles and Behaviors

A comparison of prosocial and antisocial roles and behaviors demonstrates that the two groups diverged considerably, with Group 7 relying on conflict-promoting behaviors and Group 11 relying on conflict-diffusing behaviors. Most of the social-emotional roles and behaviors exhibited by Group 7 were negative: they spent most of their time alternating between disparaging and disrupting discursive moves (Figure 5.6). The next two most common behaviors included holding each other accountable and attempting to mediate. As expected, these four types of behaviors (disrupt, disparage, hold accountable, mediate) were mutually-reinforcing.

Conversely, students in Group 11 routinely displayed roles and behaviors that benefited the flow of conversation (e.g., affirming), the quality of the discussion (e.g., discussion driving), and each other’s conceptual understanding (e.g., mentoring) (Figure 5.6). The manifest frequency of these behaviors indicates that students in this group possessed enough conceptual understanding and emotional maturity to actively guide the conversation—and their collective learning—in favorable directions. Yet one would err in thinking that Group 11 only engaged in proactive, productive, and prosocial behaviors. This group also made disparaging comments, but these were never aimed at each other. Further, they consistently joked around, a behavior that can be conceptually relevant or distracting depending on context.

Figure 5.6

Social-Emotional Discursive Moves Across Groups



Note: The figure displays the prosocial and antisocial roles and behaviors students in Groups 7 and 11 evinced during the lesson. The figure does not include affirming, disagreeing, and questioning behaviors, in part because the two groups did not meaningfully diverge with these behaviors.

Cross-Case Comparisons: Discursive Learning Tasks

The following sections will document how the two small groups in this study engaged in science talk as they discussed a clicker-question prompt on the evolution of sex and three research articles that analyzed the cost of mating in flies (*Drosophila melanogaster*, Fowler & Partridge, 1989; Chapman, 1992) and spiders (Long, Schipedda, Stewart, & Rice, 2009).

Table 5.13

Use of Scientific Reasoning

Individual	Dialogue	Code
Instructor	Why is sex maintained? You should be able to come up with a few ideas, right? Go.	
Penny	For reproduction, I guess	(S)
Noelle	Yeah!	(AF)
Grace	That’s not it, no.	(DE)
Clara	Didn’t sex evolve from asexuality? Or rather, asexuality is favored in stable environments, so sex is good when it’s not stable?	(QQ/C/L)
Grace	Yes, that’s one of the quiz questions	(AF/PM)
Clara	Yes, I know.	(AF)
Noelle	The quiz was hard. Like, I looked up all the definitions after I took it, and I still don’t know what was going on.	(CT/QQ)
Grace	You can retake the quiz up to three times.	(PM)
Noelle	Why bother?	(DE/QQ)
Penny	I bombed the last quiz, and I don’t think scientifically, so… yeah. That’s all I have to offer.	(QQ)

Individual	Dialogue	Code
Instructor	Why is sex maintained? You should be able to come up with a few ideas, right? Go.	
Jodi	[Groans]	
Mercedes	Sex allows species to survive in changing environments	(C)
Amber	And harsher environments	(EX)
Ruth	Yeah	(AF)
Eunice	And the benefits of asexuality include the fact you don’t have to give up half your genes to reproduce	(L)
Mercedes	The cost of meiosis	(AF/EX)
Eunice	Right	(AF)
Amber	I see	(AF)
Eunice	Let’s come up with at least three [examples]	(DD)
Ruth	Ok	(AF)
Mercedes	Why don’t we use how fat lady spiders are sexy, as an example?	(CX)
Amber	Right	(AF)
Ruth	If you need to mate—	(C)
Amber	—your mate might end up killing you	(C)

Note: (*Top*). Group 7. (*Bottom*) Group 11.

Clicker Question 3: The Evolution of Sex. This discussion activity solicited students to use a cost-benefit analysis to identify the environmental conditions that pressure populations to evolutionary transition between different modes of reproduction (Table 5.13). To correctly reason through this problem, students had to understand that natural selection acts on individuals, but evolution acts on populations. As an emergent process, evolution arises not from an individual's need or purpose, but from the aggregate behaviors of all individuals in the population. Only students who meaningfully engaged with the hierarchical thinking embedded in the concept map were positioned to successfully unravel this biological puzzle.

Group 7. The students' science talk fails on multiple fronts. Penny and Noelle did not contribute any pertinent content- or process-specific information. Penny's initial statement, that asexuality evolved "for reproduction," was tautological, as Grace tartly pointed out. Grace's response, however, precluded any meaningful cost-benefit analysis that methodically evaluated the environmental conditions that favor asexual over sexual reproduction. Clara, the group's mediator, provided a solid, falsifiable claim: "asexuality is favored in stable environments." Her group members could have refined the premise and supported it with evidence and logical reasoning by explicitly linking environmental conditions with the evolution of certain modes of reproduction. They could likewise have used their recently completed concept map to better evaluate how genetic, organismal, and ecological costs drive evolutionary change. At the very least, the group could have coalesced around some examples from lecture and the textbook that explicitly answered the question presented.

Grace's resentful comments might be understandable given her group members' persistent social loafing, but it served to shut down, rather than encourage, additional inquiry. Grace had the experience and disciplinary expertise necessary to consistently assume the role of discussion driver or knowledge facilitator, but she doggedly refused to. To be fair, Penny and Noelle, the students who might have benefited the most from peer mentoring, were not receptive to it. When Clara brought up the value of re-taking quizzes, Noelle dismissively replied, "why bother?", thus signaling her disinterest.

Immediately following the discussion, the instructor cold-called on Group 7, leading to a debate between group members that unveiled their dysfunction:

Instructor	Group 7!	
	Oh, they look so happy to be chosen, just look at them.	
Penny	[to the group] F**k the 8 ball.	(DI)
Clara	[to the group] Who's answering—?	(QQ)
Noelle	[to the group] Not me.	(DE)
Instructor	Alright, Group 7, what do you think?	

Eventually, the mediator of the group, Clara, took it upon herself to answer on the group's behalf:

> Well… there was a discussion, in our group, about the question, and it was like, right, like basically, if the environment is super stable, then asexuality is favored, because nothing is really changing. But if you're in an environment that's always changing, where things are chaotic, you need to change with the environment. Then sex is, sex is better… I think.

Put on the spot, Clara essentially repeated her contribution to her group's science talk. She did expand her reasoning by detailing the conditions under which sexual reproduction would be favored over asexual reproduction. As Clara observed, an unstable environment may prompt populations to shift towards sexual reproduction. However, note that Clara's reasoning contains certain epistemological errors that could have been corrected through meaningful science talk. Clara fell back on the idea that evolution responds to an individual's needs: "if you're in an environment that's always changing […] you need to change with the environment." As the concept map exercise, the textbook (Ridley, 2012), and the instructor continuously emphasized, individuals do not evolve: populations do. And evolution does not address the needs of organisms, either at the individual or the collective level. Evolution, in short, is not purpose-driven—a description that unfortunately also applies to Group 7.

Group 11. The students' science talk succeeded on multiple fronts (Table 5.13). Mercedes began by structuring the conversation around a clear, testable claim: "sex allows species to survive in changing environments." This statement builds on the previous concept map, and correctly assimilates both discipline knowledge (e.g., evolution is a population level process) and discipline norms and conventions (i.e., stating her contribution to the group as a falsifiable claim). Group members subsequently built upon the foundation Mercedes laid. Amber contributed the idea of "harshness," which highlighted how environmental dangers, such as pathogens, can impose evolutionary pressures independent of and analogous to environmental heterogeneity. Eunice added a counterpoint as evidence: “the benefits of asexuality include […] not giv[ing] up half your genes to reproduce,” which Mercedes subsequently defined as “the cost of meiosis.” As Mercedes, Ruth, and Amber jointly established, asexuality evolves in stable environments with few ecological dangers, such as predators and parasites.

Once the group coalesced on a persuasive, falsifiable claim, Eunice employed some discussion driving, reminding her teammates to “come up with at least three [examples].” Mercedes suggested relying on the study that showed how “fat lady spiders are sexy,” which Ruth and Amber re-stated more broadly, thus acknowledging that in many sexual species, including humans, “your mate might end up killing you.” At this point, Jodi entered the conversation, and contributed “increased stress” as a cost associated with sexual reproduction.

When asked to elaborate, she clarified the idea came to her as she was scrolling through Instagram:

Jodi	I’m trying to contribute as I scroll through Instagram.	(CT)
	[Laughter]	
Mercedes	Scrolling for examples?	(HA)
Jodi	No.	(DE)
	Yes…?	(QQ)
	Yes!	(AF)
	I hadn’t thought about it, but when you think about dating—	(EX)
Mercedes	Right…	(AF)
Jodi	—if you have sex, you will get pregnant.	(C)

Amber	And you might die.	(W)
Jodi	Right.	(AF)
	That’s something I am terrified about.	(CX)
Eunice	Pregnancy?	(QQ)
Jodi	Yes, pregnancy.	(AF)

Roughly ten minutes later, Jodi returned to this theme when the instructor shared data on gendered vaccination rates for HPV (i.e., the Human Papilloma Virus). While the instructor described attempts to convince her teenage son to get vaccinated, Jodi volunteered to the group:

Jodi	If you have sex, you will soon die.	(C)
Ruth	What?	(QQ)
	Where did that come from?	(QQ)
Jodi	That’s what happens with HPV, right?	(EX)
Mercedes	Right…	(AF)
Jodi	So all men should get the vaccine.	(EX)
Amber	But you heard her son…	(DE)

Jodi’s laid-back conversations may initially seem disruptive and analytically poor, but they directly relate to the previous scientific conversation around the costs of sex. Further, these conversations expanded on the previous points by contextualizing them: humans are sexual organisms subject to evolutionary processes. Additionally, this excerpt illuminates a recurring (and seemingly successful) dynamic between Jodi and Mercedes. Jodi clearly preferred to frame her contributions as jokes and personal opinions instead of falsifiable claims; Mercedes used Jodi’s comments as opportunities to drive discussion, often by first re-stating them using academic language (e.g., she engaged in conceptual and procedural mentoring).

Research Articles 1 and 2 (Fowler & Partridge, 1989; Chapman, 1992). This discussion activity asked students to first analyze a figure presented in the first research article discussed during the lesson (Fowler & Partridge, 1989). Female flies in this study were exposed to high-mating or low-mating treatments, and their lifetime survival rates were quantified. The instructor then asked students to analyze a separate graph from the second study (Chapman, 1992). In this study, some of the male flies were cauterized to render them infertile. Or, as phrased by the instructor, researchers took "individual male fruit flies, and one very hot wire, and […] cauterize[d] the skin of little dude flies so they [would] shoot blanks." She then tasked students with deciphering the rationale for this procedure. Specifically, what cost of sex where the researchers controlling for?[29] Reasoning through this question was critical, for the prior paper (Fowler & Partridge, 1989) only showed that high-mating conditions were pernicious for female flies' survival. But the article itself did not distinguish between the physiological costs of mating and pregnancy. To correctly reason through this problem, students had to understand the biological principles that animated both studies, but also the methodological decisions that structured their research.

Group 7. The group used humor to jumpstart the conversation that revolved around the graph from the first study:

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[29] The cost of pregnancy. They were also controlling for the harmful effects of seminal fluid proteins (Sirot, Wong, Chapman, & Wolfner, 2014), which are known to affect female health and sexual behavior, but that information lies beyond the scope of the course.

Noelle	Based on what we talked about last time—	(R)
Penny	Who doesn’t love sex?	(QQ/JO)
Noelle	**[**Laughter] Right. But no, really—	(FA)

Their science talk then immediately shifted to a different topic when Clara reminded Penny and Noelle to share their concept map revisions with Grace, so she could incorporate them prior to submitting a concept map for the group. The conversation only shifted back to the figure at hand when the author of this dissertation, acting as the course’s teaching assistant (TA), waddled over:

TA	What’s happening to the flies in this study?	
	[Silence]	
TA	Do you know?	
Clara	If they mate less often, they live longer.	(C)

After the teaching assistant confirmed that statement was accurate and walked away, Grace scoffed “it’s not a hard study.” As expected, the group also struggled to answer the secondary question, on why some of the male flies in the second study were cauterized:

Penny	What did she mean about the application of the hot wire?	(QQ)
Grace	What do you think?	(QQ)
Penny	Well, she didn’t really say, so I do not know	(QQ)

The group them lapsed into silence for the remainder of the discussion activity, never addressing how the cauterizing procedure rendered the males infertile, or how the two research articles on fruit flies related to one another. They consequently missed the central message of these two studies: copulation, regardless of whether it leads to pregnancy, depresses the survival of female flies because of the physical and energetic costs associated with mating.

Group 11. This group, on the other hand, eagerly dissected the figure from the first study. Amber, comfortable with graphical analysis, immediately noticed an important trend: “So, high mating flies, umm, seem to live less long.” Ruth countered that “they [the treatments] do not look that different from each other,” which prompted Mercedes to engage in some conceptual mentoring:

Mercedes	True.	(AF)
	But to me it seems that the low mating treatment has a higher probability of surviving.	(A/CM)
	See?	(QQ)
Amber	Right.	(AF)
Ruth	I guess that’s what it looks like.	(AF)
Jodi	Wait, you said high mating?	(QQ)
Mercedes	Yes.	(AF)
Jodi	Is less likely to survive?	(QQ)
Mercedes	Yes.	(AF)
Jodi	Great.	(AF)
	So if you have less sex you survive longer.	(C)
Amber	Do you think it only applies to flies?	(QQ)
Jodi	I mean, you know this class. Stay tuned.	(EX)

The students laughed and then decided to converge around one explanation in case the instructor called on them. When Amber suggested they “need[ed] a summary” that describes the graph, Ruth joked “[is the summary] that sex is bad?” Mercedes, ever the peer mentor, replied “the flies who have less sex will die sooner. Sorry, live longer.” Further, when the instructor asked them to discuss why some of the male flies had been cauterized in the second study, Ruth provided a solid claim with reasoning that satisfied the group:

Jodi	What did she mean about shooting blanks?	(QQ)
Ruth	Some researcher burned their dingus,	(R)
	so they couldn't ejaculate.	(S)
	That's why she mentioned the hot wire.	(CM)
Jodi	Oh! Oh my god.	
	I got distracted and I didn't hear that part.	
	Those poor flies[30].	

As the previous examples show, the two groups diverged in how they participated during a guided discussion of the first and second primary research articles. Further, the cauterization procedure foreshadowed the third research article, which specifically looked at harassment during courtship. The following section describes the discourse that emerged during that discussion activity.

Research Article 3 (Long, Pischedda, Stewart, & Rice, 2009). This discursive task further reinforced that courtship in animal species usually lowers the fitness of females. Prior to sharing data from the third article, the instructor posed an open-ended question: (Open-Ended Question 1: *"What makes a spider sexy?"*). As the following excerpt shows, Group 11 gamely stepped up to the plate[31]:

Instructor	There really is only one [criterion] in this spider world, related to being sexy.	
Amber	Something to do with fertility?	(S/QQ)

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[30] When Jodi later mused whether "burning men's dinguses" would be effective birth control, Mercedes laughed and replied "we call that a vasectomy."

[31] Group 7 remained silent during this open-ended question.

Ruth	What was that?	(QQ)
Amber	Anything that lets you have more babies,	(C)
	I guess?	(QQ)
Mercedes	Like size?	(QQ/S)
Eunice	Yeah.	(AF)
Instructor	It’s ok to guess. Anyone?	
Mercedes	[Loudly] Size?	(QQ/S)
Instructor	Group 11 got it right. Fat lady spiders are sexy lady spiders.	

Group 11 also correctly noted that the physical characteristics that make female spiders sexually attractive correlate with fecundity. As Amber discerned, “anything that lets you have more babies” would be an honest signal used by male spiders to choose their mates. After this short discussion, the instructor introduced the figure from the third primary research article with the following prompt: “They measured lifetime fecundity, […] the total number of spider babies each mommy had. What are these trends? [I]s there a cost to being sexy?” The following sections describe how each group solved this query.

Group 7. These students did not meaningfully engage with the instructor’s prompt, the figure, or each other. By stating “I would say yeah,” Grace solved the problem, but did not engage in other scientific reasoning roles and behaviors—such as justifying her response with logical reasoning. Clara initially affirmed Grace’s contribution, but then questioned her own understanding: “Yes,” Clara said, “to me…actually, I’m not sure what categories to compare.” Yet, as was often the case in this group, requests for additional information or clarification were ignored. Penny and Noelle did not participate in this conversation. No additional science talk beyond that already discussed ever emerged, leading Noelle to say “at least it wasn’t us” when the instructor cold-called on another student group at the end of the exercise.

Group 11. Students in this group, on the other hand, answered the instructor’s question correctly by collectively deciphering the graph:

Eunice	Yes.	(S)
Mercedes	Yes.	(AF/S)
Amber	Right,	(AF)
	the graph shows that if you get too much attention, you have fewer babies.	(A)
Jodi	Yeah.	(AF)
Eunice	It does look like there’s a cost to being sexy, which is—	(A)
Ruth	—a big cost.	(AF)
Jodi	That makes a lot of sense to me.	(AF)
	They are being harassed.	(CX)

At this point, Mercedes dabbled in discussion driving. She pointed out that this cost appeared to be contextual, since it only manifested when large, female spiders were exposed to the ‘continuous male exposure’ treatment (Figure 5.3):

Mercedes	Yes,	(AF)
	but it lowers your fitness to be sexy *only* [emphasis in the original] if you are surrounded by males a lot of the time.	(C)
Ruth	Right…	(AF)
Mercedes	If she’s sexy, but she’s not exposed to males as much, she reproduces a lot.	(A)
	See?	(QQ)

Her peers eventually discerned the distinction between treatments that Mercedes accentuated, prompting Eunice to engage in discussion driving, Amber to provide a falsifiable claim, and Ruth to contextualize it. Together, they constructed a mature scientific claim based on data from the research article:

Eunice And if we put it all together— (DD)
Amber The cost of being sexy depends on how persistent males are. (C)
Ruth Too much of a good thing… (AF)

While Group 11 successfully deconstructed the third research article, Group 7 refused to engage. As this and previous examples show, students in these two groups significantly differed in the content and effectiveness of their science talk. As the individual cases and cross-case comparisons demonstrate, the composition of small groups matters.

Discussion

The findings in this study suggest that the composition of small groups affects the learning journey of participating students. Even in single-sex collaborative groups, additional parameters, including social identities and (non-)academic behaviors, impact students' ability to develop indispensable science process skills, including scientific reasoning. In this study, the emergence of scientific reasoning was facilitated or hindered by each group's ability to function as an interrelated unit. Students who worked harmoniously, addressed conflict proactively, and equitably distributed labor were more likely to engage each other in the co-construction of scientific knowledge. The following sections tackle how these two groups differed in their rates of participation, their scientific reasoning, and their behaviors during classroom discussions.

Participation

Students in this study differed in their rates of participation. Most students spoke proportionally to their numbers (usually between 20-30% of the time), suggesting that removing men from the conversational equation does lead to more equitable participation overall (Dasgupta, Scircle, & Hunsinger, 2015; Opie, Livingston, Greenberg, & Murphy, 2019). No student in this study truly dominated the discussion—in contrast with gendered participation patterns in other coeducational spaces (Aguillon et al., 2020; Eddy, Brownell, & Wenderoth, 2014). However, some students in this study did participate less often than expected, given the number of students in each group: Grace (19%), Ruth (15%), and Eunice (8%). Since the researchers intentionally segregated these students into all-female groups, the conversational dominance of men (Tatum, Schwartz, Schimmoeller, & Perry, 2013) cannot explain these students' reticence to speak. Instead, additional social identities may be in play, necessitating an intersectional inquiry into this study's classroom participation data.

Social Identities and Participation

An intersectional lens focused on other social identities may illuminate why these three female students removed themselves from the conversation (Leupen, Kephart, & Hodges, 2020). Previous research has cautioned that female BIPOC students face a 'double bind' of racist and misogynistic barriers (McGee & Robinson, 2019; Ong, Smith, & Ko, 2018). While the two groups in this study were demographically comparable (i.e., three white students and one AAPI student in Group 7, and four white students and one AAPI student in Group 11), in both cases the student of color participated the least frequently—though likely for different reasons. Grace clearly chose to self-censor due to her deep dislike of her chaos-fomenting classmates. When she did speak, her comments were terse and conversation-stopping. Conversely, when Eunice spoke, her comments were conversation-promoting, and they tended to serve important academic and discursive functions (e.g., discussion driving), suggesting she spoke laconically, but with intent. Further, while AAPI students face discrimination in college (McGee, 2018), instructors, peers, and researchers perceive these students to be academically gifted as a class (e.g., the model minority stereotype, Hsin & Xie, 2014). The model minority stereotype that AAPI students encounter may thus complicate making broad race-based conclusions regarding classroom participation—especially in the absence of evidence that explicitly addressed this question.

Moreover, differences in volubility may not always signal that students are experiencing race- or gender-based exclusion from the classroom discourse. Introverted students, for example, approach small group argumentative discussions differently from extroverted students (Tuovinen, Tang, & Salmela-Aro, 2020), often with the goal of demonstrating participation outside of speech (Carpenter Rosheim, 2018). Introversion may apply to Eunice: though she spoke the least often in her group, her contributions were perceptive, intentional, and valuable. Analysis of the transcripts also revealed that her group members were not interrupting, putting down, or excluding her in other ways. Admittedly, Eunice declined to engage in idle chatter during this lesson, but she fully participated in most of the sense-making and meaning-deriving opportunities afforded by this lesson.

Hidden Identities and Participation

Hidden identities (Henning, Ballen, Molina, & Cotner, 2019), including first-generation status (Martin, Stefl, Cain, & Pfirman, 2020), disability (Hales, 2020), and class (Attridge, 2021), also impact whether students participate in classroom discussions. Even mental health diagnoses can impact students' ability to participate in classroom conversations (Barbayannis et al., 2020). For example, research shows that anxiety prompts students to remain silent, especially in large lecture halls (Broeckelman-Post, Johnson, & Schwebach, 2016). Therefore, this study cannot definitively explain why these differences in participation emerged. Studies on student participation that focus solely on one identity variable necessarily paint but a partial picture of the classroom auditory ecology.

Increasing Participation in the Classroom

On a practical note, to address differences in rates of participation, researchers have suggested that instructors integrate activities that require participation of all students (Cooper, Downing, & Brownell, 2018). For example, instructors could rely on random calling (e.g., the magic 8 ball in this study) to ensure all small groups engage in classroom discussion (Knight, Wise, & Sieke, 2016). When this type of accountability measure is implemented, either at the group (Broeckelman-Post, Johnson, & Schwebach, 2016) or individual (Leupen, Kephart, & Hodges, 2020) level, student responses are better, both in quantity and quality (Cooper, Downing, & Brownell, 2018). Further, requiring students to assign roles within their groups usually promotes equitable participation (Wilson, Brickman, & Brame, 2018). To preclude women and other traditionally marginalized students from being relegated to secretarial roles (e.g., the Hermione effect, Doucette, Clark, & Singh, 2020), instructors could also force students to rotate roles with each new class session (Wilson, Brickman, & Brame, 2018).

Scientific Reasoning

Scientific reasoning includes science process skills such as data analysis, claim construction, and problem solving (Klijnstra et al., 2022; Yang, Bhagat, & Chen, 2019). Previous research, stretching back decades (e.g., Kitchen & McDougall, 1999), strongly suggest that practicing scientific reasoning during collaborative episodes of science talk creates the educational conditions necessary for its development (Klemm, Flores, Sodian, & Neuhaus, 2020; Paine & Knight, 2020). Like any behavior, consistent practice leads to mastery (Kang, 2016). However, these skills are not intuitive to nonmajors (Cotner, Thompson, & Wright, 2017), and the act of providing scientific reasoning during problem solving is challenging for students at all educational levels (Seifert, Harrington, Michal, & Shah, 2022; Woolley et al., 2018). Nonmajors may therefore refuse to practice these skills, thus letting the perfect get in the way of the good. They might likewise choose to reason from science using unconventional modalities, such as humor and personal lived experiences, like Jodi and other students consistently did during this lesson.

Students Vary in their Use of Scientific Reasoning

In this study, most of the students failed to consistently provide evidence of sophisticated reasoning—that is, reasoning that included logic (L), evidence evaluation (W), and quantitative thinking (A). Out of nine students, only two (Mercedes and Amber) dependably deployed all three sophisticated behaviors throughout this lesson. Another student, Eunice, constructed valid claims supported by evidence and reasoning (C/W/L), yet did not contribute any quantitative analysis (A). The remaining students steadfastly relied on recall (R), solving (S), and observation (O), and only sometimes provided descriptive claims (C).

A review of the literature suggests that students sometimes fail to engage with higher-order scientific reasoning moves for two reasons (Paine & Knight, 2020). First, the discussion prompt may be too easy. Second, students may not understand how to construct valid claims (i.e., claims that are falsifiable, supported by evidence, and imbued with logical reasoning). Students, for example, may easily recognize evidence as necessary for scientific claim-construction, but may not understand how to use it within an argument (Zembal-Saul et al., 2012). Or they may conversely be unable the type of appropriate and persuasive evidence that supports the claim (Zembal-Saul et al., 2012). Students may also not understand what constitutes critical thinking and problem solving within science (Paine & Knight, 2020). The following section discusses these explanations in turn, and analyses whether they apply to students in this study.

Instructor Prompts and Quality of Discussion

While instructor prompts need to be carefully constructed to ensure students engage in high-quality science talk, a review of the transcripts suggests the discussion questions used during this lesson were of an appropriate difficulty. Granted, Group 11 did show reduced quality of scientific reasoning for the discussion questions they easily solved, but this happened rarely. They often engaged fully with the instructor's prompts, producing complex and detailed science talk. Group 7, conversely, seemed to find the same instructional prompts exceedingly challenging, as seen by Noelle's and Penny's constant questioning (QQ). Even Clara often voiced a lack of understanding, suggesting the group deemed the instructional prompts too challenging to address. And the reason for these students' preemptive intellectual surrender is not a mystery: Penny and Noelle were not doing the work, either in the classroom or in the laboratory. Without a solid conceptual foundation, students will fumble with scientific reasoning, regardless of the quality of the discussion questions (Crujeiras Pérez, & Jiménez Aleixandre, 2015).

Student Confusion Regarding Evidence and Logical Reasoning

If instructor prompt quality did not meaningfully preclude students from engaging in scientific reasoning, then perhaps students' discomfort with this cognitive tool explains why groups rarely used evidence and reasoning during science talk (Manz, Lehrer, & Schauble, 2020; Novak & Treagust, 2018). Paine and Knight (2020) observed that students in their laboratory course tended to share unfounded narratives, rather than falsifiable claims supported by logic and evidence—a pattern reflected in this study. Penny and Noelle's contributions to Clicker Question 3: The Evolution of Sex, for example, were merely subjective (and incorrect) descriptions of evolutionary processes. To compound matters, these two students buttressed their claims with academic rather than scientific justifications (e.g., "I read it in the book" versus "as predicted by the cost of meiosis").

These type of 'just-so' stories usually emerge when students lack the necessary expertise to frame arguments around scientific theories and trends in the data (Liu et al., 2023; Novak & Treagust, 2018). Jodi and Ruth, for example, did use information from the research studies to craft their responses, but they rarely explicitly referred to graphical components, trends in the data, or specific evolutionary theories—unlike Mercedes and Amber, who unambiguously incorporated the axis-labels and treatment names into their analysis of trends in the dataset. Just-so narratives likewise arise when students do not understand the epistemological assumptions that undergird the discipline (e.g., emergent processes in evolution, Werth, 2012). Three members of Group 7 failed to understand, for example, that evolution acts on populations, rather than individuals, which meant they could not coordinate evidence with theory during discussions that required systems-thinking (Werth, 2012; Verhoeff, Knippels, Glissen, & Boersman, 2018).

Instructors can assist students by explicitly scaffolding evidentiary reasoning into the curriculum (Liu et al., 2023; Manz, Lehrer, & Schauble, 2020). Liu and colleagues (2023) recently developed the Conceptual Analysis of Disciplinary Evidence (CADE) framework, which considers both domain-general and discipline-specific aspects of evidence. By emphasizing the importance of disciplinary sense-making conventions, this framework aided students by encouraging them to more frequently use sophisticated scientific reasoning roles and behaviors (Liu et al., 2023).

Reasoning from Science with Humor and Personal Anecdotes

This study now proposes a third reason why students may decline to employ all components of scientific reasoning. As suggested by the literature review, and validated by the findings, students can choose to reason about science in a manner that does not align to the claim-evidence-reasoning framework favored by scientific reasoning—and this discourse can nonetheless be successful. Jodi consistently relied on humor and opinions to help contextualize the information being presented. This non-academic commentary, based on subjectivity and non-traditional modalities, could be discounted as intellectually poor. However, given that her commentary usually promoted individual learning and collaborative construction of scientific knowledge, this study declines to label it off-task. In fact, future studies interested in how nonmajors develop scientific reasoning should be more open-minded in how they assess students' use of critical thinking and problem solving in science courses for nonmajors.

Social Emotional Roles and Behaviors

Courses that emphasize collaborative learning should also model social-emotional learning and skills-building, for the ability to work well with others matters both in the classroom and beyond (Lubit & Lubit, 2019). Transferable skills associated with social-emotional learning include non-academic behaviors that influence motivation, persistence, and social cohesion. As the dysfunction in Group 7 demonstrated, social-emotional skills influence the emergence of scientific reasoning, making them integral to students' success in college. As the section below will detail, the wide gap in social-emotional skills evinced by Groups 7 and 11 explains why the former floundered while the latter excelled.

Social Emotional Learning

In higher education, the application of SEL to STEM college courses remains rare (Elmi, 2020), to the detriment of students (Ingram, Reddick, Honaker, & Pearson, 2021) and their communities (Belfield et al., 2016). Social and emotional learning strategies, Elmi (2020) proposes, increase cognitive development, encourage student focus and motivation, improve relationships between students, and promote student self-efficacy.

Further, SEL mimics the collaborative nature of scientific enterprise (Jones & Kahn, 2017), where research terms collect data and refine knowledge, together. The dysfunction of Group 7 showed that a lack of SEL complicates students' academic journey. Further, as Elmi (2020) predicted, Group 11 showed higher cognitive engagement with evolutionary concepts, higher motivation, an eagerness to participate, and improved self-efficacy because of peer-peer support. Group 7, on the other hand, withdrew cognitively and behaviorally, as predicted by their lack of productive social-emotional skill. This tight correlation between academic skills-building and peer-peer support leads Ingram and colleagues (2021) to advocate for the integration of SEL into STEM college courses.

By helping students improve their social awareness (e.g., respecting others, understanding different perspectives, effectively managing conflict), instructors that incorporate SEL into their curriculum also ensure that students will develop the social skills they need to be successful partners in collaborative exercises (Anderson et al., 2019; Lubit & Lubit, 2019). More intentional integration of social-emotional learning may have supported Group 7 by equipping them with actionable steps that proactively address social loafing and other antisocial behaviors. Without this explicit instruction, the instructor had to intervene midway through the semester to separate the warring team members.

Further, these social-emotional skills will help students professionally when they enter the workforce post-graduation (Belfield et al., 2016; Schutte & Loi, 2014). As

Group 7’s dismal performance cautioned, students do not enter college with mastery over their social-emotional skill inventory (Anderson et al., 2019; Everett & Oswald, 2018). Teenagers sometimes display underdeveloped interpersonal skills and emotional intelligence, especially after the disruptive effects of the COVID-19 pandemic and remote instruction (Kardambikis & Donne, 2022). This social emotional deficit underscores that college instructors should be intentional about modeling interdependence, individual accountability, prosocial interactions, well-developed social skills, and opportunities to reflect on collaborative work (Scager, Boonstra, Peeters, Vulperhorst, & Wiegant, 2016; Walker & Gleaves, 2016). Nonmajors thus benefit from the curricular integration of content knowledge acquisition, scientific skills-building (Aikens & Kulacki, 2023), and social-emotional learning (Ingram, Reddick, Honaker, & Pearson, 2021; Jones & Kahn, 2017).

This approach, combined with explicit modeling by an inclusive instructor, will best help students grow into engaged citizens who not only practice critical thinking and problem solving, but also value community-building and collaboration (Scager, Boonstra, Peeters, Vulperhorst, & Wiegant, 2016). However, though this study definitively argues that social-emotional learning belongs in higher education, it wisely leaves for others to decipher how to implement it, given the current heated sociopolitical discourse surrounding it (Anderson, 2022; Cineas, 2023).

Limitations

While this study provides a description of the academic and social emotional behaviors present within single-sex collaborative groups in a nonmajors biology course, it suffers from the following limitations. First, it only investigated the behaviors in two all-female groups during one lesson. Whether the student behaviors observed persisted across lessons remains unknown. Likewise, the absence of mixed-gender and all-male groups obscures whether the behavioral patterns displayed by the two all-female groups were shared by the other treatments. Second, participating students did not diverge significantly in terms of their demographics, majors, and social identities, limiting the intersectional analysis that can be drawn from data collection. Third, the lack of cross-lesson data collection precludes any chronological investigation that could elucidate how students in the course refined their scientific argumentation skills over time—and whether, and how, their team composition assisted in this endeavor.

Conclusion

Helping students develop critical thinking and problem-solving skills remains of vital importance in a 21st century society characterized by conflict, complexity, and uncertainty (Cahill & Ojeda, 2021; Zummo, Donovan, & Busch, 2020). As Abrami and colleagues (2008) note, a strong and functional democracy depends on “citizens who can think for themselves on the basis of evidence and concomitant analysis, rather than emotion, prejudice, or dogma” (p. 1103). Science courses for nonmajors that highlight this principle, and encourage its emergence through inclusive, collaborative, and discourse-based instructional approaches, best equip nonmajors with the knowledge and skills they need to understand themselves and their place in the world.

As this study shows, single-sex small groups can help female nonmajors succeed in college biology courses. In these groups, women avoid some of the gender-based barriers that commonly arise in science-based higher education spaces. However, the manipulation of women's numerical representation in small groups alone will not guarantee the group will work collaboratively and succeed academically. Other social and cultural variables matter, including the social-emotional skills that lubricate all social interactions. If students cannot work cohesively as a unit, they will fail to construct knowledge collectively. The emergence of scientific reasoning, therefore, goes hand in hand with the development of a refined emotional quotient.

Chapter 6: Conclusion

When the reader first encountered Mercedes in the introduction, she felt lost and alone at the start of the semester. She dreaded enrolling in a biology course for nonmajors, and thus reported feeling anxious and discouraged during the first week of class. Yet, as the two studies in this dissertation revealed, Mercedes not only excelled academically, but she also routinely provided conceptual mentoring and emotional support for her peers. Her apprehension that she could not think quantitatively or reason scientifically proved unfounded, since she took the lead in many of the discussion activities embedded in the course. Her low science-based self-efficacy, therefore, was but a psychological mirage induced by her previous negative experiences in K-12 STEM classes. By enrolling in this biology course for nonmajors, and by interacting with her female peers and a supportive female-identified instructor, Mercedes unshackled herself from her educational past and forged a new, more confident relationship with science—and herself.

Yet Mercedes's personal story should not define the lived experience of every female student in the course. As Judith Butler (2004) famously admonished:

> "[G]ender is a kind of imitation for which there is no original. In fact, it is a kind of imitation that produces the very notion of the original as an effect and consequence of the imitation itself" (p. 127).

Rather than attempt to shoehorn one woman's experience as the "original" model, this dissertation would prefer to highlight the diversity of experiences enclosed therein.

Consider how Amber, Olena, and other female students traversed similar paths during their educational journeys: as detailed in the semi-structured interviews of the first study, women were generally perturbed about enrolling in this biology course. And they unanimously attributed their apprehension to previous hostile science experiences in the K-12 setting (e.g., gendered dynamics in middle school, Dare & Roehrig, 2016; Wieselman, Dare, Ring-Whalen, & Roehrig, 2020). These students further acknowledged that these adverse associations with STEM left them exposed to belongingness concerns (i.e., a component of social identity threat, Boucher & Murphy, 2017; Smith, Lewis, Hawthorne, & Hodges, 2012). Further, Elena, Ruth, and other female students disclosed that the positive dynamics within their groups encouraged them to engage with course concepts and their peers more intentionally and fruitfully than previously anticipated. Titilayo, for example, marveled at how she enjoyed conversing about sex, despite her conservative, religious background, while Anne rejoiced at feeling so self-assured, she could now explain biological concepts to her friends, family, and even her roommate’s pre-med boyfriend. Those moments celebrate how students developed science-based self-efficacy in real time as a function of increased knowledge—and how the all-female composition of their small groups accelerated this process. By dispelling the mirage of the mind known as social identity threat, Mercedes, Elena, and other female students leveled up into engaged and empowered learners who reveled at the opportunity to co-construct biological solutions for problems at the intersection of sex, gender, and society.

The following sections will re-visit the conclusions of the previous research chapters, foregrounding the women who appeared in them, to connect the previous celebratory statements with evidence from the research studies. These sections will furthermore contextualize these academic gains with trends in the science classroom and society at large. These sections end with a description of the implications for instructors intent on eliminating gender-based barriers in academia.

Chapter 4: Single-Sex Grouping in Academic Spaces

This study showed that women in single-sex small groups consistently displayed levels of engagement with the course material that rivaled (and often exceeded) the engagement shown by their counterparts in mixed-gender groups. Women in this grouping category attended lecture more often, and interacted with the course content, the instructor, and their peers more frequently and intentionally. Groups that lacked women, conversely, performed poorly: affectively, behaviorally, and academically. These results agree with previous research that demonstrates how the performance of small groups in college classrooms rises as a function of the number of women in the group.

The study identified two possible mechanisms that explain why female single-sex groups outperformed other small groups. First, the shared social identities of its members ensured that all-female groups avoided some of the identity-related educational barriers that emerge in coeducational spaces. Women felt more comfortable discussing intercourse, sexual violence, and pregnancy with members of their expressed sex. The existence of shared experiences increases students’ senses of belonging—which in turn amplified their willingness to participate. Second, since women experienced a greater sense of belonging in all-female groups, they were more likely to rely on humor to make connections between course concepts and their lived experiences. More than one female-identified student stated she would avoid explicit sexual humor in co-educational groups, in part because they did not want to rile male peers. In short, the all-female grouping fostered a sense of belonging in women, allowing them to succeed academically.

Despite the clear academic advantage that the all-female grouping provided, most students—both male and female—rejected the need of single-sex spaces within coeducational classrooms. Even female students in single-sex groups who openly acknowledged they personally benefited from this grouping generally stated they would not join another all-female group in the future. Only Amber definitively stated she enjoyed working in an all-female group and would seek similar group compositions in the future. Collectively, these results indicate that single-sex grouping may yield positive academic and affective gains, but students must be persuaded of both the need and the benefits associated with this type of grouping.

Chapter 5: Scientific Reasoning in Nonmajors Courses

This dissertation also explored roles and behaviors that emerged during episodes of scientific reasoning within two all-female groups. The results showed meaningful differences, both in scientific reasoning skills and social-emotional maturity. The all-female groups differed drastically in their ability to work cohesively. One group appeared to enjoy genuine rapport and worked well together, while another group was highly dysfunctional. The negative interactions in the low-performing group flowed from the persistent social loafing of two of its members. Students in this group spent their time putting each other down rather than solving the biological puzzles presented by the instructor. These poisonous interactions underscore that single-sex grouping is not an educational panacea that will cure all the ills that plague nonmajors science courses. Women will more harshly judge a low-performing all-female group than an equally underperforming mixed-gender group—a unavoidable fact any instructor who relies on single-sex grouping must confront. When student groups must police individual contributions, they miss opportunities to practice the scientific reasoning deemed essential to science talk and the emergence of science competencies. Instructors should therefore integrate meaningful accountability structures into the curriculum, thus allowing female students hounded by their peers' social loafing to find relief.

Women in single-sex groups still displayed unequal participation rates. Having eliminated gender-based effects on the co-construction of knowledge, these differences potentially derived from additional social identities. Other studies have shown that students can be excluded from classroom conversations based on their race, age (e.g., older women, and country of origin. However, the unequal rates of participation may also derive from other psychological variables, ranging from introversion (Carpenter &

Rosheim, 2018), to social anxiety. Further, students' desire to participate will naturally wax and wane depending on the course topic, their stress levels, and countless other variables. Perhaps unequal participation rates are inevitable, even in the most inclusive of learning ecologies, and educators and researchers should focus on other metrics to measure students' opportunity to meaningfully engage in the co-construction of scientific knowledge.

Finally, while students, in general, relied on multiple scientific reasoning moves throughout a classroom session, they nonetheless showed strong preferences for certain discursive moves. And these preferences often aligned with a student's comfort with science talk in academic spaces. For example, some students steadfastly used certain discursive moves (e.g., recall) at the expense of others (e.g., logical reasoning). This predilection meant students spent most of their scientific journey plucking low-hanging fruit from the tree of knowledge (Bradshaw, Nelson, Adams, & Bell, 2017). Without instructor-imposed structure that forces all students to use all types of scientific reasoning moves, students will likely default to those moves they find most comfortable or contextually useful (Fischer et al., 2014; Paine & Knight, 2020).

However, such a heavy-handed approach by the instructor may be counterproductive. There is value in having the "freedom to think as you will and speak as you think" for this expressive freedom remains "indispensable to the discovery [of personal] truths" (Brandeis, J., concurring in *Whitney v. California*, 274 U.S. 357).

Science courses that discourage thought, hope, and imagination will prove hazardous to nonmajors who enroll in them. By helping students develop pragmatism in their scientific reasoning through a lived curriculum (Wright, 2005), instructors can safeguard the central goal of nonmajors education: to equip students with the skills and knowledge they need to make sense of and find meaning in a rapidly changing world (Abbas et al., 2022; Brickhouse, 2022).

Therefore, instructors should remember that teaching students how to deploy scientific reasoning to solve real-world problems is but the means to an end. While mastery of scientific reasoning remains a categorical imperative for students majoring in STEM, reasoning from science proves sufficient for nonmajors. After all, scientific reasoning is defined as critical thinking and problem-solving *in a scientific context*—a context nonmajors like Mercedes will rarely occupy. Nonmajors science courses should consequently model for students how to use critical thinking and problem-solving to construct evidence-based solutions in all aspects of their lives. Doing so will ensure that Mercedes will not take Ivermectin to treat COVID-19 (Garegnani, Madrid, & Meza, 2022), and that Elena will seek expertise and discount political propaganda when addressing her child's gender incongruence (Puckett, Cleary, Rossman, Newcomb, & Mustanski, 2017). Doing so will ensure that the deliberative forces will triumph over the arbitrary in modern society, and that reason will prevail over ignorance, sound judgment over fear. Before the enlightenment, and the birth of the modern scientific cannon, “[m]en feared witches and burnt women.” Brandeis, J., concurring in *Whitney v. California*, 274 U.S. 357. It is therefore the function of higher education, and college courses that incentivize critical thinking and problem-solving, to “free [people] from the bondage of irrational fears.” Brandeis, J., concurring in *Whitney v. California,* 274 U.S. 357. That, at its core, is the promise of a liberal arts degree, and the ultimate goal of science college courses for nonmajors.

Implications for College Instructors

The following section will suggest practical applications for science instructors in nonmajors courses who are committed to creating an equitable and inclusive learning environment.

Increasing Women’s Numerical Representation in Small Groups

Science instructors for nonmajors who teach courses where men and women enroll in roughly equivalent numbers should consider providing female students with the opportunity to form single-sex collaborative groups. The research enclosed in Chapter 4 demonstrated that this type of grouping can ameliorate the negative effects of social identity threat. Women with previous inimical science experiences in the K-12 setting who dreaded science instruction collectively evinced higher rates of participation and perceived engagement when placed in single-sex groups. However, not all women appreciated being grouped by gender. Social identity is a psychological instead of demographic identity parameter. Female students who would most benefit from single-sex grouping would strongly identify with their gender (and weakly identify with science). Women with a weak connection to their gender may not benefit from being grouped with other women, as Julia revealed during her interview. Since students unanimously rejected being placed in single-sex collaborative groups, instructors would need to persuade students of its value.

Helping Students Develop Group Self-Efficacy

Instructors should also consider adding conflict resolution as one of the learning goals. Adults struggle to work collaboratively in professional settings for many of the same reasons Group 7 struggled. Some researchers have suggested that students complete group contracts at the start of the semester. These contracts could spell out student obligations, the proper division of labor, and mechanisms for redress when social loafing occurs (Shimazoe & Aldrich, 2010). These contracts provide "a mechanism to initiate discussion of expectations and reservations, to strengthen social skills, and to build interpersonal relationships critical to effective group work" (Chang & Brickman, 2018).

Given all the caveats associated with the proposed interventions, the reader may wonder, is all this instructional and curricular fuss worth it? The answer is an unequivocal yes. Most students work effectively within their groups and rate their overall collaborative experiences as positive when instructors structure active learning activities (Change & Brickman, 2018). And when group members function interdependently, the self-efficacy of individual students in the group increases. This increase in self-efficacy, in turn, improves academic performance (Bandura, 1977), since students with higher self-efficacy tend to effectively model appropriate academic and social-emotional behaviors (Ainscough et al., 2016), just as they engage in higher-quality discussions more frequently (Alhadabi, 2021; Wang & Linn, 2007). By explicitly addressing social emotional skills buildings in the courses, science instructors for nonmajors ultimately improve long-term learning.

Future Research

Future research focused on gender and education should expand the analytical lens to include sexual orientation and gender identity. When researchers view students as either male or female, they reduce their experiences to the heterosexual, *cis*-gender norm, thus ignoring identities that do not conform to the traditional male-female binary (e.g., transgender or gender non-conforming), and erasing other components of gender identity (e.g., sexual orientation and past lived experiences). For example, as José and Devon demonstrated, gay men experience all-male spaces differently, depending in large part to their own lived experiences (Glazzard, Jindal-Snape, & Stones, 2020). And as Elena disclosed during her interview, lived experiences matter. Since her child is gender non-conforming, Elena approached all conversations about gender identity through that lens. Personal lived experiences inform a person's gender and sexual identity—and these experiences matter when creating small groups.

Further, recent research into political ideology suggests it now functions as a super-identity that forces individuals to modify how they conceptualize other identities (e.g., race, gender, and country of origin) to conform with the political dogma they ascribe to (Sevincer, Galinsky, Martensen, & Oettingen, 2023). Political ideology influences whether students feel comfortable cooperating with others who hold opposing views. As Balliet and colleagues (2018) argued, liberals and conservatives are more likely to assist others in their in-group relative to their out-group, raising concerns about group dynamics in ideologically diverse small groups (Fryer, 2022). Further, research shows that conservative students will be less likely to accept scientific conclusions on sex, gender, and sexuality when it disagrees with their political dogma (Sevincer, Galinsky, Martensen, & Oettigen, 2023). Further, given the harmful political discourse that permeates society today, students may struggle to engage each other in academic conversations about gender and sexuality. Future studies should therefore evaluate first, how political ideology influences group work and the development of scientific reasoning, and second, whether science talk around sex, gender, and society has shifted along with the sociopolitical context.

Conclusion

Forty years ago, researchers identified a “chilly climate” for women in college classrooms—particularly within STEM disciplines (Boersma, Gay, Jones, Morrison, & Remick, 1981; Hall & Sandler, 1982). Gender-based antagonism, rather than lack of academic aptitude, constrained and complicated female students’ scholastic and professional advancement. Since then, countless academic papers, policy prescriptions, and educational interventions have been developed, shifting the educational landscape (DiPrete & Buchmann, 2013). Change, however, remains slow and unsteady. While men now struggle academically in certain contexts (Fortin, Oreopoulos, & Shelley, 2015), they nonetheless continue to dominate classroom conversations at the expense of women (Lee & McCabe, 2020). And some instructors still implement expedient yet ineffective pedagogies that reify these harmful gender-based biases (Richard, Wagner, & Brooke, 2017). Thus, higher education keeps pouring old poisons into new vials.

The findings in this dissertation imply that the long-promised thaw has not materialized, for the chilly classroom climate continues to freeze out promising female students (Lee & McCabe, 2020). At a time when political parties and powerful legal institutions have declared open season on women, researchers and educators must unite in designing equitable classroom spaces. The combination of single-sex grouping, structured active learning activities, and ample opportunities for meaningful science talk, however, has been shown to be successful in the two studies that composed this dissertation. Education remains a vital right, indispensable to a person’s sense of self and a citizen’s ability to fully participate in society. Equitably supporting their students’ academic journeys thus remains the *raison d'être* of instructors, and the selfless duty of the profession requires them to do whatever it takes to protect the academic and emotional development of their students. Anything less amounts to complicity, for “when the rights of any individual or group are chipped away, the freedom of all erodes” (Warren, 1959, p. 231).

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