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International Women in Biomechanics: Promoting, Supporting, and Sustaining the Careers of Women in Biomechanics

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Abstract (249 of 250 words)

Gender biases and inequities are prevalent across many scientific fields and biomechanics is likely no exception. While progress has been made to support women in the field, especially at biomechanics society conferences, the recent COVID-19 pandemic has exacerbated professional isolation. The International Women in Biomechanics (IWB) community started in July 2020 with the mission of fostering an environment for women and other under-represented genders in biomechanics to gain year-round support, visibility, and allyship. Nearly 700 biomechanists have joined the IWB community from over 300 universities/organizations and 33 countries. Our community ranges in career stages and professions and interacts through a forum-style platform, teleconference meetings, and social media. In 2021, we conducted a survey to identify the needs, concerns, and issues faced by individuals in the IWB community. We received 144 responses from members in 17 countries. Our survey revealed three primary needs for women in biomechanics: supportive working environments, career planning support, and addressing workplace gender bias. These results, in conjunction with scientific evidence on workforce gender bias, helped us identify three key areas to meet our mission: Member Support, Community Outreach, and Empowering Allyship. Several levels of support are required in these three areas to ensure a lasting, positive, and sustainable impact on gender equity in biomechanics. We conclude by providing our perspectives on an evidence-based call to action to continue addressing gender bias and inequity at the individual, institutional, and scientific society levels. These actions can collectively enhance our allyship for women in the field of biomechanics.

State of Gender Disparities in Biomechanics

Women have made substantial contributions to the field of biomechanics through their scientific discoveries and have served as role models for future generations of women scientists. This has, for example, included

contributions in areas as diverse as gait analysis (e.g., Dr. Jacqueline Perry (Perry, 1992)), skeletal muscle physiology (e.g., Dr. Brenda Bigland-Ritchie (Thomas et al., 1995)), and sports biomechanics (e.g., Dr. Betty Mortimer Roberts (Roberts, 1991; Roberts and Metcalfe, 1969), Dr. Doris I. Miller (Miller, 1993; Miller et al., 1973), Dr. Marlene Adrian (Adrian, 1988)). Sadly, the discoveries and contributions of pioneering women in science, like Ruth Glassow, often go unnoticed and may only get credited years later (Park, 1995; Welch, 1985).

More women are now entering biomechanics-related graduate programs than they were 50 years ago. For example, the United States National Science Foundation reported an increase from 5.4% (3,706) of female engineering graduate students in 1977 to 27.6% (19,660) in 2020 (National Center for Science and Engineering Statistics (NCSES), 2022). Targeted efforts have been made in recent years to bring more women into biomechanics-related fields. For example, The Perry Initiative provides outreach programming for women to learn about careers in orthopedic surgery and engineering (Harbold et al., 2021). Additionally, National Biomechanics Day is an initiative to recruit young scientists, particularly women and individuals from historically marginalized backgrounds, to the biomechanics field (DeVita, 2018).

However, there is a disproportionately lower number of senior women in biomechanics-related fields when compared to junior women and trainees (Hill et al., 2010). At present, women make up approximately 50% of student memberships, but around 30% of professional memberships in professional biomechanics societies like the American Society of Biomechanics (ASB) and the International Society of Biomechanics in Sports (ISBS). The number of individuals who do not identify as men or women, if reported, is small (1%). While we acknowledge that gender is not binary, this article primarily presents evidence of bias against women because that is the group for which most published statistics currently exist.

Within three major biomechanics societies, there is still a consistent lack of scientific recognition of women at the top levels (Table 1). For example, an alarmingly low number of women have received the societies' most prestigious awards (Table 1). There is a slightly higher percentage of women in leadership and service roles (e.g., scientific society presidents) (Table 1). This also speaks to the broader issues of sex and gender

biases, and inequities prevalent across science, engineering, technology, and math (STEM) fields. Women receive 30% fewer citations than men for their scientific publications – a discrepancy that has not decreased from 1950 to the 2000s, despite greater diversity within most STEM fields (Huang et al., 2020). Citation bias and lack of recognition create barriers to scientific opportunities, awards, promotions, and salaries, undoubtedly limiting the overall career progression of women. Further, this lack of recognition of senior women can have negative generational effects as visible role models can enhance the self-efficacy and retention of women in STEM fields (Drury et al., 2011).

Table 1. Number of women who have been awarded the most prestigious award and who have served as President across three professional biomechanics societies. Notably, historical data of membership demographics from these three societies could not be found in public newsletters, with the exception of ASB reporting their membership was 20% women in 1997 (Bechtold, 1997)*. In 2020, ASB and ISBS reported 41% and 33% of their total membership were women, respectively* (Janssen, 2021; Saul, 2020)*.*

Biomechanics Society	**Most Prestigious Award**	**No. Women Recipients/ Total Awards**	**Years awarded to Women**	**No. Women Presidents/ Total Presidents**	**Years of Women's Presidency**
International Society of Biomechanics (ISB)	Muybridge Award	1/18	2009	4/24	2001-2003, 2003-2005, 2009-2011, 2023-2025
International Society of Biomechanics in Sports (ISBS)	Geoffrey Dyson Award	6/34	1988, 1991, 1993, 2016, 2021, 2023	3/20	1985-1986, 1988-1990, 1992-1994
American Society of Biomechanics (ASB)	Borelli Award	2/39	2002, 2019	10/47	1983, 1999, 2002, 2008, 2010, 2017, 2019, 2021, 2022, 2023

Innovative solutions come from different perspectives, with evidence supporting gender-heterogenous teams lead to higher quality research (Campbell et al., 2013). Positively, there has been a collective effort to be more gender inclusive in biomechanics societies. For example, the International Society of Biomechanics (ISB) hosted Advancing Women in Biomechanics events at the last two ISB Congresses,

and several societies host their own Women in Biomechanics events. While these efforts are valuable, their influence is largely made at annual conference events for those able to attend. In other scientific fields, facilitating a continued, year-round supportive environment for women has been shown to enhance confidence, empowerment and professional skills, and to increase career satisfaction and self-efficacy in women (Horner-Devine et al., 2016). Thus, fostering such a community in biomechanics has positive potential to increase attraction and retention of talented individuals to the field.

Formation of International Women in Biomechanics

The International Women in Biomechanics (IWB) community was formed in July 2020, co-founded by two then-postdoctoral research fellows (A.E. and J.M.). Catalyzed by the exacerbation of STEM gender inequities and experiences of professional isolation during the COVID-19 pandemic (King and Frederickson, 2021), a single Twitter post publicizing the nascent group received over 109,000 impressions (number of views by unique individuals) and 4,939 engagements (interactions with the tweet through retweets, likes, etc.). The initial overwhelming reaction signaled a clear need to form such an affinity group, which began with a forum-style messaging platform (Slack Technologies, San Francisco, USA), recurring teleconference meetings, and social media accounts.

The IWB mission is to foster an environment where women and under-represented genders in biomechanics can gain support, visibility, and allyship (Fig 1). In forming IWB, we were intentional in developing initiatives that considered and supported intersecting disadvantaged and marginalized identities (e.g., gender, race, ethnicity, age, ability status, etc.). Towards this end, we formed a leadership and volunteer team which represented diverse intersecting identities, and we conducted a survey to better identify the needs and concerns of the group and to maximize the efficacy of the community for its members.

[INSERT FIGURE 1]

Survey to assess needs and identify gaps

The IWB leadership conducted an anonymous survey of members one year after the organization's formation to characterize the experiences of women in biomechanics. The survey (partially based on the USA National Postdoc Survey (McConnell et al., 2018)) was conducted through Google Forms and included a mixture of free-text and multiple-choice questions covering demographics, training experiences, professional development opportunities, current positions, career goals, and personal challenges (see Appendix 1 for full list of questions).

The survey was released on 7 June 2021 and remained open for three weeks. Individuals were asked to participate in the study via email, virtual meetings, and social media (~550 individuals reached in total). We received 144 responses from members in 17 countries (an estimated response rate of 26%). Quantitative data were reported as percentages of total responses (which may not total exactly 100% due to rounding). Qualitative data from each free-text response question were analyzed using a multi-stage thematic analysis process (Braun and Clarke, 2006). First, three of the authors (K.D., B.G., A.E.) independently reviewed all responses and identified potential themes, grouping related features. The common themes were then agreed upon in discussion. Next, the three reviewing authors individually assigned quantifying codes to individual participant responses based on the theme(s) to which it was assigned (Appendix 2). Finally, any coding discrepancies between the reviewers were discussed and agreement was reached by consensus.

Demographics: All IWB members who responded to the survey chose "woman" as their gender. The age range of respondents was 22-58 years (mean±SD 31.5±6.3 years). The majority of respondents were trainees who were based in academia (Fig 2). Most earned their highest degree in an engineering (39%) or kinesiology/sport sciences department (34%), 9% in a biological sciences department, 7% in an accredited

clinical program, and 11% in other areas. Eighty-five percent of respondents identified as white, and 16% were primary caregivers.

[INSERT FIGURE 2]

Work Environment: Approximately half of survey respondents reported that they work in an environment with slightly or substantially more men (28% and 23%, respectively) than women/other genders. Approximately a fifth (19%) work in an environment with an equal balance of men and women/other genders, and the remainder work with slightly (16%) or substantially (13%) more women. When asked to identify which factors were most important in choosing their current position, most respondents selected a 'supportive working environment' as the determining factor (72% responded 'very important', 23% 'somewhat important' and 6% 'not important').

Mental Health: Over ninety-seven percent of survey respondents stated that stress and mental health challenges had negatively impacted their productivity (45% high impact, 40% somewhat impacted, 13% low impact, 3% no impact). In response to a free response question on the biggest factors influencing mental health, the primary themes (with percentage of responses) included stress and overwork (26%), toxic/unsupportive mentoring and/or work environment (25%), and imposter syndrome (10%). Issues negotiating the COVID-19 pandemic (15%) included social and professional isolation, impaired career progression, and broader concerns about the pandemic's global impact. Finally, respondents mentioned negative impacts of issues not directly associated with their job (e.g., family, health, and immigration difficulties) (22%).

Training: When asked how satisfied they were with the training currently available to them, three quarters of respondents indicated they were looking for additional opportunities to upskill in career management and planning. Many respondents were also looking to upskill in mentoring (67%), technical skills (59%), grant writing (57%), data analysis and interpretation (47%), laboratory management (47%), and writing

papers/publishing (44%). Most respondents were satisfied with existing training opportunities in only two areas: experimental/research design and critical thinking/scientific reasoning.

Career Goals: Most respondents desired future employment in academia (47%) or industry (32%), and most were confident (27%) or somewhat confident (35%) that they would attain their career plans. Furthermore, while most reported that their supervisor/manager was 'very supportive' (39%) or 'supportive' (34%) of their career plan, 18% reported that their supervisor was not aware of their career plans. In a free response question asking about their long-term career goals, 14% mentioned value-based targets such as job stability, happiness, a supportive working environment, and the ability to make a difference (rather than a specific role or industry). In response to the question "*If you do not achieve your career goals within your desired timeframe, what is your next plan?*", 27% said that they would explore employment options in industry and 10% said they were unsure what they would do.

Gender-specific Concerns: In response to *"What are your biggest concerns (if any) about being a woman or nonbinary person in biomechanics?"*, the most-common theme was a lack of professional respect due to their gender (31%). Women reported not being taken seriously, having their knowledge dismissed, being undermined or talked over, and fears of being considered a token or 'diversity hire'. In addition, respondents discussed the challenges of balancing work and career progression with parenthood and other family responsibilities (8%), a fear of reduced professional opportunities available due to their gender (9%), a lack of support and mentorship (6%), and imposter syndrome (3%) – with many highlighting the current lack of female role models and mentors in the field.

While our members experience career associated stressors that are likely also faced by men in science (McConnell et al., 2018)), a notable finding of our results was the prominent responses pertaining to the effect of perceived lack of respect in the workplace. A systemic lack of respect based solely on gender at

every career level likely has substantial negative effects on career progression and retention, as well as the mental health of women in biomechanics.

There are limitations to our survey design and analysis. We acknowledge that individual and cultural experiences vary, which is a limitation in collating all responses. Based on the nature of our qualitative analysis, we only presented the most common themes that emerged from the responses, and therefore not every individual response is presented. However, we do not believe that this played a significant role in our findings as the majority of responses were coded. Another limitation is that the needs and concerns of members who do not identify as women are not captured. Still, this survey highlights broad-ranging and intersectional issues in our community, and a multifaceted approach is needed to make inclusive progress for all.

Pillars of Focus for International Women in Biomechanics

Based on our survey results and the existing literature, we defined three pillars of focus for IWB (Fig 3): (i) Member Support, (ii) Community Outreach, and (iii) Empowering Allyship. The Member Support pillar is focused on helping our members succeed personally and professionally. The Community Outreach pillar aims to increase the representation and visibility of women and under-represented genders in biomechanics. The goal of the Empowering Allies pillar is to educate and empower allyship both within and outside our membership.

[INSERT FIGURE 3]

One key finding from our survey was that our respondents prioritized a supportive work environment and that a poor environment is a major factor influencing mental health. Our Member Support pillar runs a Slack workspace, which provides the cornerstone of our activities in this area by offering a space for members to network, seek support, share successes, find collaborators, and disseminate opportunities. Our Empowering Allyship pillar hosts meetings with other biomechanics affinity groups, such as Black

Biomechanists Association (Bell et al., 2022) and Latinx in Biomechanix**,** to discuss and address racial and implicit bias in the workplace.

Another key finding was the need to better prepare biomechanists for their chosen career paths, especially if that is outside academia. Member Support runs virtual monthly meetings, which host speakers from academia, industry, and several biomechanics societies to discuss topics including applying for grants and awards, challenges faced by women in STEM, and careers in biomechanics. These meetings are often open to allies and non-members, and recordings are posted publicly on IWB's YouTube channel. Community Outreach facilitates a blog where members disseminate their advice and opinions on various topics, with several focusing on career and professional development.

The third key finding was that our respondents were concerned about a lack of respect and opportunities in biomechanics because of their gender. To amplify our diverse membership's publications and professional successes, Community Outreach launched a 'Paper of the Quarter', which highlights first-author manuscripts from members, and 'Member Spotlights', which highlight members' science to the broader community. Empowering Allyship is spearheading an effort to establish a learning platform with resources for continued education in diversity, equity, and inclusion. Our goal is to make this important initiative available to the entire biomechanics community so that we can collectively grow towards becoming a world-leading STEM field in this space.

Call to Action

Enhancing gender diversity enables us to better reflect the communities our work serves. Improving gender equity helps men and women (Holter, 2014), and here we ask that everyone educate themselves and act when they can to improve the biomechanics community for all. Below, we share our suggestions regarding positive practices to collectively enhance our allyship for women and other under-represented genders in

biomechanics (Fig 4). We acknowledge this is not a comprehensive list and that there are many ways to make positive change.

[INSERT FIGURE 4]

Local Level (Individual, Research Laboratories, Workplace)

Women consistently face bias in hiring and promotion, which often results in reduced leadership opportunities. In academia, such biases are also seen in peer review and teaching evaluations (Llorens et al., 2021). Thus, putting to action changes that are impactful within our day-to-day environments can lead to a more safe, positive, and productive space for all.

Microaggressions: Microaggressions are everyday comments which can be intentional or unintentional but that communicate negative slights and insults about a person's race, gender, sexual orientation, disability, or other characteristic (Sue, 2010). Common gender-based microaggressions include using inequitable language compared to male colleagues (e.g., women not being referred to as 'Dr.' while male colleagues are, or being described in reference letters based on personality traits rather than scientific ability) (Heilman, 2012). Another is the repeated misuse of a person's pronouns. Evidence shows that male allies can play a key role in reducing the negative effects that result from male-dominated environments by reducing the isolation women feel and by facing less consequences for speaking up in inequitable situations (Moser and Branscombe, 2021). Concurrently, allyship toward all under-represented groups can play a vital role in supporting intersecting disadvantaged and marginalized identities across our biomechanics community.

Mentorship and Sponsorship: Mentors play a critical role in the life of a student or early career researcher. Misuse of a mentor's power can have long-lasting personal and professional consequences, while positive mentoring experiences can substantially increase retention and success (Byars-Winston and Dahlberg, 2019). Further, all scientists can be a sponsor for their

mentees and peers by publicly acknowledging achievements, advocating and nominating individuals for awards, and speaking up against gender bias and disrespect (Chow, 2021). There are several resources for mentors and mentees to develop positive mentor/mentee relationships and for all to develop their sponsorship skills through the National Research Mentoring Network (Sorkness et al., 2017), National Academies of Sciences, Engineering, and Medicine's Science of Effective mentorship (Byars-Winston and Dahlberg, 2019) and more.

Building Peer Networks and Showcasing Diverse Role Models: As noted earlier, evidence supports the power of peer networks and affinity groups to enhance confidence, empowerment and professional skills, and to increase career satisfaction and self-efficacy (Horner-Devine et al., 2016). Mentors can support trainees by encouraging time taken for trainees to foster their peer networks. Further, we also see that representation matters. Showcasing the work of diverse biomechanists in many domains (e.g., in outreach activities, in the classrooms, on speaker panels, and in professional society awards) can broaden views of what it looks like to be a biomechanist.

Institution/Industry Level

Diverse teams bring diversity of thought, which leads to better ideas and practices, and ultimately enhances the quality and reach of programs and environments (Campbell et al., 2013; Page, 2008). For example, social scientists have computationally modeled a problem-solving framework and found a group of diverse problem-solvers can outperform individuals with the highest-ability to solve the problem (Hong and Page, 2004). Thus, enacting equitable recruitment and retention practices are in everyone's best interests.

Anti-bias Training: Current recommendations support anti-bias training as one component of a larger diversity and inclusion strategy within the institution or organization (Carter et al., 2020). If provided, employees need the tools and protected time and incentive to complete this training.

Retention Practices: Studies have specifically outlined ways to improve retention, including pay equity and offering childcare or primary caregiving resources, especially for trainees at the pivotal postdoctoral stage (Ysseldyk et al., 2019). Since the start of the COVID-19 pandemic, four times the number of women have left the U.S. workforce compared to men, primarily due to inequities and structural barriers that systemically have primarily placed childcare responsibilities on women (Reese et al., 2021). Childcare and caregiver policies should be enacted in a manner that protects individuals who can give birth and who are primary caregivers from facing the choice between their careers and their families.

Advancement/Tenure: Some career advancement protocols have been redefined since the onset of the COVID-19 pandemic (e.g., an additional year added to promotional deadline). This shows longstanding practices of tenure and promotion can be malleable. Citation bias and lack of recognition are two interrelated factors that can negatively influence review of a candidate. The 'diversity tax', often used to denote the inequitable service responsibilities placed upon under-represented faculty, is rarely acknowledged by promotional committees (Puritty et al., 2017). Teaching evaluations are commonly weighted for promotion consideration, yet these evaluations have been shown to be biased against women (Chávez and Mitchell, 2020). A multi-faceted approach will be needed to equitably address these issues for all. Several suggestions for policies and programs to retain women in academia include stop-the-clock policies, establishing mentoring programs, addressing childcare needs and flexible benefits, and controlling bias (Law, 2013).

Hiring Practices: Rigorous reviews of current hiring and promotion practices, especially as they relate to implicit bias, can illuminate structural barriers. New models, like Cluster or Cohort Hiring, are being implemented to facilitate community by hiring diverse individuals who share common interests and identities across different fields (e.g., see the U.S. National Institutes of Health Faculty Institutional Recruitment for Sustainable Transformation initiative ("Faculty Institutional

Recruitment for Sustainable Transformation (FIRST)," 2022)). Holistic Review, a strategy currently implemented in many medical and graduate school admissions, is another technique that may be adapted for use in hiring academic faculty to diversify the candidate and new hire population (Harris et al., 2018).

Scientific Society

Many scientific societies are working to improve the environment and culture at annual conferences and society activities throughout the year (e.g., ASB and ISBS have formed Equity, Diversity, and Inclusion committees, others have published guidance for conferences ("Academic Conferences: How to Build Capacity for Equity, Diversity, and Inclusion (EDI)," 2022)). Our biomechanics community will continue to benefit from dissemination and collaboration on initiatives that bolster the careers, growth, and retention of disadvantaged and marginalized identities.

Sexual Harassment Reporting: Scientific societies can capitalize on their authority to develop independent policies in order to address sexual harassment (Johnson et al., 2018). The implementation of transparent codes of conduct, which clearly outline appropriate and inappropriate behaviors, and sexual harassment reporting policies can be used to affect cultural change.

Reward Good Mentorship: ASB recently created an award focused directly on excellence in mentorship (the Jean Landa Pytel Diversity Mentorship Award). Such awards can be initiated and promoted to provide further opportunities to recognize this critical component of scientific training.

Visibility and Recognition of Women's Science: Everyone can play a role in noticing and addressing when representation is lacking for any demographic that a given society purportedly represents (e.g., on panels or in seminar series). Journals can recommend authors use tools like

citation diversity metrics to highlight and quantify disparities in the demographics of cited authors (Rowson et al., 2021). Furthermore, visibility of women's scientific contributions (and those of other under-represented genders) can be increased by evaluating biases in criteria for awards and keynote nominations (Ford et al., 2018).

***Build Community**:* Affinity groups are a place to seek mentorship, observe role models, and obtain resources that promote career success. Many affinity groups are grassroots organizations created out of a need and a hope for a more inclusive field. We encourage our community and all scientific biomechanics organizations to engage with and support biomechanics affinity groups (e.g., IWB, Black Biomechanists Association (Bell et al., 2022), Latinx in Biomechanix).

Conclusions

Biomechanics is, by nature, interdisciplinary. It brings together fields such as Biological Sciences, Engineering, Ergonomics, Sport Sciences, Orthopaedics and Rehabilitation Sciences. Thus, supporting women in biomechanics will strengthen the field and may assist in retaining them at pivotal career points. Looking to the future, the objectives of IWB are to: (i) continue to foster the established IWB community and support the professional needs of its members; (ii) grow our membership visibility with a focus on uplifting members' science; (iii) expand our ally network and offer appropriate resources and/or training to this important cohort; and (iv) implement sustainable initiatives that will ensure the ongoing success of IWB. To get involved as a member or ally, visit our Twitter @intwomenbiomech! We look forward to seeing how the next generation of biomechanists learn, grow, and continue this important work.

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Figure Legends

Figure 1. The International Women in Biomechanics logo, designed by member Nuria Morales Garcia. The IWB mission is to foster an environment where women and under-represented genders in biomechanics can gain support, visibility and allyship. As of July 2022, the IWB community currently

stands at over 650 members (women or under-represented gender in biomechanics) and 40 allies (self-identified IWB supporters).

Figure 2. Profile of respondents (N=144) by geographical location (left) and current position (right) from our internal survey (June 2021). Respondents were from the United States (58%), United Kingdom (13%), Canada (8%), and Australia (8%) with 12 other countries making up the remainder (14%). Respondents were primarily graduate students (42%), postdoctoral fellows (18%), university academic faculty (26%), and industry professionals (7%).

Figure 3. Overview of the three primary needs extracted from the survey results (rectangles) and the three pillars of IWB (circles), as well as the intersecting pillars that we are working to address.

Figure 4. Overview of actionable changes suggested for the biomechanics community at the local, institution or industry, and scientific society level.

Conflict of Interest Statement: The authors have no conflicts of interest to disclose.

Figure 1.

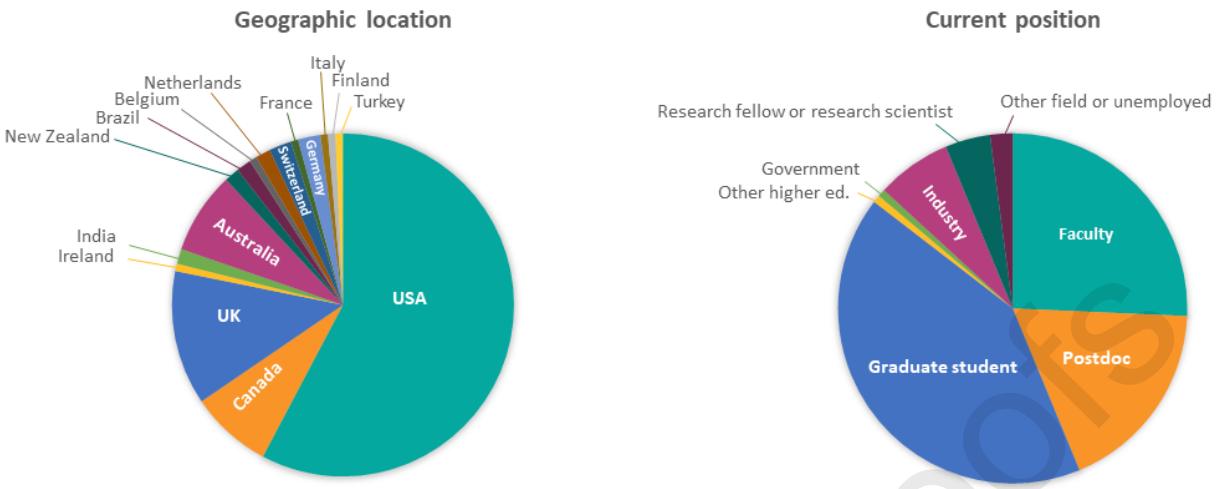

Figure 2.

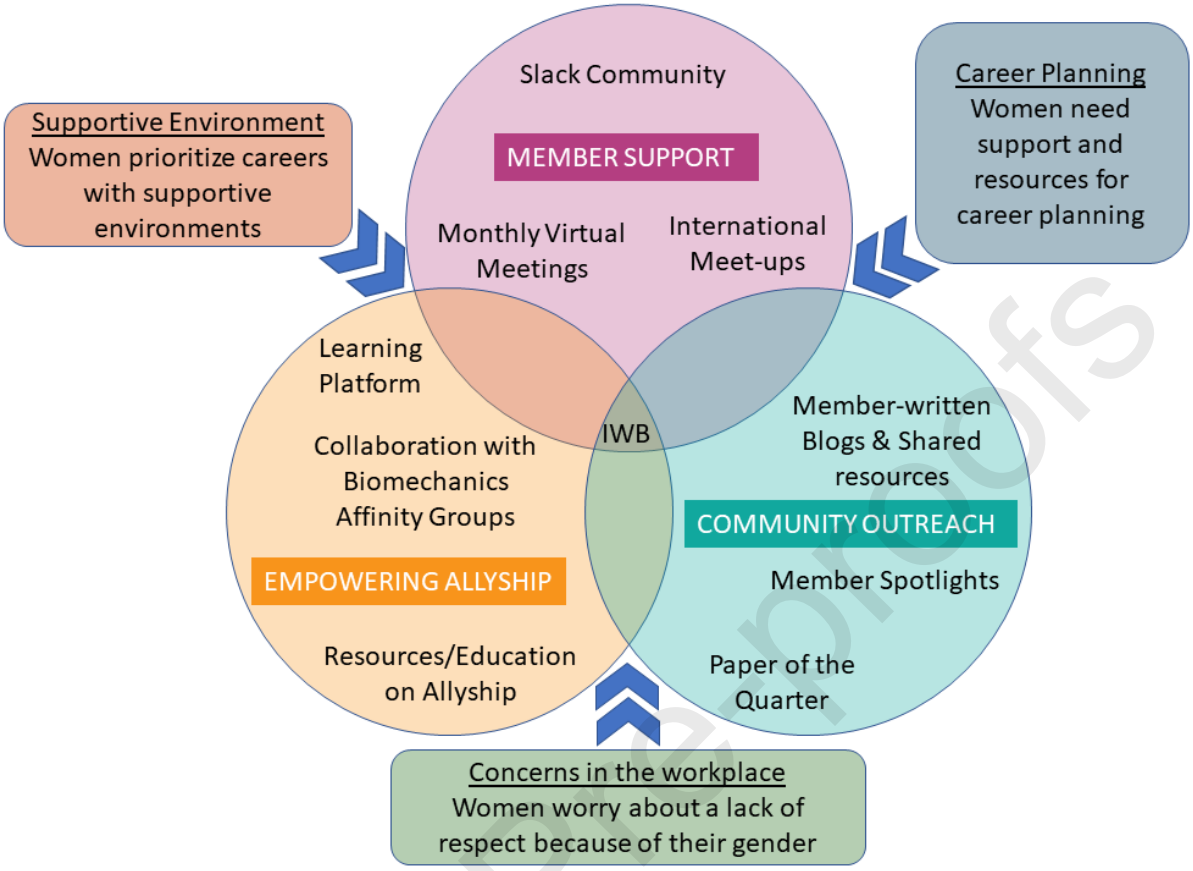

Figure 3.

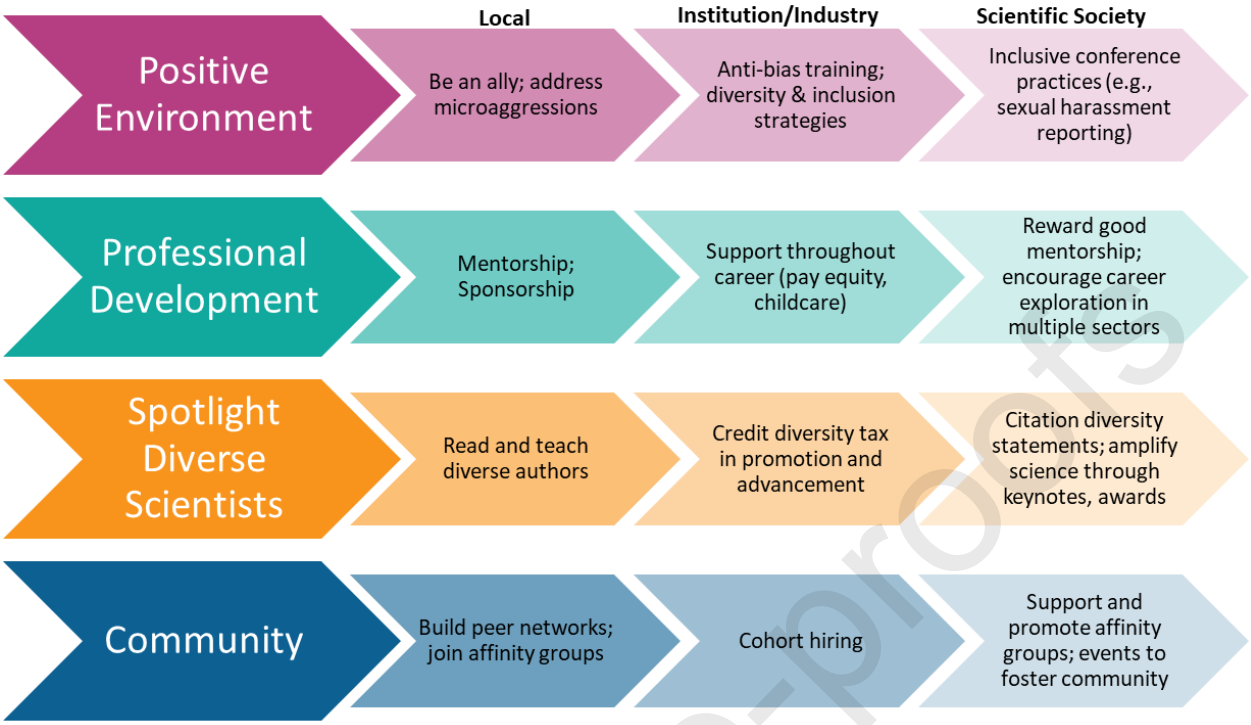

Figure 4.