Invited paper

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Leveraging diversity and inclusion in the polymer sciences: the key to meeting the rapidly changing needs of our world

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Abstract: Diversity, equity, inclusion and belonging (DEIB) will be key to unlocking and accelerating sustainable polymer-based solutions to meet the needs of our rapidly growing world. To achieve faster innovation, we must increase team performance by embracing diversity, ensuring systems and processes within polymer science are equitable and through increased emotional intelligence (EQ), fostering inclusion and belonging. In examining the participation of women and other historically marginalized groups in publishing, intellectual property filings and society leadership, this paper highlights the gaps and the extent of the work needed to close those gaps. Additionally, we provide an opportunity for members of the polymer science community to provide their perspective on DEIB. Polymer science is for everyone and it is imperative for all to be able to make full and meaningful contributions to advance the field. To this end, we provide recommendations for cultivating a more inclusive culture in all facets of the polymer sciences.

Keywords: belonging; centenary of macromolecules; classroom; culture; diversity; equity; high-performance; inclusion; innovation; IUPAC polymer division; meetings; organization; polymer chemistry; teams.

Foreword

Professor Dame Athene Donald DBE, FRS

It is not hard to think of a notable woman involved in the development of polymer science, someone who made an enormous difference: think Stephanie Kwolek, du Pont employee and inventor of Kevlar in 1964. Scratch one's head a bit harder and another inventor, Patsy Sherman comes to mind, inventor of 3M's Scotchgard and a few years younger than Kwolek, although her invention came earlier. Both industrialists. Both pioneering women.

However, polymer science doesn't have many such early role models and heroes – or heroines if that's the language you prefer. At least until nearing the end of the 20th century, numbers remained low. As a relatively young researcher I remember being invited to the Annual High Polymer Conference, back in the days it was held at Moretonhampstead in Devon. I was flattered to be invited – this would have been in the mid-1980s – but somewhat startled to find that there were only two women out of the hundred or so invitees: Julia Higgins and myself. The next time I went, a couple of years later, there were three of us, and two of us were heavily

Article note: A collection of invited papers from members of the IUPAC Polymer Division Celebrating a Centenary of Macromolecules.

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pregnant, which must have seemed a radical departure. Times have certainly changed since then. The continuing conference has a good gender balance, although now it must work on other aspects of diversity.

Considering the number of women who attend is not sufficient: it is also whether they are made to feel welcome, and my experience over the years shows progress has certainly been made on that front too, at conferences around the world. For this specific conference, taken – fairly or unfairly – as a microcosm of the wider polymer world, explicit steps have been taken to ensure better representation amongst both the speakers and the organizing committee, as well as actively seeking to broaden the pool from which attendance is drawn. Nevertheless, there is more to be done.

Bad experiences in the bar are probably common at conferences in any subject and any country. Having an explicit policy regarding behavior may be necessary. Even better if it has some teeth in it. I've had my share of uncomfortable situations, ranging from my science being attacked as 'domestic' science because I worked on starch, to character assassination. I've been pinned to the wall in unpleasant ways, sexual innuendo tossed in my direction, even as a decidedly mature scientist. And if that can happen to me, it worries me greatly about what the younger, more vulnerable women may be enduring. On one occasion, my complaint caused a senior scientist to be banned after entirely inappropriate behavior. And that's how it must be, if everyone is to be comfortable and made to feel welcome.

None of that stops the systemic issues in our daily work: the expectation that women take on more of the 'pastoral' care and are expected to sit on committees to make up numbers, both activities taking them away from the research so relevant to progression and promotion; the biases that seem to lead to women being less likely to win large grants; letters of reference that underplay originality or drive, stressing instead collegiality and temperament. The leaky pipeline – replace with your analogy of choice if you don't like that one – continues to leak at every career stage. This is not down to anything as crude as the pull of motherhood; it is often active discouragement or the feeling the environment in many labs is just too unpleasant for women for them to want to stay. Many of these challenges are not specific to polymer science, but all indicate there is a long way to go before this issue will go away.

Introduction

Since Hermann Staudinger's pioneering research, "Über Polymerisation" ("On Polymerization") [1], was published in 1920, polymer chemistry and physics have ushered in major advances in our quality of life and economic progress. In the first century of polymer sciences, collaborative research was fundamental to rapid advances. From the outset of publications and patents, it was recognized that sharing and building on the research of others was critical to understanding fundamentals and was key to innovation [2]. As the field of polymer sciences continued to grow, so did multidisciplinary collaboration.

In the second century of macromolecular science, today's challenges of transitioning from non-renewable sources and sustainability, require disruptive innovation. To move beyond incremental innovation, we need to be more intentional in ensuring that we foster high-performing teams and organizational cultures where diversity, equity, inclusion and belonging (DEIB) are paramount. Diversity can be inherent and/or acquired and refers to differing perspectives influenced by age, ethnicity, gender identity, mental and physical abilities, mindsets and ways of thinking gained through experience, religion, sexual orientation, socioeconomic background and other factors. Inclusion refers to deliberate efforts, promoting a welcoming environment where different perspectives are respectfully heard, appreciated and individuals feel valued for their unique contributions. Equally important is equity, which includes organizational norms, values and policies. To effectively address world needs by employing the polymer sciences, fair and impartial treatment, equal access to opportunities and advancement, while simultaneously removing barriers to participation is essential. At the intersection of diversity, equity and inclusion is belonging, the feeling of being an important member of the team and the ability to be your authentic self (Fig. 1). Belonging enables individuals to freely contribute to their teams by sharing their ideas and boldly speaking up.

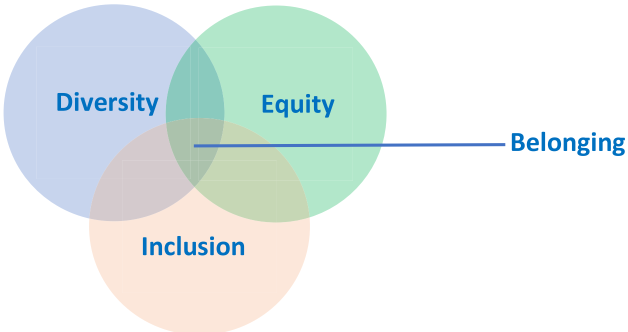

Fig. 1: The relationship between diversity, equity, inclusion and belonging.

When compared to homogeneous teams, diverse and inclusive teams comprised of individuals possessing a strong sense of belonging, generate better outcomes in all facets of the chemical sciences, including academia, government and industry [3–5]. Optimal outcomes achieved by high-performing teams are the result of strategic efforts to foster diversity, equity and inclusion. Faster innovation, complex problem-solving, economic benefits, learning, growth and other desired outcomes are evident when there is diversity as well as equitable or inclusive cultures (Fig. 2). Having both an equitable and inclusive culture, further lowers the activation barrier to achieving optimal outcomes and teams performing in that environment faster arrive at the targeted optimal outcomes (Fig. 2). Additionally, heterogenous teams that reap the diversity dividend [6] work hard to eliminate social exclusion and develop strategies to successfully navigate the challenges of intersectionality [7, 8] in the workplace.

To achieve and sustain innovation in the second century of macromolecular science, diversity, equity, and inclusion must interact synergistically, the result of which will be high-performing teams and organizations, where individuals have a strong sense of belonging. We must work assiduously to develop a carefully planned DEIB strategy, have good execution of said plan and a measure for determining our level of success. Key to developing a robust DEIB strategy is understanding the history of diverse teams in polymer chemistry as this will lay the groundwork for sustainable and forward-thinking improvements. Furthermore, fostering improved DEIB environments requires a multifaceted approach, including understanding and enhancing personal experiences, addressing the implicit biases in promotion, publishing, intellectual property and awards, as well as increasing visibility of scientists from historically marginalized groups. In this perspective, we will provide an overview of DEIB in the polymer sciences and recommendations for building more inclusive cultures that promote the highest level of innovation. We include a balance of personal narratives to provide insights into the experiences of historically marginalized polymer scientists with a data-driven discussion of metrics that

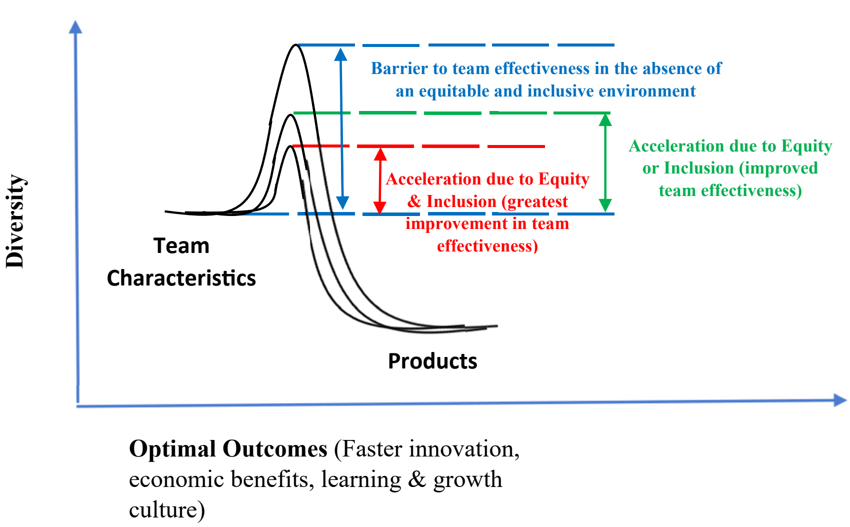

Fig. 2: Catalysis of diversity by equity and inclusion leads to optimal outcomes.

highlight challenges in DEIB in the community to enable understanding at both a personal and operational level. Finally, we conclude the perspective with narratives from young scientists that highlight the excitement and drive for a diverse and strong future for the field.

One hundred years of polymer chemistry

Polymer science is generally considered to be a specialized field of materials science. In recent years, it has experienced a tremendous expansion in depth and diversity through developments in its core domains and interfaces with materials science, supramolecular chemistry, nanoscience, biophysics, and biology [9]. Since 1950, seven (7) Nobel Prizes in polymer science have been awarded, with six awarded in the field of chemistry and one in physics.

The Nobel prize for the discovery and development of conductive polymers, jointly awarded to MacDiarmid, Heeger and Shirakawa in 2000, was a prime example of researchers from various (scientific) backgrounds working together to advance the field. Respectively, MacDiarmid and Heeger, professors in chemistry and physics at the University of Pennsylvania, initiated a collaboration conducting research on sulfur nitride compounds. MacDiarmid, who was born and raised in New Zealand received a Fulbright Fellowship to pursue research at the University of Wisconsin and Heeger hailed from the Midwestern US, his Jewish family having emigrated from Russia in the early 1900s [10]. MacDiarmid connected with Shirakawa when he was a visiting professor in Japan. MacDiarmid attended the Tokyo University of Technology to present work on sulfur nitride compounds and discussed conductive materials with Shirakawa (allegedly) over a cup of tea. When Shirakawa showed him a silvery polymer, metallic shine is generally associated with conductivity, MacDiarmid promptly invited Shirakawa to work with their team on conductive polymers at the University of Pennsylvania for a year. Together, via doping of the polymer, the team achieved formidable increases in conductivity, up to million times. The low-cost, ease of manufacturing and lightweight of the conductive polymers, led to a revolution in the field of flexible “plastic” transistors, electrodes, batteries, and displays [11].

In 1963, the Nobel prize was jointly awarded to Ziegler, a chemist, and Natta, a chemical engineer, for their work pertaining to the chemistry and technology of high polymers. Their collaboration was formed after Natta visited Germany in 1952 and attended one of Ziegler’s lectures [12]. These two examples (and other discoveries not mentioned here) highlight the significance of multidisciplinary teams in their research breakthroughs. The 2019 Royal Society of Chemistry’s (RSC’s) Science Horizons survey claimed that 90 % of researchers in chemical sciences had collaborated with people outside of their own field. While in the 20th century only around a third of Nobel prizes for chemistry were awarded to collaborating researchers, during this century collaborating researchers stands at 85 % so far and is expected to rise further [13]. This drive for interdisciplinary research asks for global action, and the same survey claims that 85 % of researchers have been involved with an international collaboration in recent years [13].

Scientific interdisciplinarity raises performance and is only one aspect that contributes to cultivating diverse teams. And while polymer science might be renowned for interdisciplinary work, there are few examples of well-known polymer scientists from underrepresented groups and/or scientists identifying as female that were a part of these teams as cultural and societal biases limited the participation of women in the STEM for much of the 20th century. Stephanie Kwolek is perhaps one of the best-known women scientists. In 1965, while working at Dupont, she invented Kevlar. For Kevlar and her other contributions to polymer science, she was awarded several prizes, including the Perkin medal, the highest award in American industrial chemistry. In addition, she was admitted to the National Inventors Hall of Fame in 1994. For her research leading to the discovery of Kevlar, a key component of bullet-proof vests, she said, “I don’t think there’s anything like saving someone’s life to bring you satisfaction and happiness”. Other well-known industrial female polymer scientists include 3M’s Patsy Sherman, the inventor of Scotchgard, and Uma Chowdhury, who specialized in ceramic materials and was appointed DuPont’s science and technology officer in 2006. In 2020, the impactful research of other well-recognized women leaders and rising stars in polymer science was underscored by the *Journal of Polymer Science* in collaboration with several Wiley polymer journals [14].

At times, when scientists from historically marginalized backgrounds were able to navigate the organization/institution, their contributions to the advancement of STEM were ignored. In part, this "hidden figures" phenomenon has contributed to the dearth of well-known scientists that identify as members of protected classes. Often, the STEM discoveries and contributions of "hidden figures", mostly women and members of other historically marginalized groups, were unrecognized and thus are missing from books about pioneers in polymer science. In recent years, several STEM "hidden figures" have been unveiled and their work has been recognized for its significant impact in advancing STEM.

Today, while the roster of speakers at conferences is somewhat more diverse and the contributions of historically marginalized groups are becoming more widely recognized through prizes and awards, there is still a long way to go in harnessing and directing the talent of all polymer scientists towards the most challenging problems facing our world. For example, as a teenager, inventor, Kiara Nirghin won the 2016 Google Science Fair for creating a super absorbent polymer that can retain over 100 times its mass. This discovery will revolutionize water conservation. She described the spark of her interest in water conservation as the 2015 drought in she experienced in South Africa. Nirghin lent her voice to the UN Women's Equality campaign, where she stated: "*Role models are so important because they are proof to young girls and aspiring scientists that they too can achieve their dreams*" [15]. Although the COVID-19 pandemic has compounded our efforts towards a more inclusive culture within polymer science and the disproportionate negative impact of the COVID-19 pandemic on historically marginalized groups in STEM is becoming clear [16], we must continue our efforts to highlight the importance of including and fostering the development of all polymer scientists for continued incubation of groundbreaking research in polymer science.

Diversity, equity and inclusion in intellectual property (IP) and publishing

Introduction

In the early years of polymer research, numerous publications and patents were authored by a single or a few researchers. Today, the increase in the number of authors to an average of 5–7 authors and inventors [17] coincides with an increase in the interdisciplinary nature of polymer research. In many scientific careers, publishing and creating intellectual property are key metrics of success and these important performance metrics are used to determine research funding and promotions. Therefore, examining the publishing/IP productivity for polymer scientists over their careers, as well as comparing the publishing/IP productivity of the dominant group to that of polymer scientists that identify as members of historically marginalized groups will be useful in understanding the differences in their career trajectories. Most available data examine only gender-based differences, which we will discuss more here. Although there are gaps in the data due to the limited ability to analyze the intellectual property trends along gender lines for some countries in the Asia Pacific region as a result of low gender inference, limited data for other regions and other reasons, the analyses provide a useful starting point for the development of strategic DEIB plans in IP and publishing. For the future, the ability to dissect the publishing and IP data along other dimensions of diversity would be equally important in understanding and closing the gaps.

Women inventors in STEM

Using data from the European Patent Office Worldwide Statistics Database, the UK's Intellectual Property Office 2019 report analyzed trends in worldwide female inventorship over a twenty-year period (1998–2017) [18]

Worldwide, it was found that female inventorship rose from 6.8 to 12.7 % [18]. Proceedings from a session of the 116th Congress in the United States [19], highlighted a recent paper by the USPTO that shows that the number of women inventors has not increased appreciably since the early 2000s. Additionally, the data that the UK's Intellectual Property Office 2019 report reviewed illustrated that over the 2-decade period, patent applications with at least one female rose from 12 to 21 % [18]. To put this into context, between 1915 and 1975 women made up less than 4 % of all named patent filers. While this might sound encouraging, 69 % of all new patent applications were filed by sole males or all male teams in 2017, whereas only 6 % were from sole female inventors and 0.3 % from all female teams. In addition, when the data was examined through the lens of academic versus industrial research, the proportion of corporate affiliated female inventors (≈10 %) were distinctly lower than academic affiliated female inventors (≈20 %). [18], though more women pursue non-academic careers [19].

Further insights revealed that female inventors were prominent in biotechnology and pharmaceuticals, and as a whole, there were large differences in the proportion of female inventors when the data was parsed by country and by technology area. Examination of the data from the 15 countries with the highest rate of inventorship showed that Russia and France had the highest proportion of female inventors at ≈18 % and ≈16 % respectively, while South Korea (6 %), Japan (6 %) and Germany (7 %) appeared to have the lowest proportion of female inventors. Of note, China, had the most significant increase in female inventorship from 10 % in 1998 to 14 % in 2017 [18].

Focusing the analyses on the countries with the most prolific inventors may cause us to overlook strategies that have been successful at reducing the gender gap in inventorship. For example, as noted by IP Australia, between 1980 and 2016, the number of Australian women named as inventors on patents has increased more than tenfold. In the WIPO technology areas of biotechnology and organic fine chemicals, the percent of filed patents with at least one female inventor is greater than 50 %. For basic materials chemistry, macromolecular chemistry and polymers, and chemical engineering the percent of patents featuring at least one female inventor increased from less than 10 % in 1980 to approximately 40, 42 and 22 % respectively in 2016. This increase in the representation of females named on patents was achieved in part via policy [20].

Though there has been an increase in the number of female inventors over the last several decades, implicit biases, including social and cultural biases, and systemic barriers prevent the full participation of women. To eliminate these barriers change is needed at the individual and organizational level. Coupled with policy, these initiatives may enable sustainable increases in the proportion of women inventors. The report of the proceedings of the 116th Congress in the United States posits that greater inclusion of women and historically marginalized groups in IP would provide economic value to America [21]. Extrapolating to other geographies and all polymer scientists of historically marginalized backgrounds, the impact of inclusion in IP would be expected to have a similar positive and substantial impact on GDP (Gross Domestic Product) per capita.

Participation of women in publishing

Globally, women account for just 28 % of all researchers, however, a more nuanced examination of women researcher's participation in science and engineering will reveal that 20 % of countries have achieved gender parity. When it comes to STEM researchers, countries that have achieved gender parity span the globe and include Argentina, Bolivia, Guatemala, Panama, Trinidad and Tobago and Venezuela in the Americas, Armenia, Azerbaijan, Georgia, Kazakhstan, Kuwait and Thailand in Asia, as well as Bulgaria, Denmark, Latvia, Lithuania and Portugal in the European Union (EU). In addition, New Zealand, Norway and Tunisia have >50 % women STEM researchers [22]. It is thought that the large number of women STEM researchers in Eastern Europe and Central Asia is due to strong support for women's participation in science, especially to pursue research in government-funded facilities. In Nordic countries, social and welfare policies have positively impacted women's retention in STEM careers. Research focusing on women in STEM highlights that there is a gender gap in research productivity and impact, with women publishing less and receiving less citation than men, even in countries that have >50 % of researchers identifying as female [23].

It is widely accepted that there is a gender gap in publishing and to date, many reasons, including the Matthew effect, Matilda effect and other implicit and explicit biases, have been cited for the disparities in productivity and impact (as measured by citations) between women and men researchers [23]. More recently, Hofstra et al. have explored whether the peripheral nature of new conceptual linkages primarily accounts for the lower uptake of novel ideas presented by women and other historically marginalized groups [24]. Further research highlights that persistent biases, such as, women are not as good and cannot do as well at science as men, though debunked, are still widespread [25].

The 2019 Royal Society of Chemistry's (RSC's) report on gender bias in publishing focused on chemical sciences as a discipline but the trends are applicable to the polymer sciences [26]. The report concluded that there are biases at each step of publishing and though in isolation, this might appear minor, together, the combined impact of these hurdles, put women at a significant disadvantage. For example, it was shown that 24 % of all contributions to RSC journals have a woman as corresponding author, which means female authors are less likely to benefit from visibility provided by being a corresponding author [27]. To address bias in publishing, four key areas for action were identified, which included, (1) increasing process transparency, (2) recruiting diverse editorial boards and reviewers, (3) empowering editors to interrupt bias and fostering innovation among editors by providing training and other resources and (4) encouraging intervention by partnering with other institutes and developing a new Inclusion and Diversity Framework. Other publishers have interrogated their own publications, including Elsevier and Nature Publishing, underlining that there is underrepresentation of women as authors, editors, reviewers and members of editorial boards [28–30]. Although the reasons for the gender disparities in publishing are still under debate, in general, most investigations agree that the percentage of females decreases with seniority of authorship [31].

When compared to men, women's reduced access to research funding directly impacts their ability to pursue impactful research. While there is ample evidence on the gender bias in publishing, especially in western societies, there is less evidence available for other protected characteristics [21, 32]. Only recently, the RSC has published data on success rates for fellowships and funding based on ethnic backgrounds and similar evidence is needed for publishing. The Royal Academy of Engineering has acknowledged that a large proportion of case studies focused on gender; their 2015/2019 reports showed that 100 % of respondents indicated there was an inclusion plan that addressed gender diversity whereas only 74 % addressed age/ethnicity and 68 % disability [33]. Additionally, polymer science is a multidisciplinary field and while evidence is available on bias in chemical sciences, this is likely to be higher in engineering since the proportion of female professional engineers is generally lower compared to female professional chemists. This is acknowledged as a particular problem in the UK, which has the lowest proportion of female engineers compared to other European countries [34].

To address the gender gap, strategies to retain women and STEM professionals of historically marginalized backgrounds in science are key. Via the RSC, 35 publishing organizations within scholarly publishing joined together to set a new standard for a more inclusive and diverse culture (reaching beyond gender bias). This group acknowledges that biases exist in scholarly publishing and commit to scrutinizing their processes in order to minimize biases and strive towards a change in research culture. Action points involve setting minimum targets to achieve appropriate and inclusive representation in all stages of the publishing process, in addition to developing resources to improve representation and inclusivity of diverse groups [35].

Power and visibility

Success in a research career requires more than excellent technical skills, it relies on recognition of contributions and visibility in the community. In academia, this is often achieved through national/international awards and leadership positions. Similarly, in industry, it often includes significant internal and external recognition. Thus, is it important when examining diversity in STEM careers that we look beyond numbers of degrees awarded or faculty positions and consider highly visible positions such as society presidents and major awards. In polymer science, there are no comprehensive studies examining diversity in awards and leadership in professional societies, but we were able to find data that enables us to discuss some observations here.

In the United States, the major societies for polymer science involvement are the American Chemical Society (ACS), the American Institute of Chemical Engineers (AIChE), the Materials Research Society (MRS) and the American Physical Society (APS). These four organizations publish their lists of past presidents [36–39] and have provided select press releases for specific milestones, however, they do not publish full data on gender, race or other dimensions of diversity, so we can only examine diversity observationally. We have also included the presidency of the International Union of Pure and Applied Chemistry (IUPAC) and the Royal Society of Chemistry (RSC) in this discussion.

The United States' two oldest societies, ACS (1876) and APS (1899) have had a total of 133 and 124 presidents, respectively, but have only had 13 and six presidents that identify as female. Anna J. Harrison was the first female elected as president of ACS in 1978 and notably, from 2015 to 2017 the society was led consecutively by three women [40, 41]. The ACS and APS have each had two African American presidents, all four being men [40, 42]. Since the founding of the AIChE in 1962 there have been 60 presidents, including six women and two African Americans [43, 44]. The AIChE's 2021 president-elect, Christine Grant, who has a long history as an educator and leader and was recognized with the Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring from the National Science Foundation (NSF), will be the seventh woman and first African American woman to lead one of the four major US societies supporting polymer sciences. MRS (founded in 1973) has similarly low representation of women (8) and African American men (1) that have led the society [45].

Cumulatively, there have been less than 10 presidents of Asian backgrounds in each of these societies (this may not represent an accurate count as demographic data is self-reported). According to her convocation speech at the University of Illinois in 2012, Marinda P. Li Wu described herself as the first Asian-American elected to serve as president of the ACS in 2013 [46]. She was an industrial scientist at the Dow Chemical Company for around 20 years, where she held roles in R&D and Marketing, before founding "Science is fun" and other start-ups.

As an international organization, IUPAC lists the country of origin of each of its presidents, 39 since its founding in 1919, five of which have been from Asian countries [47]. There have been two female presidents and none of African descent in the organization's history [47, 48]. Prior to 1975, women were scarcely represented at all leadership levels in IUPAC [48]. In 1979, Eloisa Mano of Brazil, one of a handful of women, was the National Representative (NR) on the Polymer Division and she served in that role from 1979 to 1985 [48]. It wasn't until 2010 that Nicole J. Moreau of France became IUPAC's first female president. Then in six short years, just prior to the IUPAC's centenary in 2019, Natalia P. Tarasova of Russia became only the second woman to lead IUPAC [47, 48].

There has been progress in representation, especially of women, in society leadership since 2000 and there is still room for improvement. A comprehensive study examining diversity in the leadership of professional societies would be highly valuable in understanding the extent of the challenge and bringing more attention to diversity, equity, inclusion and belonging. Demographic data would aid in analyzing the role that scientists of historically marginalized backgrounds, such as those identifying as Hispanic, LGBTQIA, persons with disabilities and historically marginalized groups in other regions of the world play in leadership at all levels. Additionally, societies have an excellent structure for growing leaders, through conference chairing, division leadership, etc. and can be a powerful opportunity to train a diverse cadre of leaders. Intentional recruiting of persons from historically marginalized backgrounds can have outsized impact on development and future preparation for senior leadership positions.

Another highly visible career outcome is an award, which provides recognition for accomplishments and announcements are typically disseminated to a large audience. There are a few high impact awards in polymer science, including the IUPAC Polymer International Award, ACS Poly Fellows, ACS PMSE Fellows and the APS Polymer Physics Prize, to name a few. The Polymer International Award, which was "established to recognize creativity in applied polymer science or polymer technology" and focuses on awardees less than 40 years of age, has been given to seven recipients, two of whom were women and all of whom hailed from the United States, Europe and Australia [49]. Similarly, the Rennie Memorial Medal, an Australian National Award, given by the Royal Australian Chemical Institute (RACI) to an outstanding early career scientist with less than 8 years of experience has been awarded to six women since the inception of the award in 1931 [50]. RACI has been tracking inclusion and diversity of women in its membership, at its conferences, in its award selection process and the results are published via the RACI Inclusion and Diversity Committee (RIDC) report [51].

The ACS Poly [52] and PMSE fellows [53] honor polymer scientists and engineers for career achievements. The ACS Poly fellows program started in 2010 and has honored 140 fellows to date, with only 20 women. The 2020 fellows class contained no women or members of other historically marginalized groups [52, 53]. ACS PMSE fellows program started in 2000 and has honored 109 recipients, with nine being women. Both programs have less than 15 % female honorees, despite being programs that have been operating at a time when awareness of the importance of diversity and inclusion in STEM has been high. The APS polymer physics prize [54] started in 1960 and has a long history of honoring impactful researchers, including Paul Flory and Pierre-Gilles de Gennes, but there have only been two female awardees since its inception. The 2021 recipient, Samson Jenekhe, is of African descent and he was honored "for pioneering and sustained outstanding contributions to the synthesis, photophysics, and structure-morphology-performance relationships in semiconducting polymers for electronic and photovoltaic applications." [54]

Through observations of this subgroup of polymer-related awards, it appears that the polymer science community has not been able to confer awards in proportions equal to the population of various demographic groups. As diversity leads to better science [55–58], a more in-depth study would be valuable to understand the full picture and help guide award committees and to ensure the recognition of all in the polymer enterprise for their significant contributions. Barriers to people from historically marginalized groups being nominated for awards may include smaller networks, lower understanding of nomination processes, etc. These are barriers that can be readily addressed by the granting agencies through deliberate education and outreach.

Individual perspectives on diversity, equity and inclusion today

For polymer scientists to lead in an increasingly VUCA (Volatile, Uncertain, Complex, Ambiguous) world sustainable, equitable and inclusive environments are important for optimal outcomes. To create sustainable and inclusive environments that will lead to the best scientific advancements and business outcomes, personal experiences are a crucial aspect of any DEIB discussion, as many of the challenges to creating inclusive, equitable environments and aspects of progress cannot be solely captured by numbers. The definition of inclusion and belonging is different for various historically marginalized groups and does vary within different historically marginalized populations. We provide here a set of narratives from polymer chemists located in different regions of the world and who self-identify as members of historically marginalized groups or who led diverse teams. The stories of the polymer chemists highlight that everyone must be included in the conversations regarding the setting and execution of the DEIB strategy as we all benefit from an inclusive working environment. These personal experiences illustrate that while various initiatives provide an overarching framework to improve DEIB in organizations and institutions, granularity is equally important for sustainable change.

Prof. Jarka Glassey – Newcastle University (United Kingdom)

Growing up and qualifying in the then Czechoslovakia, gender balance never entered my mind as an issue. Even studying chemical engineering at University, the gender balance was, in some specialisms, tipped towards females. The first time I ever became aware of any potential inequalities was when the head of department wasn't prepared to 'waste the PhD scholarship on a girl, since they just get married and end up in a kitchen'. That statement spurred me into accepting a position at Newcastle University and completing my PhD and finding employment there instead. Over the years I became more aware of inequalities not just in terms of gender and became involved in my University's efforts to ensure equality, diversity and inclusion (ED&I) is embedded in our daily working lives. We've made a lot of progress, but there is a long way to go still to reach a position, where we genuinely do not need to talk and think about ED&I because it is just part of our normal lives.

Prof. Mark Geoghegan – Newcastle University (United Kingdom)

With more than 20 years as an academic it is easy to be aware of how diversity affects different groups. Coming from a physics background, one often sees white male groups. These are not there because of any overt biases but there is a certain joylessness about all of this because one learns very little about the world and one learns very little about other people. Having an internationally diverse research group brings different social opportunities into the group. It restricts some too, as not everybody can simply go to the pub, but less of a drinking culture is no bad thing. Having an internationally diverse group brings different ideas to the table and different ways of looking at problems. Furthermore, we are a diverse society, and we should reflect that. If we only support white men, then we are implicitly making others feel that they cannot achieve. If a research group has a good male and female balance, then it will attract men and women. If it is all men, then it will attract men. People don't want to feel isolated in a community that does not share their interests or needs. People want to feel like they belong, and an open environment is a welcoming environment. And it is far better to be recruiting the best rather than simply the best of those who look like us. And diversity is not simply about the make-up of our groups, departments, and universities. Polymer science and engineering is global, but with local problems. We can apply our knowledge to problems that don't affect us, for the betterment of humanity. This is not simply a social endeavor. It allows us to use our research tools in hitherto unexplored ways and makes us better at what we do.

Dr. Seumo Patrick – University of Yaounde I (Cameroon)

My name is Seumo Patrick from The Analytical Chemistry Laboratory, University of Yaounde I, in Cameroon. I have defended my PhD at University of Yaounde I in December 2016. My scientific background is in electrochemistry, proteins, silver nanoparticles and polyelectrolytes – in 2019 I was introduced to polymer science to improve my sensors. This was possible via my visit to the research lab of Professor Patrick Wagner at KU Leuven (Belgium), and it allowed me to move my research into the healthcare direction. However, the transfer of this know-how to Cameroon would be difficult since our lab is not equipped with a glove box, or even something as simple as a spincoater. However, this was a great opportunity for me to see how polymers can be used to mimic antibodies or enzyme-based technology. Because of my interest in this work, I pursued another international visit with Dr. Marloes Peeters at Newcastle University (UK). There, I combined my background in electrochemistry for functionalization of electrodes with polymer synthesis for the detection of troponin I, an important cardiac biomarker. While this work does not require a glovebox for instance, the transfer of this "simpler" synthesis to Cameroon is still impossible due to the lack of equipment needed for characterization. To boost polymer science in Cameroon, a step change in infrastructure is needed. Polymer science can address fundamental questions such as water depollution or sensors of clinical biomarkers for tuberculosis and could therefore have high societal impact particularly in developing countries.

Prof. Vanderlan da Silva Bolzani – IQAr-UNESP, member of ABC, ACAL, TWAS and president of the ACIESP (Brazil)

When I was invited to write this brief text, I had two feelings, the first being happiness from being invited to participate and give an overview about diversity and inclusion of women in Polymer Sciences, an investigation area strongly formed my men. In this fantastic initiative dedicated to diversity in chemistry, I believe in new times and trajectories for women in science, worldwide. The second was concern to write about my point of view on gender discrimination if I am happy with my scientific career! However, I accepted the challenge to provide a perspective of the Brazilian women in science, emphasizing the contributions Brazilian women have made to natural products chemistry and to science and technology in general in Brazil. It is very difficult to separate the personal life from the private life of a scientist. As I realized while writing this text, our stories and accomplishments interact in such a way that my career as a researcher and my role as a housewife, mother, professor all contribute to what we, as women, can do for our country and our society. Chemistry is the science of life on the Earth, and thus a wonderful research area for women to work in. Polymers are part of nature and all modern life, and it is so nice see a notable woman involved in the development of polymer science. The article "Historical comparison of gender inequality in scientific careers across countries and disciplines" published in PNAS, March 3. Vol. 117, 2020 (4609–4616) emphasizes that we continue to be underrepresented in most scientific disciplines and publish fewer articles throughout a career, and our work acquires fewer citations. However, I am so optimistic with new times and opportunities, considering the Sustainable Development Goals (SDGs), known as the Global Goals, adopted by the United Nations in 2015 as a universal call to commit to ending poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. Included in the 17 objectives, no. 5 is related to gender equality. I believe in a world where men and women work together for a sustainable world for future generations.

Prof. Melissa Chin Han Chan – Universiti Teknologi MARA (Malaysia)

Women's glass ceiling in Malaysia

Global Parity Index (GPI) denotes a ratio of the number of females over the number of males. A GPI < 1 represents a disparity in favor of males, while a GPI > 1 represents a disparity in favor of females. When the GPI is at 0.97–1.03, it indicates that gender parity has been achieved.

There are 20 public universities currently operating in Malaysia. In 2013, a review of the undergraduates in these universities showed five universities with 1.5 < GPI < 1.99 and eight universities that had a GPI of over 2.0, indicating that female undergraduates more than double their male counterparts in those universities [59]. These values of GPI are far from an anomaly. A 2018 review of the graduates from the public universities found that the GPI was 1.85 [60].

The 2016 Ministry of Education Report [61] indicated that women comprised 54.3 % of the academic labor market in Malaysia. These women academics are from both private and public universities, University College, college, polytechnic and community college; and their job scope ranged from teaching to research. However, in the context of senior positions of women academics, there's an upward trend in the absolute number of woman professors at the public universities from 9.6 % (1997) to 16.9 % (2000), 22.1 % (2004) [62] and 30 % (2016) [61].

We are still waiting for the first female president of the Malaysian Institute of Chemistry, which is a statutory professional organization incorporated under the Chemists Act 1975 on 1st November 1977. The Chemical Industries Council of Malaysia (CICM) was established and incorporated in 1982. Currently, CICM is the umbrella body representing the various sub-sector chemical groups (ranging from oleochemicals, paints, fertilizers, petrochemicals, agriculture chemicals, industrial gases, coating resins and biodiesel sectors). The affairs of the Chemical Industries Council of Malaysia (CICM) are governed by 10 Executive Committee

Members and up to 10 Honorary Members consisting of the Chairmen/Presidents of the sub-sector chemical groups in Malaysia. For the 2019–2021 term, all the 10 Executive Committee Members are male and there is only one female in six Honorary Members.

The “lost boys” phenomenon has been critical in public universities since 2000, however, because women are still underrepresented in top management positions in universities, professional organizations as well as industries it illustrates that women’s glass ceiling is still unbroken.

Summary and future outlook

Over the first century of polymer science, scientists made stellar individual and group contributions in the design, preparation, characterization and applications testing of polymers that have advanced our quality of life. In our daily lives, polymers are ubiquitous and their utility ranges from basic uses to biopolymers and therapeutic polymers. Since the development of semi-synthetic derivatives of cellulose, rubber and silk, as well as the first synthetic plastic, Bakelite, several noble prizes related to polymer sciences have been awarded in chemistry and physics.

Looking forward, there is growing recognition, especially within the last year that for organizations to thrive and provide the best solutions for a sustainable future through chemistry, we must move beyond diversity [63, 64]. Equitable and inclusive organizational cultures will provide the requisite environments for unlocking creative solutions to address the urgent needs of a rapidly growing world. We each have a unique role to play in the transformation to more equitable and inclusive cultures within the polymer sciences. In the second century of polymer sciences, we posit that scientific excellence can only be built with inclusive leadership as a foundation. Polymer scientists and engineers in every sector and at every level have a sphere of influence and as such inclusive leadership at every level and stage of development is essential. Inclusive leaders are visibly committed to diversity, equity and inclusion in the polymer sciences and share several key signature traits [65, 66]. These traits include but are not limited to:

- Self-awareness, including implicit/unconscious bias awareness: Understanding ourselves better, that is our strengths, weaknesses, how we show up and our blind spots will help us to better interact with our colleagues, make better decisions and productively manage conflict. We’re all hardwired for bias. Cognizance is the first step in addressing our biases and limiting their influence on our thoughts and behaviors. There are several tools available to help us in becoming aware of our biases and an instrument such as the Implicit Association Test (IAT) is a useful tool to promote awareness of our biases.
- Curiosity: Openness, practicing perspective taking and being comfortable with ambiguity are hallmarks of curiosity that define inclusive leadership.
- Effective collaboration: Inclusive leaders’ express appreciation for their colleagues’ contributions/feedback, engage in purposeful dialogs and are versed in productively and creatively resolving conflicts that will arise when extracting the maximum benefits of neurodiverse environments.

Inclusive classrooms and meetings [67, 68] are led by inclusive leaders and are psychologically safe environments that promote learning and innovations. In these brave and inclusive group settings, participants feel empowered to make their best contributions and are comfortable speaking up. Additionally, the ideas of all polymer scientists, in particular women and people that identify as members of other historically marginalized groups are amplified and not hijacked, and participants are engaged until the end of the session. At the outset, there will likely be a level of discomfort experienced by participants engaging in inclusive group discussions. It is important to note that the productive conflict generated from truly inclusive conversations is a significant criterion for innovation and is distinct from psychological danger. Bias interrupters [69] that are deployed by Allies and liberating structures [70] are among the many tools that can help us to achieve inclusivity in meetings and the classroom.

Inclusive organizations promote systems and practices that support diversity, equity, inclusion and belonging among its members, partners and within the society at large. Systems and practices supporting DEIB address hiring, employee development, training, performance reviews and promotions [66]. Providing resources that individuals are able to access in order to foster their development as inclusive leaders and for them to effectively lead a team, mentor and sponsor others is key and these must be deployed in concert with systemic changes to capture the diversity dividend. In organizations and institutions, too often the focus of diversity and inclusion is implicit bias trainings, holding listening sessions, creating employee resource groups (ERGs) and appointing a head of diversity and inclusion, among other actions along a similar vein. As important as these actions are, without coupling them with audits of internal systems and removing the barriers for historically marginalized groups, institutions and organizations will find it difficult to remain competitive in our rapidly changing world. The RSC's Inclusion and Diversity Team's recommendations [26] and the IPO Women in IP's Gender Diversity in Innovation Toolkit [71] provide insights and actionable steps to close the gap in publishing and patent filings between historically marginalized and dominant scientists and underscore the important role that managers have in these endeavors. Additionally, there is a crucial role for professional organizations to play in promoting DEIB in polymer science and the STEM enterprise as a whole and we would be remiss if we didn't mention the critical role that policy has played in helping select countries in Eastern Europe, the Asia Pacific region, the Middle East and Africa as well as the Americas achieve gender parity [22], especially at the university level. Policy focused on creating a more inclusive environment for professionals in all sectors that utilize polymer science would be complementary to the individual and organizational actions.

Building an inclusive culture [72] that yields maximum return on investment (ROI) in the form of higher engagement and faster, more innovative problem-solving requires individuals, teams and organizations to examine possible hidden inhibitors to DEIB, the most common of which are competing priorities. Once all the other facets of creating a diverse, equitable and inclusive environment have been addressed, we should consider whether our individual or collective "immunity to change" may be impeding our progress. In their book, "*Immunity to Change: How to Overcome It and Unlock Potential in Yourself and Your Organization*" [73], Kegan and Laskow Lahey provide a helpful framework and useful language for exploring our unconscious assumptions that often hinder change on an individual and organizational level. Furthermore, it is imperative for organizations to have a clear vision for DEIB, a well-communicated strategy and the ensuing specific, measurable goals that will facilitate the organization's vision becoming a reality. Social scientists have long studied organizational behaviors and possess insights that will enable more inclusive organizations and accelerate a more sustainable future through polymer science. Learning from and partnering with social scientists within and external to organizations could foster the growth of inclusive cultures.

Finally, in her perspective, Prof. Vanderlan da Silva Bolzani mentioned that she is happy with her scientific career. We recognize that for every highly successful polymer scientist that identifies as a member of a historically marginalized group, there are countless others for whom the barriers to full participation have been or continue to be insurmountable and as a result, they have not had the opportunity to live up to their potential and make their most significant contributions to the advancement of polymer science and other STEM fields. We are aware that the associated emotional tax of being an "only" or one of a few polymer scientists that identifies as a member of a historically marginalized population has had detrimental personal impacts which cannot be fully captured here. Continue to seek out and build supportive communities of Allies, mentors, sponsors as well as proteges from historically marginalized backgrounds with whom you can share your story and together advocate for change. As highlighted by the young investigators, Drs. Joel H. Bombile, Scott Danielsen and Allison Goins, in their perspectives below, polymer science will continue to be essential in addressing challenging world needs and diversity, equity, inclusion and belonging is crucial for success. Recent events have begun to transform our collective potential energy to kinetic energy. Let's not lose momentum and put the kinetic energy to positive work!

Perspectives on the next 100 years of polymer science

We close this article with perspectives from three up and coming polymer scientists who identify as members of historically marginalized groups. We asked them, the future leaders who will drive impactful progress, to tell us where they think the field of polymer science is going in the next 100 years. Specifically, we asked them to reflect on the following: (1) how they see diversity and inclusion shaping polymer science in the future as we tackle the world's biggest challenges and (2) what do they look forward to the most when they envision the future of polymer science. To create an inclusive field that allows each of us to become our best selves and makes our maximum contributions, we must align on the vision of the future and the starting point for alignment is inclusive conversations [74].

Dr. Scott Danielsen, Postdoctoral associate, Duke University

Over the last century, polymer science has progressed from the production of rubber to commodity plastics and finally to the current gamut of functional materials. As polymer research has expanded across many industries and applications, so too has the diversity of those researchers. Looking towards the next century, I hope polymer science continues to answer fundamental questions, expand into new functions, and grow the diversity of our community. Our field, like many others, has cherished examples of lineage with members of a family working in similar areas, speaking to a shared intellectual spark. Likewise, it is more important than ever to strive to treasure the new voices, particularly those underrepresented in our field's past including first-generation graduates, those with non-traditional families, and societal minorities.

Our research is not just science, but a chronicle of our personal discovery, bursting with curiosity, persistence, and passion. Inclusion of this individualism needs to be the light guiding the future of polymer science. Correspondingly, I see *individualized* polymers as our scientific future: responsive on demand, sequence-specific functionalities, morphologies, and dynamics. We're at the advent of connecting the single (macro)molecular behavior to the collective properties of the statistical ensemble. Harnessing the tunability of the molecular structure and interactions to tailor material properties will continue to drive applications to address humanity's largest challenges. Part of our communal challenge will be resolving the issues of our past, including mitigating our environmental impact of single-use plastics and reducing the barriers to participation in our future.

Dr. Allison Goins, science communicator, relatable science

I think that diversity, equity, and inclusion's most significant role in the future of polymer science will be its necessity to inform our approaches to developing new materials and solving challenges with current materials. Issues like climate change and the effects of one country's consumption habits on another country's economy, ecology, and citizens' well-being are pressing challenges. As polymer scientists, we must include diverse voices and opinions in our development processes to ensure we are positively affecting the worldwide ecosystem. From communicating our work in ways that engage everyone; to providing platforms and support to people from historically underserved populations, the future of polymer science will be brightest if it is inclusive, equitable, and diverse. I believe polymer science is moving into an era of not only discovery and development but also sustainability and social responsibility. I am looking forward to seeing the unique and exciting materials developed from renewable resources and innovations in recycling and repurposing current single-use products. I am also excited to see the continued incorporation and development of polymeric biomaterials in tissue engineering and regenerative medicine applications with the hopes of regrowing functional organs one day. I gained an appreciation and love for polymers as an undergraduate student that has impacted and influenced my life in so many positive ways. I hope creating a space that makes polymer science accessible and engaging, will encourage others to become invested and work towards solving new challenges that arise.

Dr. Joel H. Bombile, Postdoctoral scholar, University of Kentucky

Diversity and inclusion of different social groups within the polymer science community is not only morally imperative based on equity, but also essential for enhancing discoveries while we tackle the world's most pressing challenges. It is well established that promoting more socially diverse groups within scientific organizations improves creativity, as teams have different perspectives to problems and are more likely to consider alternatives [55, 56]. Another benefit of diversity and inclusion is that individuals from underrepresented groups bring to the field passion to pursue personally relevant research, which broadens science and makes it more meaningful for the community [57].

I grew up in the Democratic Republic of the Congo, where eight in 10 people do not have access to electricity. This has fueled my interest in developing polymers for energy conversion and storage applications. A prospective outcome of this research are flexible, light weight and low-cost photovoltaic devices, which will enable broader access to electricity for millions of underserved people around the world, many of whom are in situations where silicon-based solar panels are not practical. In turn, the science and knowledge derived from such focused research moves the field forward [58].

Just as the recent trend of interdisciplinary research in polymer science broadened the reach of the field and led to rapid progress on many fronts, diversity and inclusion will enhance innovation, enabling effective solutions to the many challenges that humanity faces. It will also ensure that these solutions reflect contributions from various social groups and that underserved communities are not overlooked.

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