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EDITORIAL

Organic Chemistry: A Retrosynthetic Approach to a Diverse Field

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This editorial was written by junior faculty members in the summer months of 2020 during a confluence of global events. While facing a worldwide pandemic, we began to confront the ways that a racist, sexist, and xenophobic culture continues to shape our field. We came together at first not to write an editorial, but to find a sense of community, forming a cohesive peer-mentoring network during social isolation at the onset of the pandemic. While we identify with distinct academic and personal backgrounds, we found solidarity in conversations discussing our independent careers, how they abruptly changed, and how to mentor and support our students in the wake of social unrest. The publication of the Hudlicky perspective amidst magnified Black Lives Matter and LGBTQ+ movements, along with overt white supremacy and unjust immigration policies, triggered a swift and uniformly strong reaction among us. Many of us have been victims of the destructive norms that pervade our field; all of us have witnessed them in practice. We unanimously agree that they must not be a part of our future. What we wish to share is our thoughts on how we might change the organic chemistry community for the better as a collection of steadfast voices. In doing so, we join with many of our colleagues in condemning exclusionary and inequitable traditions. Yet, our position as rising leaders in this community demands an even greater responsibility to future generations of scientists, work that we joyfully take up to honor the commitments of the mentors, families, and friends who have lifted us up to where we are now. Each author of this Editorial commits to making a positive change in their group and at their school, and we will hold each other accountable over the course of our careers.

TOWARD A DIVERSE ORGANIC CHEMISTRY FIELD

Organic chemistry benefits society in profound ways, yet the composition of scientists in the field does not accurately reflect the diverse communities we serve. A significant portion of the chemistry talent from college is not retained in the workforce.[1] This population includes women and Black, Indigenous, and People of Color (BIPOC) along with other underrepresented groups and those with invisible identifiers (e.g., first generation, immigrants, low socioeconomic status, LGBTQ+, and/or scholars with disabilities). Numerous studies have documented the disparities that exist in salary, recognition, and awards between men and women;[2−7] this inequality is further exacerbated for those with intersectional underrepresented identities (e.g., women of color and Black transgender scientists).[8,9] Our field's limited diversity has long been anecdotally attributed to lack of student interest, ability, or commitment without examining the historical biases within organic chemistry that dissuade potential scientists.

Herein, we, a diverse group of junior faculty in organic chemistry, reflect on the toxic aspects of our field's culture and offer an optimistic vision for the future that embraces diversity, equity, and inclusion (DEI). Research has shown that diverse teams lead to greater innovation,[10−15] but striving for DEI is also a moral imperative because any other scenario is unjust. We use a retrosynthetic approach to identify ways to achieve that goal and emphasize that *being inclusive and rigorous are not mutually exclusive*. Lastly, we make a commitment to effecting positive change in our own groups and academic communities that we hope will inspire others to do the same.

For far too long, systemic racism, white supremacy, sexism, and other overt discriminatory practices have created barriers

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for entry into organic chemistry. Many laboratories have preserved hierarchical power structures wherein racially charged slurs and sexual harassment are ignored. Organic chemists have tolerated an unhealthy work environment, where working long hours at the sacrifice of mental and physical health was accepted as the "nature of the work."[16−20] Cultural norms encompassing a "master" and "apprentice" have reinforced arbitrary metrics for academic rigor, such as quantifying the number of working hours per week,[21] reactions or columns run, and/or notebook pages completed. Moreover, the expectation that personal boundaries will dissolve to accommodate advisors' needs further impairs our ability to retain STEM talent.[21] While persistence, dedication, and resilience are necessary virtues for pursuing a Ph.D., evaluation obsessed with quantity rather than quality promotes a lifestyle for students in which many suffer from extreme sleep deprivation, anxiety, and/or depression.[22−24] Group meetings and qualifying exams that feature public berating for not knowing the name of a reaction or mechanism engender feelings of isolation and worthlessness for students. Yet, these practices have remained pervasive in earning one's stripes as a "true organic chemist".

Our vision begins by recognizing that the organic chemists of this and future generations should be diverse. The normalized picture of an older white gentleman at a benchtop—distilling liquids night and day without social interaction—no longer encapsulates the essence of who an organic chemist is and what an organic chemist does. We, as organic chemists, embody a range of identities. We are responsible for not only research, but also for communication and dissemination of knowledge. Rather than do this in isolation, we work in research groups, teach, attend conferences and meetings, and socialize with peers. We are human. We have unique life experiences, perspectives, and interests. And yet, we are united by our passion for synthesis and the exquisite beauty of orchestrating the architecture of molecules.

Despite a historically pinpointed focus on architecturally complex natural products, contemporary organic synthesis has expanded to include biomedically relevant macromolecules, polymer science, biocatalysis, nanochemistry, and computationally-guided synthesis, among others. In the same way that organic chemists are multifaceted, we must accept that organic chemistry is no longer just applied to natural product synthesis; even the goals and philosophy of total synthesis have diversified. Elevating a single interest area over another hinders innovation, as embracing new directions in organic chemistry has greatly benefited our field.[25] We commit to training the next generation of chemists in a more holistic way that emphasizes all of our strengths. In our vision for organic chemistry, our field will not be afraid to replace destructive traditions with healthy, new norms. The end result: a discipline in which embracing diversity leads to the most creative century of science our field has witnessed.

A RETROSYNTHETIC BLUEPRINT TO IMPROVING DEI IN ORGANIC CHEMISTRY

Arguably one of the most important contributions to synthesis lies in the principles we use to deconstruct molecules: retrosynthetic logic. This transformative concept is a long-standing framework for complex molecule synthesis wherein routes are designed with the target in mind. Integral aspects of successful retrosyntheses include artistic freedom, biomimicry, and/or the display of a newly developed chemical transformation. Over time, the emergence of new bond disconnections has enabled progressive solutions to grand challenges. Across all retrosynthetic approaches, a series of measurements are used as "self-evaluation" from a novelty and efficiency standpoint, including step, atom, and redox economies. Even the concept of retrosynthesis is inclusive and has been extended to a diverse subset of syntheses: crystal engineers model supramolecular synthons, solid-state inorganic chemists use retrosynthetic logic to design complex nanoparticles, and materials scientists conceive innovative architectures using discrete retrons. Indeed, molecular architects using retrosynthesis have a vision in mind, and careful selection of constituents leads to convergent routes to obtain the target.

Given the widespread implementation of the logic of "starting from the end" in organic chemistry, perhaps any complex target can be "deconstructed" into smaller building blocks using retrosynthesis. For instance, a vision to advocate for DEI in organic chemistry[10,12,15] requires identifying what steps lead to the most convergent path and what intermediates lie along the route. What would the starting materials in a convergent path be? Here, we identify our starting materials: (i) increasing awareness; (ii) improving approachability of organic chemistry; (iii) teaching inclusively; (iv) providing both mentorship and sponsorship; and (v) building communities (Figure 1).[26] While these starting materials are complex, it is important to recognize that they are readily accessible, meaning *we can work with these today to carve a path forward*. After developing an inclusive work environment that espouses optimal methods toward retention and recruitment, we can build efficient convergent routes toward the target of DEI in organic chemistry.[27] We detail below methodology in which individuals can access these building blocks and empower diversity of personnel, backgrounds, and research.

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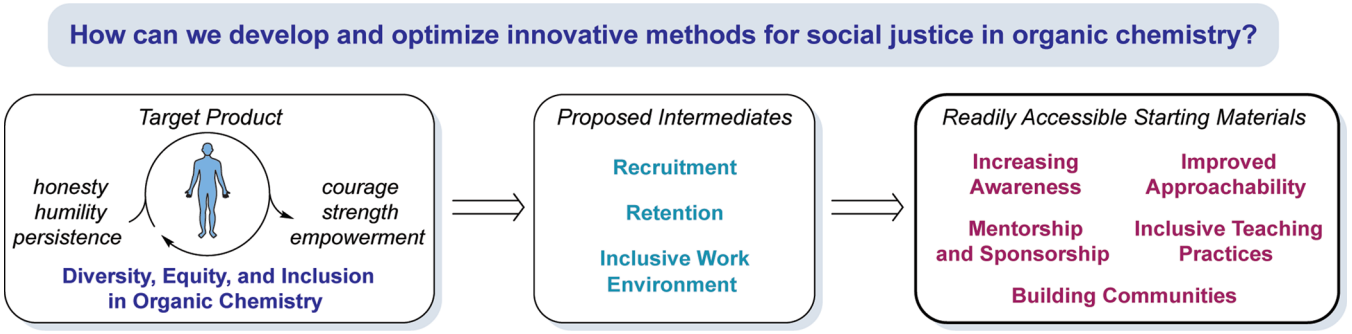

Figure 1. Retrosynthetic approach toward diversity, equity, and inclusion (DEI) in organic chemistry.

I. Increasing Awareness. To improve the culture of organic chemistry, we must increase awareness of the widespread challenges that exist for underrepresented scientists. Ignorance and denial of these issues exacerbates the problem and prevents effective solutions, but passive acknowledgment without action can be equally destructive. It is therefore important that we understand how our individual, informed actions can contribute to positive change.

As practitioners, teachers, and leaders in organic chemistry, we must recognize our position of power and influence on students and colleagues. First, we must own the current state of our field by identifying actions or inactions that contribute to the toxic culture. Next, we must use our authority to positively shape our groups. Similar to our emphasis on safety in the laboratory, we must commit to regular DEI education, which will help broaden each person's awareness of the barriers that exist within our field. We will increase awareness by

- Educating ourselves through resources[28] from experts in advocacy of DEI in STEM
- Listening to personal accounts and amplifying the voices of diverse chemists (e.g., invited seminars, featured research in group meetings, safe spaces for reflection)
- Encouraging participation in and serving as faculty mentors for groups that promote inclusivity
- Implementing equitable institution-specific policies
- Stimulating consistent discourse on DEI problems, effective solutions, and community buy-in

II. Improving Approachability of Organic Chemistry. Organic chemistry has historically been an exclusive club because systemic racism, sexism, and overt discrimination have long created higher activation barriers for marginalized scholars. Identifying and dismantling these obstacles are critical to improve approachability and build a field that welcomes diversity, including race, country of origin, sexual orientation, gender identity and expression, ability, and socioeconomic status. We commit to confronting known barriers[29] that perpetuate exclusivity by

- Propagating inclusive application policies (e.g., removing GRE requirements[30] and fees)
- Forming meaningful partnerships with national organizations (e.g., NOBCChE, SACNAS, AISES, EWOC, CWIC, and oSTEM)[31] and their constituents to engage students outside of traditional pipelines
- Offering flexible work hours
- Ensuring students receive a competitive living wage
- Advocating for cluster hires to cultivate a sense of belonging and mitigate homogeneity
- Expanding the definition of organic chemistry by championing interdisciplinary research and encouraging collaborations

III. Teaching Inclusively. As educators, we are committed to using inclusive teaching strategies that consider the diverse backgrounds, perspectives, and lived experiences of the student body as a framework to develop curriculum, class activities, and assessments.[32] Inclusive teaching can generate a greater sense of community and engage underrepresented students. Here are some proven strategies to make our classrooms more inclusive and reflective of the contributions and scholarship of diverse scientists:

- Emphasize the broader impacts of organic chemistry through culturally relevant topics to develop the identity of our students as chemists[33,34]
- Incorporate social justice issues into discussions (e.g., history of hazardous chemical exposure to vulnerable populations)[35−37]
- Utilize active learning strategies, such as peer-led team learning and collaborative learning[38,39]
- Employ varied and equitable methods of assessment, such as specifications or mastery-based grading models[40,41]

IV. Providing Both Mentorship and Sponsorship. Mentorship (i.e., guidance) and sponsorship (i.e., advocacy) are critical for retaining minoritized scientists. Compassionate and effective mentors and sponsors can help these scientists achieve success.[42,43] Our ability to support our mentees should not be restricted by our identities and

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should extend beyond our own classrooms, groups, departments, and institutions. Our commitment to unbiased mentorship and sponsorship will involve:

- Identifying and calling out bias within our groups, our departments, and our field
- Empowering mentees to follow their career paths and professional goals using individual development plans, even when these goals differ from our own
- Identifying and seeking unique opportunities for professional development and networking that are in alignment with our mentees' career aspirations
- Evaluating individuals based on progression, establishing expectations, and revisiting them regularly
- Actively supporting and nominating underrepresented scientists for awards and advancement
- Refereeing conflicts and being an ally for students in vulnerable situations
- Championing peer-to-peer support, mentoring, and teamwork

V. Building Communities. Building supportive learning communities is vital to retain a diverse workforce. Each individual faces challenges (e.g., mental health, childcare, disability, discrimination) of which we may not be aware. Therefore, it is our responsibility to create an inclusive environment where everyone can thrive. Such teams founded on mutual respect emphasize that the whole is greater than the sum of the parts. Our philosophy is incompatible with the historical master−apprentice hierarchy. Instead, we commit to build communities by

- Practicing compassion in interactions with our mentees
- Replacing microaggressions[44] with microaffirmations[45]
- Normalizing life outside of the laboratory by taking time off and actively promoting extracurricular activities and affinity groups
- Placing an equal emphasis on mental and physical health
- Discouraging unhealthy intra- and intergroup competition
- Allowing team members to freely develop into independent scientists

SYNTHESIZING A DIVERSE AND INCLUSIVE FIELD

Achieving our long-term vision will require humility, honesty, and courage—traits that are already essential to our work as scientists. Chemists are accustomed to the humility of a failed experiment that "worked on paper." These "failures" often precede the serendipitous discoveries that propel our field forward; yet, they only reveal themselves when we honestly accept that our prior knowledge was incomplete. Similarly, to engage in collaborative science requires the courage to admit that our individual expertise has limits. The same virtues that enable us to address complex research problems can be applied to the grand challenge of reshaping the chemistry landscape to reflect the richness of humanity. For this reason, we believe our field is poised for transformation.

Our plan to realize lasting change in the chemistry community is *both a pledge and a call to action*. In every facet of our roles as PIs, we commit ourselves to inclusive excellence by building truly diverse departments that place an equal emphasis on scientific scholarship and the dignity of its members. Even so, we acknowledge that our own training within a flawed system has left us with implicit biases and habits that demand reevaluation. In isolation, our commitments are not enough; it is imperative that such efforts are collaborative and anchored within a network of collective action so that the burden of change does not fall on the few. The task at hand is much like the practice of total synthesis: a recursive process that rarely proceeds without failure, critical revision, and inspiration from collaborators. The most "expedient" or "elegant" syntheses are often achieved by merging independent efforts. Indeed, the diversity and multiplicity of routes to a single product represent the beauty of this enterprise. *Our ideas on how to seek justice by changing the culture within our organic chemistry community may be merely a starting point, but we will proudly lead the charge, and we invite you to join us.*

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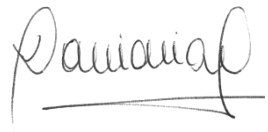

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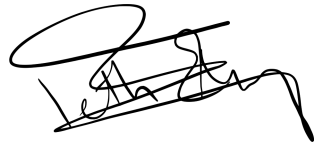

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Notes

Views expressed in this editorial are those of the authors and not necessarily the views of the ACS.

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