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Sneddon, Helen orcid.org/0000-0003-1042-7692, Martinez, Isamir, Steven, Alan et al. (9 more authors) (2025) GChELP: A Vital Resource for Teaching Practical Green Chemistry in Industry and Academia:In celebration of the 20th anniversary of the ACS Green Chemistry Institute Pharmaceutical Roundtable: leading the way for green chemistry and engineering implementation. ACS Sustainable Chemistry & Engineering. ISSN 2168-0485

https://doi.org/10.1021/acssuschemeng.5c00379

ACS Sustainable Chemistry & Engineering
pubs.acs.org/journal/ascecg

Perspective

GChELP: A Vital Resource for Teaching Practical Green Chemistry in Industry and Academia

In celebration of the 20th anniversary of the ACS Green Chemistry Institute Pharmaceutical Roundtable: leading the way for green chemistry and engineering implementation

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Cite This: https://doi.org/10.1021/acssuschemeng.5c00379 Read Online

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ABSTRACT: Over the past three decades, there has been a significant increase in the creation and implementation of curricular materials that emphasize green chemistry. While these materials are slowly proliferating in undergraduate courses in higher education, there remains a critical knowledge gap in two key groups: graduate students and chemists in the workplace. Chemists in these groups may not have access to training in green chemistry at any point in their academic training, limiting their readiness to meet industry standards that now include knowledge of green chemistry. This perspective emphasizes the need for more graduate and professional training in green and sustainable chemistry and collaboration between academia and industry to evolve a curriculum that better prepares students to meet employer expectations. The latter requires new curricular resources, which are accessible to advanced undergraduates, graduate students, and chemists in the workforce. The American Chemical Society (ACS) Green Chemistry Institute Pharmaceutical Roundtable (GCIPR), a 20-year collaboration between the ACS Green Chemistry Institute (GCI) and more than 50 companies to advance green chemistry in the production of active pharmaceutical ingredients and related chemistries, shares herein the development of a web-based resource for training in practical green chemistry techniques, the *Green Chemistry and Engineering Learning Platform* (GChELP). The free resource consists of training modules that cover green chemistry fundamentals, synthetic reagent guides and green chemistry metrics, selection of greener solvents, a synthetic toolbox, principles of process design, and life cycle impacts. Potential uses of the resources by academia and industry are described, with an emphasis on the need to continue development of resources that meet the needs of chemists in the workforce as well as those still in academic training.

KEYWORDS: *green chemistry, sustainability, industry−academia collaboration, professional development, pharmaceuticals, workforce training, web-based learning*

INTRODUCTION: EVOLUTION OF THE GREEN CHEMISTRY CURRICULUM

Since the late 1990s, there has been increasing awareness of the impact chemistry can have on human health and the environment, leading to the formulation and application of the 12 Principles of Green Chemistry and, subsequently, the 12 Principles of Green Engineering.[1,2] More recently, "sustainable chemistry" has also been formally defined, and, like green chemistry and engineering, provides a framework for innovative chemistry to advance global sustainability.[3]

These frameworks have facilitated the development and steady proliferation of curricular resources, tools, and materials in green chemistry that can be directly incorporated into secondary and undergraduate courses.[4−8] This growth has been fueled by organizations in the US and abroad, including the ACS Green Chemistry Institute, Beyond Benign, the Center for Green Chemistry and Green Engineering at Yale and IUPAC. In addition to providing resources, some organizations, like Beyond Benign, have also established communities of practice to support faculty in modifying and developing new lecture and lab-based curricula.[9]

The increased supply of resources has also been fueled by increased demand from students to connect global sustainability

Received: January 13, 2025
Revised: May 31, 2025
Accepted: June 2, 2025

challenges and fundamental skill sets in chemistry. In addition, the ACS now includes green chemistry and systems thinking concepts in the requirements for accreditation for bachelor's degrees in chemistry, further fueling demand for relevant curricular materials.[10] As a result, numerous academic institutions have revised their chemistry curricula to incorporate green chemistry concepts into foundational chemistry courses, and some have developed programs dedicated to green chemistry.[11]

■ THE GAP BETWEEN UNDERGRADUATE AND GRADUATE/PROFESSIONAL TRAINING IN GREEN CHEMISTRY

Despite the slow but steady advances in incorporating fundamental concepts of green chemistry into foundational undergraduate courses, the incorporation of such concepts into upper-level undergraduate and graduate courses is very small. Students' options for receiving *specialized* training in green and sustainable chemistry, beyond what might be shared in a research lab, are even more limited. A recent ACS survey found only 11 graduate and professional programs worldwide that are specifically dedicated to green or sustainable chemistry.[12] This is likely due to a combination of three primary factors: the lack of readily available and accessible graduate-level curricular materials, the higher level of instructor training required for faculty to facilitate change in the classroom and laboratory, and the slow response from higher education institutions to student and societal demand for such training. The relative scarcity of curricular materials for upper-undergraduate and graduate-level training in green chemistry is underscored by an analysis of the Green Chemistry Teaching and Learning Community (GCTLC) Library, a repository of community resources in green chemistry for instructors (Figure 1).

Professional development and training for faculty that will equip them to include the principles of green and sustainable chemistry and engineering in their teaching *and research* is a critical necessity. Broader systemic factors, such as the need for

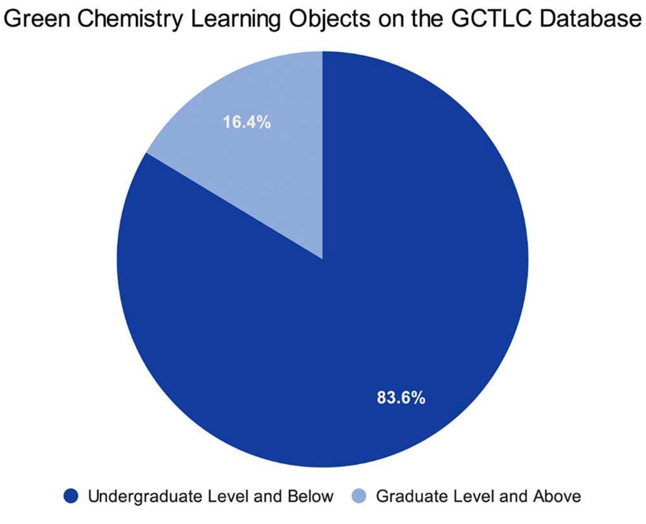

Figure 1. Green Chemistry Teaching and Learning Community (GCTLC) Library is a database of green chemistry education resources and curricular materials. Of the 207 resources listed on the Web site (accessed on April 25, 2024), 34 are categorized as "for graduate or professional training." Note: GCTLC Library resources are uploaded and labeled by community members.[11]

dramatically increased funding and recognition for curricular development and green and sustainable research initiatives, are also important to consider. We are currently collecting data that will develop a future article focused on these and other barriers to curricular change in higher education.

As a result of the factors mentioned above, most chemistry graduates have little or no formal training in green chemistry. For practicing chemists already in the workplace, there is also a notable lack of standardized training opportunities and resources for individualized self-paced learning. These combined factors create a gap between the skill sets possessed by chemists entering the workforce and the evolving demands of industry.[13] The potential to further evolve the research agenda—a key objective of the ACS GCIPR—is also hindered when students are not empowered with the skills necessary to generate new ideas relevant to the development of greener chemical processes and safer commercial chemicals.

■ DEMAND FOR GRADUATE AND PROFESSIONAL TRAINING IN GREEN CHEMISTRY

The increased consumer demand for more sustainable products has been one of the many drivers for the chemical industry to evaluate and increase its supply of products that meet customer expectations. Chemists engaged in those industries must have access to regularly updated resources that provide a toolset for the design of chemical processes and chemicals that meet the principles of green chemistry. For example, to begin to meet this demand over the past several years, the ACS GCIPR has offered workshops at the ACS Spring and Fall National Meetings since 2017. Attendance for this workshop, "Practical Green Chemistry Tools and Techniques for Research and Development Scientists," has consistently risen, with notable increase in participation from chemists in the workforce. Future training resources should build on this model of addressing the critical knowledge gaps and ideally be developed collaboratively by academia and industry to ensure their relevance and adherence to pedagogical standards.

■ GREEN CHEMISTRY AND ENGINEERING LEARNING PLATFORM (GCHELP)

To this end, the ACS GCIPR, a collaboration between the ACS GCI and over 50 companies working to implement green chemistry and engineering into the development of active pharmaceuticals globally, recently relaunched the Green Chemistry and Engineering Learning Platform (GChELP), a free online resource designed specifically for research chemists and chemical engineers.[14,15] The tool was developed to promote the adoption of sustainable methodologies within the pharmaceutical industry by providing a suite of training modules in practical green chemistry tools that can enhance scientists' ability to develop chemical processes with reduced environmental impacts. To effectively address graduate and professional training needs in green and sustainable chemistry and engineering, the ACS GCIPR leverages extensive collaborations with pharmaceutical companies, contract research and development organizations, and allied industries (e.g. animal health and agriculture). Education of current and future leaders, alongside the development of innovation tools, are central to ACS GCIPR's strategic priorities. Consequently, its working groups are uniquely positioned to provide valuable input and guidance to the Green Chemistry Education and Learning Platform (GChELP).[16−18]

https://doi.org/10.1021/acssuschemeng.5c00379
ACS Sustainable Chem. Eng. XXXX, XXX, XXX−XXX

The GChELP tool was born out of the Innovative Medicines Initiative (IMI)−CHEM21 Project, established in 2012 as a collaboration between the European Federation of Pharmaceutical Industries and Associations (EFPIA) and the European Union (EU).[19] The project aimed to address the environmental impacts of pharmaceutical manufacturing through a public-private partnership between six pharmaceutical companies, ten universities, and five small-to-medium enterprises (SMEs) (Figure 2).

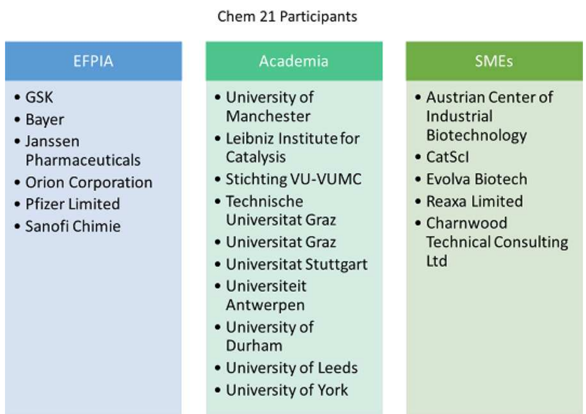

Figure 2. Original participants of the IMI-Chem21 project established in 2012.

The early versions of the tool aimed to promote the adoption of sustainable biological and chemical methodologies, catalytic chemistry, biocatalysis, and synthetic biology. Based on discussions beginning in 2017, the ACS GCIPR further developed and updated the Chem21 tool and relaunched it as "GChELP" in 2022, attracting more than 50,000 users.[20]

The green and sustainable development and manufacture of pharmaceuticals and other high-value chemicals relies on whole-process thinking, including choices made about equipment and unit operations. With this in mind, the ACS GCIPR was keen to acknowledge "engineering" in the name of the toolbox. While the toolbox content is currently biased toward informing decisions that the scientist can make when developing the chemical reaction itself, the importance of chemical engineering is acknowledged through content on solvent recovery, flow chemistry, process safety, reaction workup and product isolation, lifecycle impact, as well as an "Introduction to Process Engineering" module. Going forward, the number of units aligned to chemical engineering will increase, reflecting opportunities for green and sustainable processing posed by closed-loop manufacturing, continuous processing, and the exploitation of novel processing windows and separation technologies that are less energy-intensive than distillation.

The GChELP platform is comprised of 35 multimedia modules, each consisting of reading materials, videos, and quizzes designed to provide self-paced, asynchronous training in advanced green chemistry and engineering concepts and tools that are not currently offered at most colleges and universities. The content was developed with an emphasis on providing a practical skillset that can be readily applied in the research lab. To this end, GChELP fills a knowledge gap for both research chemists already working in the laboratory and students who will enter the workforce.

For research chemists, GChELP provides structured instruction on practical tools and techniques that support developing synthetic processes based on green chemistry principles. It can thus be instrumental in training new research chemists during the employee onboarding process. Equipping scientists with a specialized palette of green chemistry and sustainability tools, skills, and knowledge that are considered

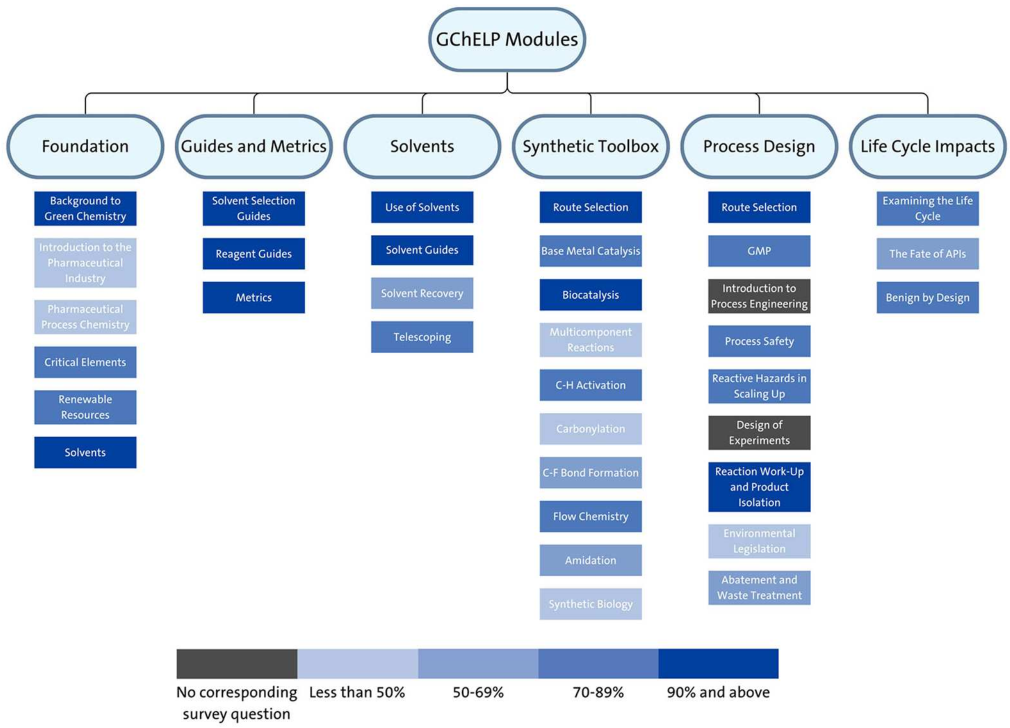

Figure 3. Content map of GChELP toolset, with six modules and subtopics. Color coding corresponds to survey ranking of how critical ACS GCIPR members ranked the skills for chemists in the pharmaceutical industry.[21]

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ACS Sustainable Chem. Eng. XXXX, XXX, XXX−XXX

highly valuable from a corporate perspective can help them transition to new industry positions or from academia to the industrial environment. Such early career training can provide a uniform foundation in both the ideology and tools of green chemistry, helping align new hires with research team members and accelerating the team's ability to develop chemical processes with improved sustainability profiles.

GChELP is equally useful to seasoned researchers looking to augment their expertise through advanced modules on green chemistry tools. The latter modules empower chemists to seamlessly integrate green chemistry into their research and development processes from the outset, enabling them to make informed decisions when selecting solvents, reaction conditions, reagents, and more. The modules are self-paced, include self-assessment questions and links to reference resources and tools accessible as needed.

Industry Input in Curriculum. The priority skill areas emphasized in the GChELP content were identified via a survey of chemists in the ACS GCIPR member companies.[21] These priority areas identified included solvent selection, reagent guides, foundational content on green chemistry and green engineering, small molecule pharmaceutical route design, solvent usage in the pharmaceutical industry, and green chemistry metrics. These and others, part of the foundational concepts, make up the six content buckets of the toolset (Figure 3).

UPTAKE OF GCHELP: INDUSTRY CASE STUDIES

Case Study 1: CatSci. GChELP is already being employed during onboarding or other training by a number of companies. Among these is CatSci, one of the original industry collaborators on the IMI-Chem21 project. Completing training modules, such as those offered within GChELP, allows for the standardization of awareness of green and sustainable practices among the research staff. This, in turn, provides customers with confidence that their products and the processes used to make them are being developed by scientists trained to an industry standard that has evolved to require more sustainability knowledge.

High levels of growth in recent years have led to a steep increase in the number of lab-based scientists within the CatSci organization. This has created a challenge in ensuring all team members understand workflows that facilitate the development of economically and environmentally sustainable chemical processes for small molecule therapeutics. It also creates a challenge around how bench-facing scientists can be given day-to-day autonomy to make fit-for-purpose project decisions in keeping with green and sustainable chemistry with minimal oversight from more experienced colleagues. The company finds it expensive and impractical to employ in-person training provided by an external vendor. In contrast, GChELP is a viable solution, given that it can be accessed "on demand."

New employees with graduate degrees are directed to the toolbox to enhance their awareness of the foundational material. Their engagement and understanding of the material are evaluated with their team leader over the six-month probationary period following their hiring. Employees with bachelor's or associate degrees often have no formal background in green chemistry. In this case, individuals at CatSci are given an intensive six-week upskilling "boot camp," where they have protected time to engage with the learning toolbox and its assessment questions. A score below 75% in the assessment prompts follow-up coaching by their team leader over the remainder of their six-month probationary assessment.

Feedback on the toolbox from both sets of constituents—new employees with graduate and undergraduate degrees alike—has been overwhelmingly positive at CatSci. It highlights the trade-offs that accompany any move toward a processing solution that is "greener" than its predecessor, particularly in the case of solvent selection. According to a survey, 80% of new employees with graduate degrees and 87% of employees with undergraduate degrees in Chemistry cited that they had meaningfully drawn on the toolbox content for drug project work in the six months following their introduction to it.

Case Study 2: Sanofi. Sanofi, another pharmaceutical company represented within the group of authors, has also employed GChELP as part of onboarding new employees. To contribute to wider organizational ambitions related to achieving carbon neutrality, Sanofi's process chemistry group in the United States is committed to integrating green and sustainable chemistry into drug substance development. The GChELP platform has been advertised internally as a resource that allows newly hired chemists and engineers to self-train in green chemistry principles in an on-demand fashion. Its use has been integrated with in-house training in Sanofi-specific eco-design tools and goals. Since the relaunch of GChELP in March 2023, users of the platform have praised it for its accessibility, thoroughness, and autonomy. It has a proven track record of yielding positive results when used every day to help with the delivery of projects in the early phases of process development.

Case Study 3: Pfizer. Pfizer, another one of the original participants in the Chem21 Project, placed a significant onus on the educational component of the learning platform. This included sharing many of their internally developed resources, including reagents and solvent guides, to facilitate the assembly of the initial teaching materials. As the Chem21 consortia comprised both academic and industry partners, working within this group enabled Pfizer to expand and reach consensus on teaching tools (for example, creating a decision-tree network to allow the development of a new cross-organizational solvent guide) as well as present the materials in a format to bridge the learning gaps between academia and industry. At the same time, it was possible to introduce new concepts such as green metrics used to assess chemical processes.

The reboot and reimagining of this educational resource as "GChELP" allowed the ACS GCIPR to leverage the broad range of expertise of its member organizations (spanning pharmaceuticals, biotechnology, contract manufacturing organizations, and agrochemical organizations) to both expand and update existing materials, such as for instance providing additional case studies and providing additional training units, many of which are focused on emerging technologies. Within Pfizer, GChELP is actively presented to new chemistry hires during onboarding, and its utility is promoted throughout the company's chemistry community, among both discovery- and development-based colleagues. The value of the GChELP resource is particularly emphasized with new hires, specifically those transitioning from academia. While internal green chemistry teams provide new hires access to a full suite of tools, colleagues' time to provide adequate training for their use presents a challenge. Having the self-paced GChELP platform available allows new hires a programmed approach to learning the tools, the context of their development, and most importantly, how to utilize them in a real-world setting.

Case Study 4: Sai Life Sciences. Sai Life Sciences is a contract development and manufacturing organization with process chemistry groups in both India and the United

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ACS Sustainable Chem. Eng. XXXX, XXX, XXX−XXX

Kingdom. The tools and resources available on the ACS GCIPR Web site are promoted to all Sai Life Sciences staff, from new graduates to experienced process chemists. Staff new to process chemistry are encouraged to use GChELP for continuous professional development as this fills a gap in most new starters' knowledge and awareness of such topics. In addition, posters outlining green chemistry principles and traffic-light style ranking of solvents (red/yellow/green) have been distributed around Sai Life Sciences laboratories to encourage a "right first time" approach to green process chemistry. The Reagent Guides are particularly useful to staff as they provide guidance on preferred reagents for common transformations along with case studies and general literature reviews. This is a valuable resource and provides a baseline when optimizing these transformations. The metal scavenging review was particularly useful for a recent manufacturing process where Pd, Cu, and Ru needed to be tightly controlled. Additionally, Sai Life Sciences recently attended the seventh Indian Green Chemistry World (IGCW-2023) conference in Mumbai and presented a demonstration of the Reagent Guides - a standalone ACS GCIPR tool that is referenced in GChELP - on behalf of the roundtable to further spread the word and encourage uptake more widely throughout the community.

Case Study 5: Corteva. The utility and impact of GChELP extend beyond the pharmaceutical industry to other areas of high-value chemical manufacturing.[1] One such allied industry is agrochemicals, where active ingredients for crop protection are routinely produced on a scale of >1000 MT/year. Given the manufacturing scale and end-use of its products, Corteva Agriscience ("Corteva") strategically integrates green chemistry and engineering principles to drive the design and development of sustainable technologies. To further advance such efforts, Corteva recently established an internal Green Chemistry & Engineering team to integrate additional tools, metrics, and training materials into its chemical R&D program. This objective was accelerated with the relaunched GChELP, and Corteva anticipates the integration of additional GChELP resources in their chemical R&D training. For instance, GChELP's module titled "Guides and Metrics" motivated the team to expand Corteva's internal training resources to include acid and base selection tools with ongoing efforts to incorporate reagent selection resources. Additionally, Corteva has leveraged the solvent guide produced by the original Chem21 initiative—still featured on the learning platform—to aid the selection of industrially preferred solvents among individual scientists and project teams. Lastly, GChELP resources are being integrated into a revitalized "Process Development" training course at Corteva. The training materials from GChELP modules, such as the "Synthetic Toolbox" and "Process Design," will be leveraged to specifically highlight green chemistry considerations. Overall, advancing the development of sustainable technologies at Corteva relies on strategic workforce training and accessible green chemistry resources, both of which are foundational elements of GChELP.

■ ADDRESSING GAPS IN ACADEMIA

GChELP is also well suited as an instructional tool for faculty and as a supplement resource for students in courses ranging from undergraduate organic chemistry to graduate-level curricula in green chemistry, green engineering, and organic synthesis. Its versatility is connected to its module-based format; for example, Module 1, "Foundations of Green Chemistry," is accessible and relevant to the organic chemistry curriculum. However, much of the remaining content is best suited to students interested in expanding their skillset in green chemistry at the upper-undergraduate or graduate levels. As mentioned earlier in this document, we are collecting data relevant to outcomes in academia for future publishing, but there is already clear evidence of GChELP's broad utility in academic settings. For example, graduate courses focusing on teaching advanced synthesis and industrial green chemistry have been successfully launched at the University of York (York, UK) and George Washington University (Washington, DC, US). Various modules including "Solvents", "Metrics", "Renewable Resources", and "Examining the Life Cycle" have formed the basis for teaching sessions at the annual ACS GCI Green & Sustainable Chemistry Summer School program, with strongly positive results (student learning and feedback). More generally, modules within GChELP, specifically exercises on solvent guides and reagent guides, have been widely used across many institutions in both undergraduate and graduate-level courses. These curricular additions have been shown to engage students in discussions, inspire thoughtful questions, and support students as they seek to understand and apply higher-level green and sustainable chemistry concepts.

The self-paced aspect of GChELP allows for modules to be assigned as homework, with self-assessment reflecting the level of understanding. The classroom discussion that follows can then substantively engage students to identify which of the tools and techniques would apply to the redesign of specific syntheses. Such a discussion can be based on a short in-class assignment or a multiweek group project that allows for a comprehensive assessment of the student's mastery of the techniques. Finally, students who have used this resource in their formal training can highlight this valuable skillset when meeting with potential employers during their job search.

■ VISION FOR FUTURE USES OF GCHELP

The ACS GCIPR is committed to using feedback to iterate on the relevance of the module content, keep it up to date, and make the resource as practical as possible. To this end, individual modules are continually being revised and updated to include the most current expertise and real-world relevance. New modules that add topical content to GChELP will be developed as the need arises and resources become available. Additionally, the ACS GCI and the ACS GCIPR are working together to develop a standardized workforce training course that could offer an optional certification. However, the modularity of the GChELP resource will be retained, as this provides a practical way to obtain as-needed training on different skill sets. Looking ahead, developing content that is global and practical rather than purely academic is most productive for teaching new staff how to make decisions in the context of green and sustainable chemistry.

■ CONCLUSIONS

The increased integration of green chemistry principles into both academic curricula and industrial practices marks significant progress in how the chemical enterprise is addressing global sustainability challenges. Despite these advances, there remains a gap in green chemistry knowledge among graduate-level chemists, chemists newly entering the workforce, and those already established in their careers.

The revitalization of GChELP is an important step forward in providing accessible and practical training resources for

https://doi.org/10.1021/acssuschemeng.5c00379
ACS Sustainable Chem. Eng. XXXX, XXX, XXX−XXX

graduate-level and working chemists. By offering structured modules on skills that are highly sought by employers, GChELP empowers both research chemists and students to effectively incorporate sustainability considerations into their chemical and process designs. The modular format of GChELP makes it versatile enough to use in industry onboarding and continuous learning programs as well as in academic settings. This is particularly valuable for graduate-level programs where fewer green chemistry resources exist.

The ongoing refinement of GChELP content, informed by feedback from users and industry stakeholders, will ensure its continued relevance and effectiveness in addressing the evolving needs of the chemistry community. The authors of this Perspective hope that increased use and development of educational resources like GChELP will help close current knowledge gaps and facilitate the practical application of green chemistry and green engineering principles.

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Author Contributions

The manuscript was written through the contributions of all authors. All authors have given approval to the final version of the manuscript.

Notes

In celebration of the 20th anniversary of the ACS Green Chemistry Institute Pharmaceutical Roundtable: leading the way for green chemistry and engineering implementation.

The authors declare no competing financial interest.

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https://doi.org/10.1021/acssuschemeng.5c00379
ACS Sustainable Chem. Eng. XXXX, XXX, XXX−XXX

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Ashley Baker is currently the Scientific Content and Community Manager at the ACS Green Chemistry Institute, where she provides communications and programming support to raise the visibility and implementation of greener scientific practices worldwide. Ashley is a project lead for the Green Chemistry for Sustainability platform (www.chemistryforsustainability.org), collaborates to produce *The Nexus* newsletter, reports on green chemistry initiatives, and provides guidance on outreach campaigns and community engagement. Using her Bachelor's in chemistry and Master's in multimedia journalism, her focus is on empowering sustainability-focused organizations through content production, event planning, program management, and strategic communications.

Christiana Briddell is the Sr. Communications and Marketing Portfolio Manager at the ACS Green Chemistry Institute®. In this role, she enables the Institute to fulfill its mission by providing greater visibility and uptake of sustainable and green chemistry tools, resources, programs, and events. She is the editor of the Institute's newsletter and blog, *The Nexus*, and a frequent contributor of green chemistry news and articles to journals and news publications. Christiana joined the American Chemical Society in 2013 having previously co-founded a web development and marketing company where she was an early innovator of social media campaigns and online educational platforms. She has a Master's in Communication from John Hopkins University and a B.S. in Environmental Science from Dickinson College.

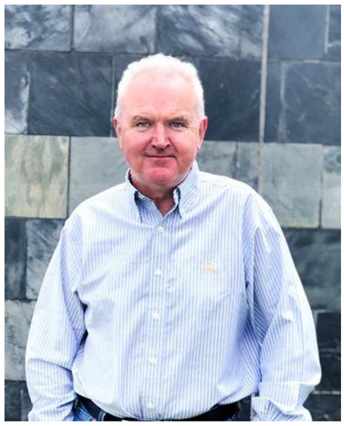
Naoko Ichiishi obtained her PhD degree in synthetic organic chemistry from University of Michigan Ann Arbor in 2016. She is currently a Principal Scientist in high throughput innovation technologies, process chemistry at Sanofi Cambridge Crossing.

Shazia Keily is a Senior Chemist in Medicinal Chemistry at Vertex Pharmaceuticals UK. After completing her Chemistry degree from the University of Leicester, Shazia held roles at Rhone-Poulenc Rorer and OSI Pharmaceuticals before moving to Vertex in 2004. Over her 20+ years of industrial experience, she has contributed to multiple clinical candidates in a range of therapeutic areas. Her current role includes leadership of the UK Green Chemistry team, driving cross-site and cross-function collaborations and initiatives to make impactful progress towards Vertex's sustainability goals. Under her guidance, the UK Green Chemistry team has achieved the highest 'Green' MGL accreditation, pivoted away from "non-green" solvents, and drastically reduced waste streams. Additionally, she has played an important role in the Oxford Learning Lab as the

Researcher in Residence, inspiring and mentoring the next generation of scientists from underrepresented backgrounds.

Andrew Kennedy is a Vice President and Site Head for Sai Life Sciences Ltd, an Indian CDMO based at Alderley Park in Cheshire in the UK. He has a responsibility for managing process development projects and technology transfer projects to the Sai sites in Hyderabad and Bidar in India. He has a total of 28 years of experience in process chemistry with 23 years at GlaxoSmithKline in Chemical Development prior to joining Sai. Andrew has worked in mainly in the small molecules space and has a long-standing interest in improving sustainability of chemical processes with large scale manufacturability in mind.

Rebecca Newton started her professional career in the Chemical Development department at GSK, Stevenage in 1999. She obtained her PhD in organic chemistry from the University of Leeds and then undertook industrial postdoctoral work at AstraZeneca, Macclesfield. Rebecca has worked in the pharmaceutical industry for the last 20 years in both process chemistry and discovery chemistry.



Paul Richardson earned his Ph.D. in Chemistry from the University of Sheffield (Synthetic Methodology/Total Synthesis, Professor Istvan Marko) and did postdoctoral studies at the University of Exeter(Biocatalysis, Professor Stan Roberts) and The Scripps Research Institute (Asymmetric Catalysis, Professor Barry Sharpless). He is currently the Director of Analytical and Synthesis Methodologies within Oncology Medicinal Chemistry at Pfizer in La Jolla, California and current co-chair of the ACS GCI Pharmaceutical Roundtable.

Helen Sneddon obtained her PhD from the University of Cambridge under the supervision of Professor Steven V. Ley. Following postdoctoral studies at the University of California, Irvine with Professor Larry Overman, she joined GSK. Whilst at GSK she has developed a particular interest in Green Chemistry as applied to the Pharmaceutical Industry. She took up the position of Professor in Sustainable Chemistry and Director of the Green Chemistry Centre of Excellence at the University of York in April 2022.

https://doi.org/10.1021/acssuschemeng.5c00379
ACS Sustainable Chem. Eng. XXXX, XXX, XXX−XXX

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ACKNOWLEDGMENTS

This manuscript was developed with the support of the ACS Green Chemistry Institute Pharmaceutical Roundtable (https://www.acsgcipr.org/). The ACS GCI Pharmaceutical Roundtable comprises companies in pharmaceutical, biotechnology, agricultural, and animal sciences as well as supporting organizations such as CMOs and CROs. The organization was established to encourage innovation while advancing the integration of green chemistry and engineering in the pharmaceutical industry. The activities of the Roundtable reflect its members' shared belief that the pursuit of green chemistry and engineering is imperative for business and environmental sustainability. The ACS GCI Pharmaceutical Roundtable was established in 2005 by the ACS Green Chemistry Institute (ACS GCI), whose mission is to catalyze the implementation of innovative approaches to chemistry and engineering that enable sustainable development across the globe. Special thanks to Dr. David Laviska for useful discussions about the manuscript.

ABBREVIATIONS

ACS-American Chemical Society
ACS GCI-American Chemical Society Green Chemistry Institute
ACS GCIPR-American Chemical Society Green Chemistry Institute Pharmaceutical Roundtable
APIs-active pharmaceutical ingredients
GChELP-Green Chemistry and Engineering Learning Platform
GCTLC-Green Chemistry Teaching and Learning Community
IMI-Innovative Medicines Initiative
EFPIA-European Federation of Pharmaceutical Industries and Associations
EU-European Union
SMEs-small and medium enterprises
GMP-good manufacturing practice

ADDITIONAL NOTE

[1]Reflecting the principles that underpin the missions of these industries, the ACS GCI Pharmaceutical Roundtable has member companies that operate in the areas of human pharmaceuticals as well as agrochemicals and animal health.

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