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Article

A Resource to Support Decolonization of the Undergraduate Chemistry Curriculum

Kelechi O. Uleanya,* Samantha K. Furfari, Leonie C. Jones, Kgato P. Selwe, Amelia B. Milner, and Caroline E. H. Dessent*

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ABSTRACT: In our taught chemistry curricula, the majority of individuals who are used to illustrate historical aspects of chemistry topics are white, western chemists. Decolonizing the undergraduate chemistry curricula is increasingly recognized as an important step toward developing a more inclusive higher-education environment for students from minoritized ethnic backgrounds. Here, we provide the first openly accessible resource that provides examples of both individual scientists and groups that can be used to illustrate chemistry teaching, and hence provide role model examples of scientists from different cultures. More generally, the resource provides a significant body of examples for chemistry educators to use as they begin working toward decolonizing their curricula.

KEYWORDS: *Decolonization, Curriculum, Chemistry, Ethnic Minority, Undergraduates*

■ INTRODUCTION

Decolonization, in a general sense, involves finding structures and relationships that have emerged from colonial origins, and endeavoring to remove them. In relation to scientific study, it involves questioning our awareness of science as a discipline that grew from the work of a sequence of famous individuals from the global North West. Therefore, the goal of decolonizing the sciences is to develop a more complete, scientific perspective that embraces the whole globe. The activity of decolonization is not only about the curriculum itself, however, but should also encourage us to think more broadly about the structures we use to teach and assess, thus facilitating a shift in culture that enables different and more inclusive ways of teaching and learning.

In 2021, a number of the current authors contributed to a commentary article that was published in this journal, giving an account of how a Chemistry Department might embark on a process toward decolonizing its undergraduate curriculum.[1] We related how and why the Department of Chemistry at the University of York had begun such a process, and described a strategic, multifaceted approach that could be used to decolonize chemistry teaching. This strategic approach suggested grouping together different types of examples for use in teaching resources, such as *Student Voice and Leadership*, and *Ethical Considerations of Applying Science in a Global Society*. The commentary has been very widely read, gaining one of the highest attention scores for an article published in this journal, and thus indicated a widespread enthusiasm from the chemistry education community to engage with decolonizing chemistry.

Efforts to decolonize University-level curricula have been motivated by the widely acknowledged challenges that minority ethnic individuals face in higher education. Focusing on Chemistry, minority ethnic individuals are significantly underrepresented across the academic chemistry population, from student through to professor. This trend of under-representation continues into the broader, commercial-chemistry workforce that recruits graduate chemists.[2−5] Considered together, these facts constitute an urgent issue for us to address as a chemistry community since they represent a loss of talent which must hamper the progress of our discipline. As early as the 1970s, a survey by Hernan Young revealed the extremely low proportion of ethnic minoritized scientists in the United States.[6] More recently in the UK, analysis of the longitudinal British Cohort Study revealed that people from white ethnic backgrounds were around 1.5 times more likely to have worked in the sciences than those from minority ethnic groups.[7] Despite continued, long-standing awareness of underrepresentation of minoritized individuals in

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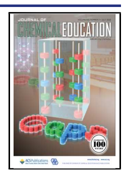

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the sciences and "calls-to-action" over many decades, it remains an issue that needs to be urgently addressed today.[8−12]

A recent report on progression trends for ethnic minority students has highlighted a sharp decrease in the number of students from this group who progress from undergraduate to PhD level study.[13] The reasons for this are not completely understood, but a large proportion of minoritized ethnic students report that they do not have a positive experience in higher education.[14−16] For example, there is a significant and widespread attainment gap between the number of high-quality degrees awarded to UK-domiciled white students compared to UK-domiciled students from ethnic minority groups.[13,17,18] A high proportion of black UK students say that the curriculum does not reflect issues of diversity, equality, and discrimination,[16] and that they therefore do not feel a "sense of belonging" while participating in higher education. Moreover, a recent study by Egan et al. on the experiences of students from Black, Asian, and Minority Ethnic (BAME) backgrounds who dropped out of university education categorically identified problems with social and cultural integration as a major issue that needs addressing to improve retention of this group.[19]

The inclusion of role models in teaching and learning materials has been acknowledged as crucial in encouraging women to pursue careers in STEM over the past two decades.[20] There is now growing evidence that inclusion of role models in teaching material similarly improves the academic retainment, progression, and achievement of ethnic minority students.[21,22] Role model inclusion promotes levels of positive engagement with the subject area as well as highlighting potential career pathways.[20,23] Encountering realistic and relatable role models has also been shown to contribute strongly to increased self-efficacy and positive self-identity for pursuing and persisting in STEM.[24,25] These considerations indicate that the promotion of Black, Asian, and Minority Ethnic role models has the potential to positively impact on the attainment of students from ethnic minorities.[26,27]

Universities UK published a report in 2019 on closing the attainment gap for higher education undergraduate degrees which recommended that increased efforts be made to support minority ethnic individuals, including decolonizing the curriculum.[28] This provided an impetus for academic departments to decolonize their curricula, as a part of work that they should conduct to address racial inequalities in university attainment. The report importantly noted that where decolonization is carried out as part of broader work to "diversify" course content (usually by considering other aspects of diversity such as gender, disability, and sexuality), it is important to ensure that this does not result in a loss of focus on the issue of race.

Taken together, all of these factors provide a very significant body of evidence to motivate the decolonization of role models in teaching material produced by Chemistry Departments. Such activity very clearly aligns with the category *Role Model Scientists from Different Backgrounds and Cultures* that was identified under our suggested strategic approach to decolonizing chemistry. Three years ago, the Department of Chemistry at York decided to begin compiling a cocreated, live document where examples of diverse role model scientists could be shared for incorporation in teaching material. Our experience is that this resource has been important in lowering the barrier for academics to embark on decolonizing the curricula they were delivering. Here, we share a version of the resource we compiled, in the hope that it similarly lowers the barrier for a much wider section of the chemistry community to decolonize their curricula through incorporating a greater number of diverse role models in their teaching. While much of the material included in our resource is publicly available, we strongly believe that by compiling and presenting it in a single place, we will enable a much greater number of academic chemists to embark on decolonizing their curricula.

The resource we have developed largely features historical examples from different ethnic and cultural groups, primarily from Asia, the Middle East, and Africa. Most of these historical examples come from the Ancient and Medieval periods, with a small number of more recent examples. In addition, we include a selection of examples from the early 20th Century onward of prominent Black and Asian scientists, to increase the number of identifiable individuals who are included in the resource. We have chosen to focus on historical examples here to provide a counter balance to historical examples that are generally incorporated in teaching material. Further work is desirable to develop an additional resource on contemporary scientists from under represented groups. Scientific examples in our resource are included from all of the main chemistry sub disciplines. Where possible, we have included information on where the examples could be incorporated in university chemistry teaching material.

We note that there have been a small number of other very recent publications reporting activities to introduce aspects of Diversity, Equity and Inclusion (DEI) into chemistry teaching that overlap to some extent with the work we present here.[4,25,29−31] For example, Gee et al. described the development of a "Not all Chemists are White Men Poster" and slideshow as a resource for providing diverse role model,[30] and Pence and Pence presented a virtual activity, "Profiles in Chemistry", which included eight videos of women scientists and people of color.[31] The resource we present here complements these other activities. Importantly, it gives a much wider number of examples than previous publications, and thus provides examples that can be included in courses delivered across a much fuller breadth of university chemistry teaching.

Methodologies

Curation of Resources. While the resource presented here was inspired by our departmental depository of diverse role model scientist examples,[1] we followed a separate, structured approach to gathering the material included in the resource (Sections S1−S4). Initial work began with a manual search through the *Encyclopedia of the History of Science, Technology and Medicine in Non-Western Cultures*,[32] to identify Chemists and Scientists who were instrumental in the development of materials and techniques in chemistry and closely related fields. This material was supplemented with additional examples from the departmental depository. These two primary sources constituted the foundation of the resource.

To expand on these examples, targeted keyword/string searches were performed in a variety of search engines. These keywords/strings included "*History of Middle Eastern Chemistry*", "*History of science in China*", "*Significant contributors to science in India*" as well as further research on general subject areas mentioned in the *Encyclopaedia of the History of Science, Technology and Medicine in Non-Western Cultures* that are of chemical relevance, such as fireworks. Examples were

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i. **Inorganic Chemistry**

Date/period (if known)	Chemistry	Undergraduate Course	Sources
700 BC	Evolution of the idea to classify all compounds into 'Elements'	Main Group Chemistry	1. Adolph, W. H. The History of Chemistry in China. The Scientific Monthly, **1922**, 14(5), 441-446. https://archive.org/details/jstor-6621/6621 (accessed March 18 2023).
1100 BC	Discovery of five important metals (Gold, silver, copper, iron, tin)	Transition metal chemistry	1. Adolph, W. H. The History of Chemistry in China. The Scientific Monthly, **1922**, 14(5), 441-446. https://archive.org/details/jstor-6621/6621 (accessed March 18 2023).
9th Century (Tang dynasty)	The invention of fireworks	Inorganic materials chemistry. Atomic structure. Atomic spectroscopy.	1. Kirby, M. Hot Pot Spot. China's Great Inventions and the Irony of Fire Medicine, 2021.https://www.hotpotspot.co.uk/post/china-s-great-inventions-and-the-irony-of-fire-medicine (accessed August 23 2022). 2. Gondhia R., The Chemistry of Fireworks. https://www.ch.ic.ac.uk/local/projects/gondhia/history.html (accessed August 23 2022).

Figure 1. An excerpt from Section S1ai which lists examples of inorganic chemistry from Asian Chemists, by date, chemistry, undergraduate course (where the example could potentially be used), and reference sources.

identified, collated, and categorized. The type of material we have compiled to date is summarized below:

- Examples highlighting contributions from Asia, the Middle East, and Africa, and the work of 20th Century Black and Asian chemists, to provide role model examples for decolonizing chemistry teaching material.
- Links to related resources featuring ethnic minority chemists, including magazine articles, blogs, and social media posts (for example, items created for Black History Month).
- Examples of best practice of what decolonizing a curriculum means for a science department and why it is important (e.g., reports by professional bodies, newspaper reports, university web sites, etc.).
- Compilation of references from the published literature, conference abstracts, and web links on decolonizing the science curriculum.

As a general principle, we worked to try to balance the number of examples evenly across the regions we studied, and we also attempted to balance the number of examples from the core chemical subdisciplines of Inorganic, Organic and Physical Chemistry. We have chosen to use the BC/AD system of dating, rather than the alternative BCE/CE, due to BC/AD still being used more often in journalistic publications, and also more generally in high school and university science teaching.

Access to Resources. In compiling this resource, we were extremely keen to ensure that the document we created was as inclusive for users as possible, to allow the material within it to be accessed and further disseminated as widely as possible. This is particularly important for academics wanting to deliver a decolonized curriculum who do not have the logistical, or financial resources (e.g., those from the global south) to enable them to access primary journal resources. For this reason, we decided that the sources and references in the resource should be as widely available and accessible as possible. Where a particular example is not easily accessible, this is clearly noted and the easiest approach to accessing it has been outlined.

Survey. To test whether the resource we created could be useful to chemistry educators, we ran a survey for faculty members of our department. This was conducted via a Google survey form that was circulated to all faculty members, and included a link to the full resource (Section S1−S4). A free-text section was included so that respondents had the opportunity to provide general feedback in addition to answering questions. All responses were anonymized to maintain confidentiality. The survey was open for 6 weeks to allow a flexible time window over which respondents could complete the survey.

Project Outputs

The Resources. The resources outlined in the methodology can be found in Sections S1−S4. The three key sections (Sections S1−S3) are discussed in more detail below, with the collection of general references being listed in Section S4.

Section S1: Tabulated Contributions of Chemists from Asia, the Middle East, and Africa. In this section, 84 different contributions to the development of chemistry from Asia, the Middle East, and Africa were catalogued under the subdisciplines of chemistry, e.g., organic, inorganic, physical and medicinal chemistry. This allows educators to straightforwardly select examples linked to specific topics or modules they are delivering. To further lower the time barrier for educators who wish to use the resource, where possible, we have also included brief suggestions on where the example might be included in a university chemistry course. Figure 1 provides an extract from Section S1ai to illustrate the general layout of material.

We highlight two examples to illustrate how the material in Section S1 can be incorporated into an undergraduate Chemistry course. One widely applicable example would be the work of Jabir Ibn Hayyan (Section S1bvi), a Chemist from the Medieval Middle East, who developed distillation processes that are still used in the same way today. Indeed, images of the glassware used by Jabir Ibn Hayyan indicate that it closely resembles the shape of the glassware used in today's chemistry teaching laboratories. This could be noted in an introductory section of a laboratory handbook, or highlighted to students by demonstrators when introducing a practical session. Indeed, one of us (SAF) has recently introduced this example into a Year 2 laboratory practical to extract limonene. A second example that could be generally incorporated in Year 1 undergraduate courses is the early history of main group chemistry elements (Section S1ai). One of our Departmental Colleagues, Dr. John Slattery, used the resource to source

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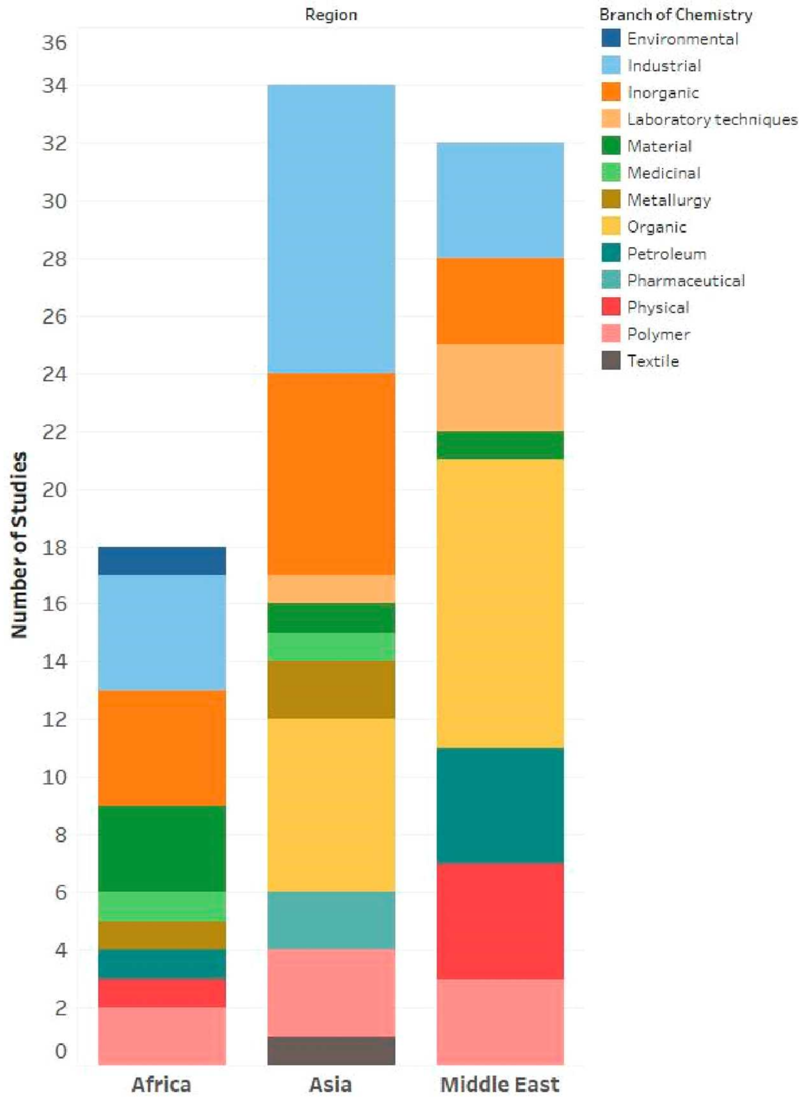

Figure 2. Bar chart showing the number of studies from Africa, Asia, and the Middle East. The colors indicate the different branches of chemistry covered by each study collected in Section S1 of the resource.

material on the use of tin and lead alloys in the Middle East, China and Egypt at the start of the Bronze Age, and incorporated a presentation on this topic during a lecture break in a Main Group Chemistry lecture course that he delivered to Year 1 undergraduate students.

Figure 2 provides a graphical overview of the scope of the material included in the resource, illustrating the balance between geographical area and branch of chemistry of the examples. It shows that the number of examples we have catalogued reduce in the order Asia > Middle East > Africa. Although we aimed to balance the number of examples from each of these regions, it was challenging to find a sufficient number of examples from Africa. This is consistent with the African practice of transferring historic information orally rather than through documents, and reflects the fact that further historic scientific work from this area is needed. Figure 2 illustrates the variations in the types of chemical examples we identified from the various regions. For example, organic chemistry examples form a significant number of the examples from Asia and the Middle East, but not Africa (due to particular difficulties we experienced in finding Organic chemistry examples from Africa), whereas a good number of inorganic examples from all three regions were identified.

Figure 3 provides a further schematic to illustrate the diversity of the material collected in Section S1, showing the spread of dates of the chemical examples, indexed by geographical location. The figure illustrates a number of points including (i) that the majority of very early examples (<2500 BC) come from Egypt and China, (ii) that examples from India can be found across a wide time period from 2700 BC onward, and (iii) that examples from African countries, such as Nigeria, come from the period from 1400 AD.

Section S2: Short Biographies of 20th Century Asian and Black American Chemists Including Their Contributions to Chemistry. This section contains short biographical profiles of 24 black Asian and Black American chemists, including a summary of the chemistry they performed, organized by subdiscipline of chemistry. Keywords have been added to facilitate searching and clarify links to related areas of chemistry. References are included with each biography, with a reference to a picture of the Chemist where one is currently available. Where possible, the examples include a description of where the chemistry described can be included

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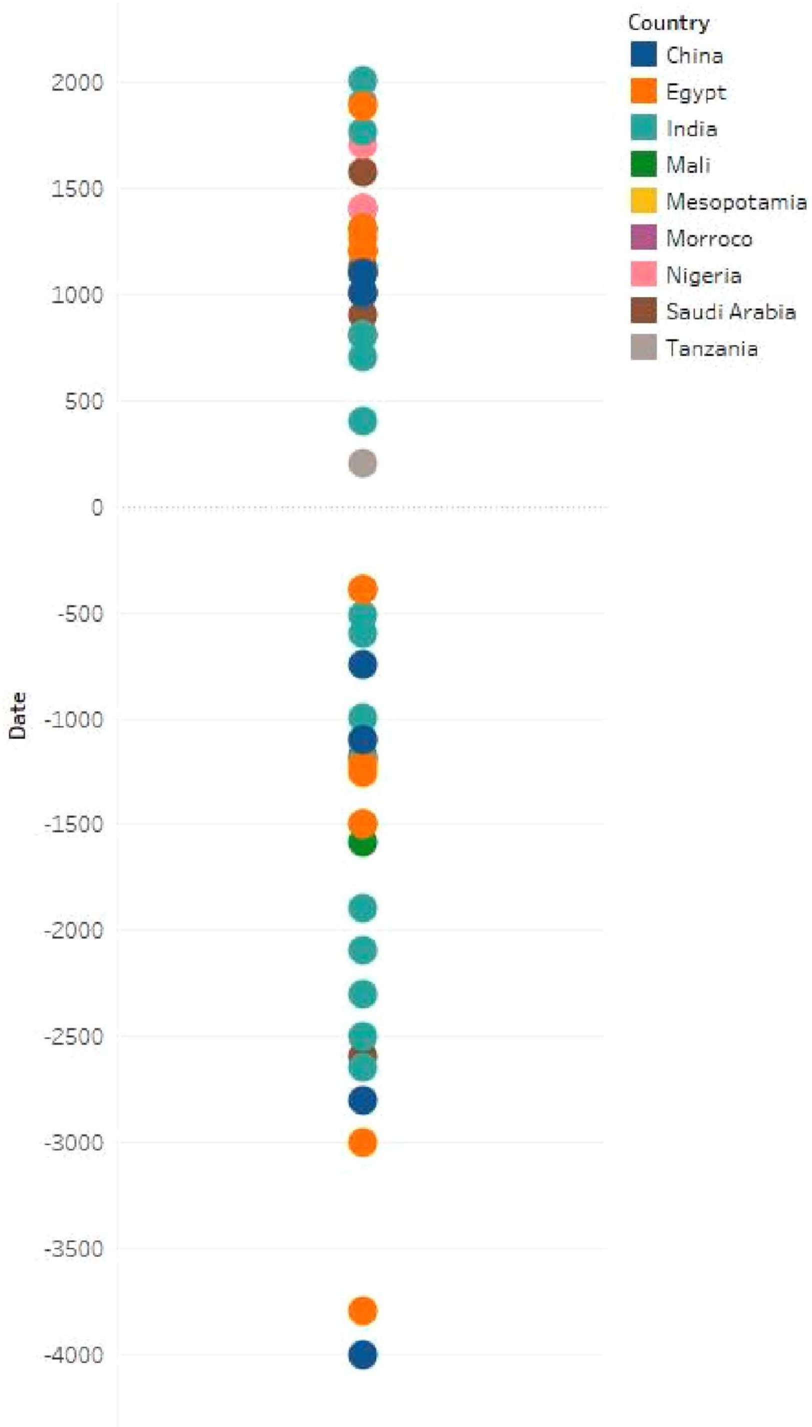

Figure 3. Schematic diagram of the dates (from 4000 BC to 2000 AD) of the chemical examples that are included in Section S1. The colors indicate the geographic location where the studies were conducted.

in a chemistry curriculum. The web-links given are openly available, and while this improves the inclusivity of access, this is necessarily tensioned against possible changes to these links over time.

An example of one of the biographies is shown in Figure 4 to illustrate the format used in Section S2.

Sections S3 and S4: General Resources. Section S3 includes a range of links to other collated lists and web-resources including directories of contributions of Black, Asian, and African female scientists and contributions of scientists from the Medieval Islamic world. These resources provide a further range of examples to facilitate decolonizing topics in the wider science curricula, as well as providing some intersectional role models. At the end of Section S3, we have also included some examples of publications from the educational literature (web and print) where ethnic minority and female scientists have been introduced into undergraduate chemistry teaching, and also descriptions of publications discussing the principles of decolonizing science. Section S4 is distinct from Sections S1−S3, and has been included here

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Dolphus Edward Milligan (1928-1973): was an African American chemist with expertise in spectroscopy. His research focused on using spectroscopy to study reaction intermediates at extremely low temperature. Milligan's research on free radicals and the spectra of molecular ions earned him many different awards.

Areas of research: spectroscopy, intermediates, free radicals, ions, analytical, kinetics.

1. Wikipedia. https://en.wikipedia.org/wiki/Dolphus_E._Milligan (accessed 2022-08-23).
2. Wisniewska, Z. https://www.blackpast.org/african-american-history/milligan-dolphus-1928-1973/ (accessed 2022-08-23).

Photo: https://nistdigitalarchives.contentdm.oclc.org/digital/collection/p16009coll5/id/491/

Figure 4. An example of a biographical profile from Section S2, which highlights the chemical research performed by Dolphus Edward Milligan. Areas of research (keywords) indicate the areas where his work may be included in the chemistry curriculum, and are presented with references, and a link to a photograph of Milligan.

simply to share further reading material on the broader topic of decolonization.

■ DISCUSSION

The resource presented here has been developed with the specific aim of reducing the practical barriers that exist for educators who wish to begin decolonizing their chemistry curricula, such as lack of time,[33] lack of fundamental knowledge on how to decolonize a since course, and lack of awareness of examples from ethnic minority scientists and those from indigenous cultures. Such examples have not been included in common textbooks or lecture courses historically.[34,35] The material provided can usefully be employed to connect to themes such as *The diverse histories of chemistry and science*, and *Role model scientists from different backgrounds and cultures* as part of the strategic approach to decolonizing a curriculum.[1,36]

Beyond the work presented here, we acknowledge that it is important to consider how examples of the contributions of ethnic minority scientists are introduced into teaching materials in a meaningful way. Reis and Mensinger have reported that biographical information on diverse scientists should connect to the taught content rather than act as stand-alone elements,[4] while Gee et al. suggest the use of "Try this" problems to connect with lecture material.[30] A study of student views on decolonization suggests that who is teaching the curriculum, and how it is delivered (e.g., through the use of active learning) are also important considerations.[37,38]

Finally, we acknowledge the inherent challenges of working on this project that arise from the authors all being scientists by training. The development of the resource has involved the reading and interpreting of historical documents and electronic material from which we have abstracted details, generally without exploring the wider historical validity of the chosen examples. There are clearly potential problems around accuracy in this approach, particularly for the older examples. Furthermore, terminology and classification of examples (by date and by geographical area) are additional problems we encountered. Despite these challenging issues, we have completed this work because we believe that decolonization has the potential to positively impact on the learning experiences of minoritized chemists, and a resource (even with limitations) is urgently needed.

There is almost certainly fundamental historical research that should be conducted to better understand the way in which scientific endeavors from non-northern-western communities and individuals has influenced research that has subsequently been solely attributed to northwestern global scientists. Considerable further work is warranted to develop a fuller academically historical database of examples of scientific work from minoritized global communities that are relevant to today's academic chemistry curriculum.

■ CONCLUDING REMARKS

Fostering a sense of belonging is increasingly recognized to be an important factor in building a more inclusive higher education environment for students who are members of minoritized groups. White et al. have written eloquently on this recently, stating that best-practice should include cultivating relationships, allowing students to make mistakes, and the importance of group work.[39] A sense of belonging within an academic department or discipline for minoritized students can also be fostered by providing teaching materials and activities that include role-model individuals or indigenous groups. The resource provided here provides the first openly available document for chemistry lecturers to use as they begin working toward decolonizing their curricula and hence improving the learning environment for students from ethnic minority groups. We share the resource conscious of its limitations, but are confident that it will reduce barriers to enable a greater number of academics to embark on decolonizing their curricula. This work is important for increasing participation and attainment by students from minority ethnic groups. Furthermore, we wish to encourage the wider funding of the development of resources to decolonize the curriculum. Such material is urgently needed across higher education, and also for primary and secondary chemistry education.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c01003.

Section S1: List of contributions from Asia, the Middle East, and Africa; Section S2: List of short Biographical Profiles of 20th Century Asian and Black American Chemists; Section S3: List of other resources; Section S4: List of references (PDF)

Section S5: Survey to Assess the Utility of the Resources (PDF)

■ AUTHOR INFORMATION

Corresponding Authors

Kelechi O. Uleanya − *Department of Chemistry, University of York, York YO10 5DD, United Kingdom*; Email: kelechi.uleanya@york.ac.uk

Caroline E. H. Dessent − *Department of Chemistry, University of York, York YO10 5DD, United Kingdom;*

orcid.org/0000-0003-4944-0413;
Email: caroline.dessent@york.ac.uk

Authors

Samantha K. Furfari − *Department of Chemistry, University of York, York YO10 5DD, United Kingdom*

Leonie C. Jones − *Department of Chemistry, University of York, York YO10 5DD, United Kingdom;* orcid.org/0000-0003-0950-5075

Kgato P. Selwe − *Department of Chemistry, University of York, York YO10 5DD, United Kingdom*

Amelia B. Milner − *Department of Chemistry, University of York, York YO10 5DD, United Kingdom*

Complete contact information is available at:
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Notes

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