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Inclusive Outreach Activity Targeting Negative Alternate Conceptions of Chemistry

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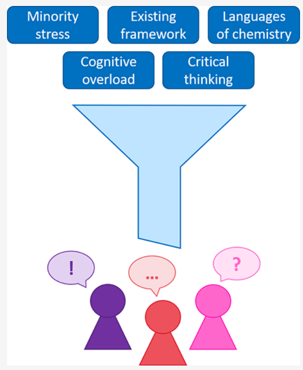
ABSTRACT: Chemistry outreach has an important role in building trust between scientists, scientific research, and the public. Ensuring that chemistry outreach is relevant and inclusive to diverse participants is necessary to achieve genuine inclusion of individuals from minoritized groups. We describe the design, delivery, and evaluation of an outreach workshop developed to challenge negative alternative conceptions of chemistry, counter chemophobia, and develop critical thinking skills. This was developed with the principles of equality, diversity, and inclusion at its core, designed for and delivered to participants from marginalized groups that are underrepresented in the chemical sciences. The approach was informed by critical theory, constructivism, and cognitive load theory. Autobiographical critical reflections, thematic analysis of workshop transcripts, pre- and postquestionnaires, and participant feedback (N = 7, response rate = 100%) were used to evaluate the activity and identify recommendations for practitioners. The activity received positive feedback from participants, who were able to demonstrate identification and critical analysis of chemophobic attitudes.



KEYWORDS: *General Public, Continuing Education, Philosophy, Public Understanding/Outreach, Collaborative/Cooperative Learning, Misconceptions/Discrepant Events, Applications of Chemistry, Minorities in Chemistry, Problem Solving/Decision Making, Constructivism*

Inequality exists in access, participation, and experience in science, technology, engineering, and math (STEM) education and careers.[1−3] Stereotypes about who can and cannot succeed in STEM persist, which put additional burden on minoritized students in STEM courses and majors. Studies have focused on individual marginalized characteristics such as race,[4−11] gender,[12] disability,[13] sexuality,[14−17] or socioeconomic status.[18−20] Often when marginalized groups are discussed, only brief reference is made to the concept of intersectionality; individuals who hold multiple marginalized identities will experience compounded and unique disadvantages.[21,22] While considering a single marginalized characteristic can uncover valuable insights, the complexity and diversity of lived experiences is often lost. For instance, when McGee and Bentley explored the experiences of undergraduate and postgraduate black women scientists, in addition to structural racism and sexism, they reported racialized sexism, and sexualized racism, and these experiences were sources of significant strain.[23]

The importance of focusing chemistry education research efforts on diversity and justice was highlighted in a recent call to action in the Journal of Chemical Education, which encouraged the chemistry community to "*explore topics of social and environmental justice in the chemical and scientific enterprise*" and "*the cultivation of inclusive learning environments*".[24] A wide variety of approaches to further equality, diversity, inclusion and justice have been reported.[25] Examples within chemistry education include outreach,[26,27] developing justice-centered pedagogies,[28] adopting student partnership approaches,[29,30] adopting culturally relevant pedagogies,[31] case study evaluation of inclusivity efforts,[32] and inclusive flipped teaching methods.[33] White et al. concluded their recent review with the recommendation to build learning environments and communities where minoritized students feel welcome, valued, and validated.[34] In this paper we discuss an outreach activity developed with Equality, Diversity, and Inclusion (EDI) at its core.

In addition to educating and engaging the public,[35] chemistry outreach has an important role in building trust between scientists, scientific research, and the public. Ensuring that chemistry outreach is relevant and inclusive to diverse participants is necessary to achieve genuine inclusion of participants from minoritized groups. A chemistry for all approach has benefits to individuals such as consumer criticality,[36] and developing health and environmental literacy.[37,38] These skills are hugely important but often overlooked, as individuals may not see the relevance of chemistry in their everyday lives.[39−43] Chemophobia, a fear of chemistry or chemicals, is thought to be a contributing factor in this lack of chemical literacy.[44−46] A fear of chemistry or

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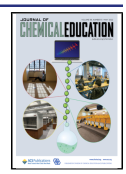

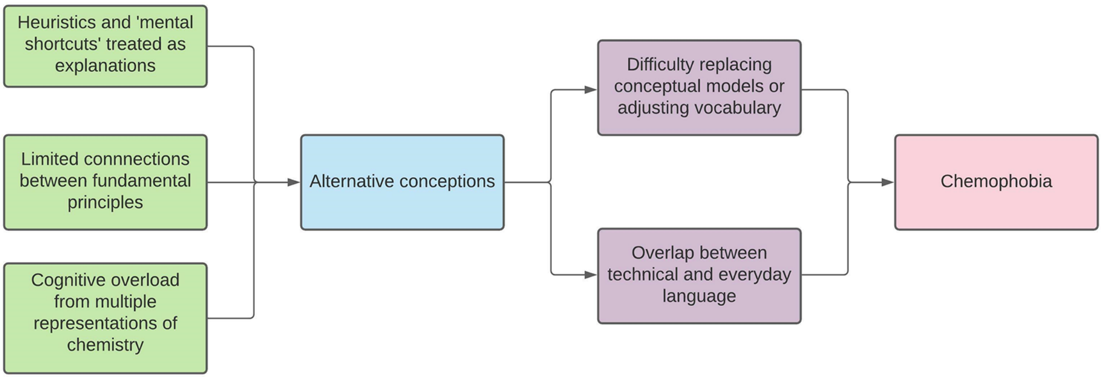

Figure 1. Summary of proposed model describing the factors involved in the development of alternative conceptions and chemophobia. [Descriptive text: The model is represented using connected text boxes. Beginning on the left, three vertically aligned green boxes contain the text: "*Heuristics and "mental shortcuts" treated as explanations*", "*Limited connections between fundamental principles*", and "*Cognitive overload from multiple representations of chemistry*". These text boxes are connected by an arrow to a blue box containing the text "*Alternate conceptions*", which is then connected by arrows to two purple boxes contain the text: "*Difficulty replacing conceptual models or adjusting vocabulary*" and "*Overlap between technical and everyday language*". These purple boxes are connected by arrow to a pink box containing the text "*Chemophobia*".]

chemicals is commonly attributed by chemists to a lack of knowledge.[47] However, this is only one aspect of chemophobia: these fears, such as the perception of chemicals as "dangerous" in contrast to "safer", "natural" substances, can be linked to alternative conceptions, as outlined in Figure 1.[48−50]

Alternative conceptions are ideas at variance with scientifically accepted knowledge. These ideas influence how people understand new information, as individuals relate information to their existing knowledge in ways that are often intuitive and may not be scientifically accurate.[51] Conceptual frameworks, defined by Wang and Barrow as "*a network of interrelated assumptions, knowledge and beliefs*",[52] are not necessarily altered by acquisition of new information.[53−55] Adjusting meanings of technical vocabulary or altering a conceptual framework once it has been formed is difficult.[50,56] These alternative conceptions can give rise to serious fears and negative perceptions of chemistry. Such fears have been noted by researchers of vaccine hesitancy and vaccine refusal.[49,57] Multiple individuals interviewed by Ward and colleagues referenced "*bad chemicals*" in food, fabrics, and paints, with one individual stating that there were "*no chemicals*" in their home.[49] While this assertion is untrue, it is demonstrative of the underlying conceptual model that some individuals hold—that all chemicals are synthetic, dangerous, and entirely separate from the world around them.

As observed by multiple research groups, vaccine-hesitant or vaccine-refusing interviewees often consider themselves to have "*done the research and to be knowledgeable about the issues*".[49,58,59] Similarly, the subgroup analysis from Public Attitudes found that the group most likely to prefer "natural" chemicals and to generally perceive chemistry as unnatural also considered themselves to be "fairly" or "very" well-informed about chemistry.[41]

We must avoid reductionist analyses when challenging chemophobia. Uncritically portraying the benefits of chemistry while ignoring the risks and harm associated not only weakens chemistry communication and erodes public trust, but it also fundamentally undermines the core principles of scientific research. Chemistry discourse is often highly polarized, with scientists and educators promoting the positives while the wider public are often sceptical or concerned about the impact of chemistry on their lives.[39,41,60]

Using deficit-centered approaches as the bases of our scientific communication work runs the risk of reinforcing these existing biases. Furthermore, a reductionist analysis that only considers the problem at the level of the individual omits the impact of structural factors. If we consider limited understanding as a knowledge deficit, or a skills deficit, without asking why this occurs or how we have defined "deficit", then we ignore the situational context. Structural discrimination specifically affects marginalized groups, introducing additional barriers and disadvantages that nonmarginalized individuals either do not experience, or experience to a lesser extent.[61−63]

■ PROJECT AIMS

1. To develop educational activities and resources to challenge negative, alternate conceptions of chemistry (chemophobia).
2. To develop an effective outreach activity designed for and delivered to participants from marginalized groups that are underrepresented in the chemical sciences, including but not limited to women and nonbinary people; other marginalized groups include Black, Asian, and minority ethnic (BAME) people, LGBTQ+ (Lesbian, Gay, Bisexual, Transgender, Queer) people, and disabled people.
3. To learn from individuals reporting alternative conceptions and chemophobia.

■ THEORETICAL FRAMEWORK

The key underpinning theories that motivated and informed this project were as follows.

Critical Theory: Critical theories aim to highlight and overcome the uneven balance of power between groups of individuals.[64−71] In the context of education, critical theory is used to seek a diversified and equitable education, through which learners develop critical thinking skills empowering them to challenge the uneven balance of power directly.[64,67,68,72]

Constructivism: Constructivist theory of learning holds that individuals apply their existing knowledge to new information to understand and incorporate it into what they know.[73−78]

Cognitive load: Cognitive load is related to the amount of information that can be held in our working memory. Within cognitive load theory, cognitive load, and related to this, our ability to learn by processing new information, is affected by different factors categorized as intrinsic, germane, and extraneous.[79]

Language, symbolism, and representations: Chemistry challenges learners to use, translate between, and manipulate information on several "*levels of thought*": macroscopic, submicroscopic, and symbolic.[80] In order to understand and describe what is happening at the atomic level, students must effectively learn a new language of chemical vocabulary and symbols.[77]

Inclusive Design for Learning (IDL): IDL aims to build equitable and adaptable learning experiences by ensuring their design is informed by the diversity of learners.[81,82]

The theories described above and the connections between them form the theoretical framework for this project. Constructivist theory of learning is key to understanding how alternate conceptions of chemical phenomena are formed, challenged, and changed. Critical theories both motivate and inform our approach, providing the justification for targeting outreach activities toward participants with marginalized identities, requiring participants to be centered in both educational activities and their evaluation. Individual circumstances, such as feeling uncomfortable in the learning environment, can contribute to extraneous cognitive load, reducing capacity of working memory, and hence learning ability. Furthermore, being a marginalized individual can manifest physically as "minority stress", and stress generally is known to increase cognitive load.[83,84]

Within the chemistry education context, it is important to consider the challenges for learners introduced by the requirement to translate between several "levels of thought". We consider challenges developing chemical literacies to be relevant to the development of chemophobic attitudes. Returning to the human context, Mahaffy[85] and Sjöström[86] championed the importance of taking a holistic, "*bildung-oriented*"[87] approach to chemistry education, which includes human perspectives (applied chemistry, sociocultural context, and critical-philosophic approaches) in addition to macroscopic, (sub)microscopic, and symbolic representations.[80,88] Educational inequalities may affect the development of chemophobic attitudes, and it is important that we acknowledge the personal contexts of their learning environment and prior experiences.

Finally, and most importantly, the outreach activities developed must provide an equitable experience for all participants, which considers individual access needs in an inclusive manner. We will employ inclusive design principles and meet the individual requirements of all participants.

DESIGN AND DELIVERY OF THE OUTREACH ACTIVITY

The outreach activity involved a synchronous face-to-face session facilitated by AP involving small groups of participants, most of whom had singly or multiply marginalized identities.

Design Principles

The central design principles were equality, diversity, and inclusion, reducing cognitive load,[79] and applying Blooms' taxonomy as a framework.[89] Putting EDI at the core of activity design is a key novel aspect of this work; marginalized groups are under-served, as they are rarely the specific targets of outreach work, so there is limited access and opportunity to engage with inclusive chemistry education.[33] This work took a student-led approach; collaborative pedagogies are linked to increased attainment, belonging and engagement.[90−93]

This activity sought to create a safe space where those from minoritized groups were in the majority, and the workshops were led by a sensitive student facilitator with relevant lived experience. The main strategies used to reduce extraneous load were removing hierarchies by adopting a facilitator role; providing a supportive and inclusive learning environment; and presenting a combination of integrated visual and auditory material;[94,95]

The activities were structured in three stages of increasing complexity; this approach was informed by Bloom's taxonomy, in which learning and assessment (e.g., recall, analysis, and evaluation) is categorized into a hierarchy of increasing complexity.[89] Evaluating and critically assessing evidence are among the highest-level skills in the taxonomy, and accordingly the activities were designed to give learners space to develop their skills as they progressed from identification of concepts to analysis and finally to critical evaluation.

OVERVIEW OF WORKSHOP AND LEARNING RESOURCES

The activity consisted of three sections, outlined in Figure 2; a lesson plan and teaching materials can be found in the Supporting Information.

Figure 2. Outline of workshop methodology. [Descriptive text: The model is represented using connected text boxes. On the left, a single purple box contains the text "Venn diagram card sort"; this is linked by an arrow to the middle, blue box, containing the text "Risk matrix card sort". This middle blue box is connected by an arrow to a green box on the right, which contains the text "Text evaluation and discussion".]

The first section was a card sort activity which required participants to distinguish between chemical and physical changes (see Figure 3 for example); card sorts are established as a method of exploring an individual's ability to recognize underlying principles, a key aspect of alternative conceptions and improving chemical literacy.[96−98] This activity was designed so that participants could build confidence and ensured that everyone had the foundation knowledge necessary for the workshop; multiple representations were included in the examples so that participants could familiarize themselves with the macro, submicro, and symbolic languages of chemistry. Participants' discussions and verbal justification allowed the separation of simple recall from understanding and was an opportunity to elicit potential alternative conceptions.[96,97]

The second section involved placing a series of activities on a risk matrix and then justifying their placement (Figure 4).[99,100] The ability to evaluate risk is a key skill, and one suggested to be inversely related to chemophobia.[101−104] In both card-based tasks, cards were designed to be simple and easy to read and were provided as both physical laminated

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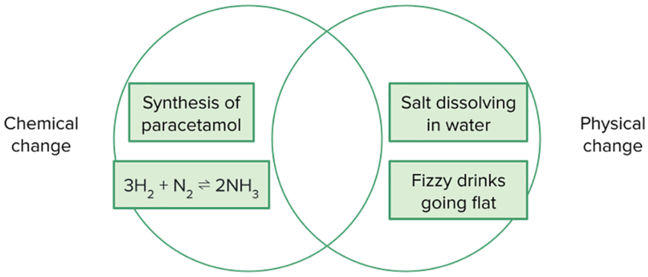

Figure 3. Example Venn diagram card sort activity. Participants were asked to place example processes on a Venn diagram as examples of either chemical change, physical change, or processes involving both. Processes were written in different forms, both plain text and symbolic. [Descriptive text: A Venn diagram of two overlapping green circles. The circle on the left is labeled "chemical change" and contains two green text boxes, the first reading "Synthesis of paracetamol" and the second reading "$3H_2$ + N_2 equilibrium arrow $2NH_3$". The circle on the right is labeled "Physical change", and contains two green text boxes, the first reading "Salt dissolving in water" and the second reading "Fizzy drinks going flat".]

cards and as digital files (to support learners with visual impairments). Additionally, participants were asked if they had any additional access needs—where these were raised, adjustments were discussed with participants and adaptations made as necessary.

The final section prompted participants to consider how chemical and scientific studies can be flawed, and then asked them to critically read a newspaper article about a chemistry topic to identify and evaluate misrepresented or questionable scientific practice or reporting. Again, participants were asked to verbally discuss and justify the elements they had identified to elicit reasoning.[96] This was followed by a brief discussion of the potential wider impacts of limited criticality, and a short plenary at the end of the workshop.

■ SAFETY CONSIDERATIONS

This activity involves card sorts, analytical reading, and verbal discussion, and there are no safety hazards associated with these activities. However, it was noted that use of overly complex or specific material could be detrimental as this could be stressful for participants. To ensure that the difficulty of tasks was suitable, a content review was conducted with four secondary-level STEM trainee teachers. These individuals were asked to review the workshop content to identify areas where secondary school level science learners might struggle so that content could be amended as appropriate.

	Trivial hazard (1)	Mild hazard (2)	Moderate hazard (3)	Severe hazard (4)
Rare (1)	1	2	3	4
Unlikely (2)	2	4	6	8
Possible (3)	3	6	9	12
Probable (4)	4	8	12	16

where 1-2 = mild risk, 3-5 = moderate risk, 6-10 = severe risk and 11 or above = intolerable

	Trivial hazard (1)	Mild hazard (2)	Moderate hazard (3)	Severe hazard (4)
Rare (1)	1	Ethanol (Year 12 chemistry)	Diethyl ether (undergraduate)	4
Unlikely (2)	2	4	6	*n*-butyllithium (undergraduate)
Possible (3)	Dilute ethanoic acid (Year 4 science)	6	9	12
Probable (4)	4	8	12	16

where 1-2 = mild risk, 3-5 = moderate risk, 6-10 = severe risk and 11 or above = intolerable

Figure 4. Example blank (top) and completed (bottom) Risk Matrix Activity table. Participants were asked to place activities on a risk matrix, using information provided about the chemical(s) used and the approximate age and education level of those conducting the activity (e.g., ethanol, year 12 chemistry students). Safety data sheet information was also provided for each chemical. [Descriptive text: Two tables, both with four headings at the top and four headings at the left side. The headings along the top rate the severity of a hazard, from trivial (1) to severe (4). The headings along the left side rate the probability of a hazard, from rare (1) to probable (4), and the boxes of the table contain the product of these values. The values are color-coded, where 1−2 are green for "mild risk", 3−5 are yellow for "moderate risk", 6−10 are orange for "severe risk" and 11−16 are red for "intolerable risk". Four example activities have been placed on the second table: from lowest to highest, these are "Ethanol (Year 12 chemistry)" ranked 2 (rare, mild hazard); "Dilute ethanoic acid (Year 4 science)" ranked 3 (trivial, possible hazard); "Diethyl ether (undergraduate)" also ranked 3 (moderate, rare hazard"; and "*n*-butyllithium (undergraduate)" ranked 8 (severe, unlikely hazard).]

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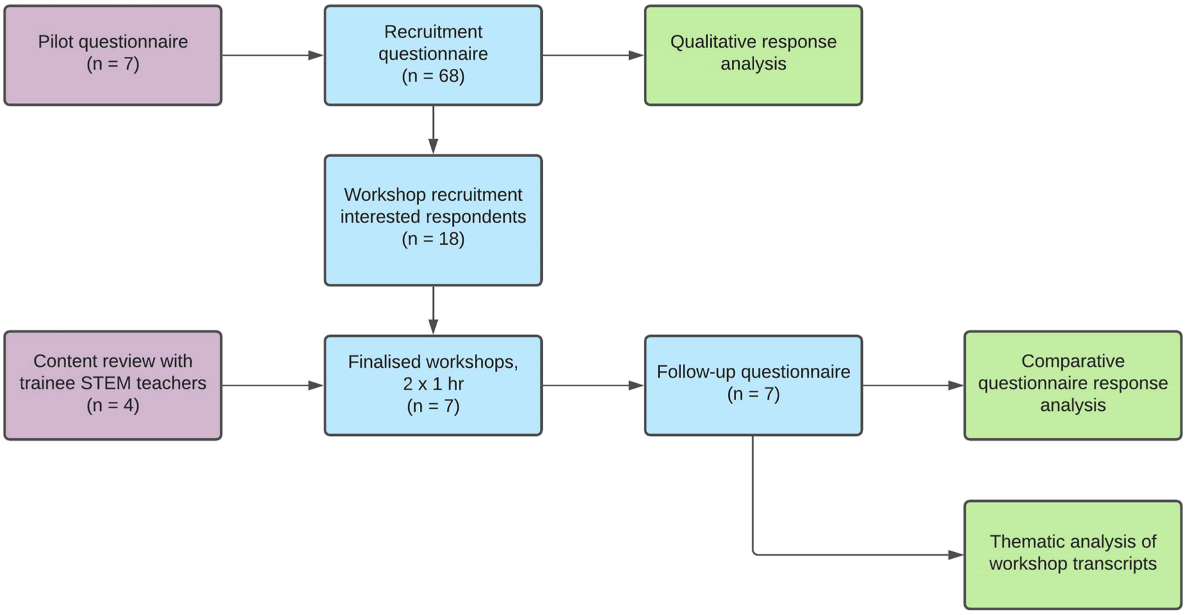

Figure 5. Overview of the recruitment of participants and evaluation of outreach activity involving piloting and then deploying the recruitment questionnaire, identifying and recruiting participants for the outreach workshop, reviewing the content of the outreach workshop with trainee STEM teachers, delivery of the finalized workshops, followed by deployment of the postworkshop questionnaire, and analysis of both the workshop transcripts and the questionnaire data. [Descriptive text: Flowchart begins with "pilot questionnaire (n = 7)", an arrow connects this text box to another with the text "Recruitment questionnaire (n = 68)", which is connected by arrows to two boxes, one reads "Qualitative response analysis" and the other reads "Workshop recruitment interested respondents (n = 18)". Both this box and another which reads "Content review with trainee STEM teachers (n = 4)" are connected by arrow to "Finalized workshops, 2 × 1 h (n = 7)", which is connected by arrow to "Follow-up questionnaire (n = 7)", which is connected by arrow to two boxes "Comparative questionnaire response analysis" and "Thematic analysis of the workshop transcripts".]

IMPLEMENTATION OF OUTREACH ACTIVITY

This 1-h workshop was conducted as a standalone activity in the spring term with two separate groups of unique participants (N_1 = 4 and N_2 = 3 respectively). The first two sections of the workshop (chemical changes card sort, risk matrix placement) were conducted in pairs or threes, with the evaluation and discussion of the article conducted as a whole group.

Small-group work was intended to promote collaboration between participants, allow them to ask questions, and to discuss their ideas and reasoning without judgment. This supported students who may not have felt comfortable challenging ideas or expressing their confusion in a classroom-style situation to do so.

PARTICIPANT RECRUITMENT

Workshop participants were recruiting via a recruitment questionnaire (see Figure 5, survey provided in Supporting Information) to assess incidence of chemophobic attitudes and collect demographic data. This approach allowed us to identify participants with marginalized identities, who were willing and available to attend the workshops.

Participants were recruited through humanities department emails to undergraduate students; humanities department Twitter accounts; University liberation networks' (a collective term for the LGBTQ+, BAME, Disabled, and Women and Nonbinary student groups) Facebook groups and Twitter accounts; and authors' Facebook and Twitter accounts (see Table 1 for demographic data for recruitment questionnaire and workshop participants).

Students studying humanities were targeted directly to ensure that the workshop would be delivered to individuals most likely to benefit. Greater prior knowledge of chemistry is suggested to be inversely correlated with incidence of chemophobia.[47,105] Therefore, humanities departments were contacted and asked to promote the questionnaire to their students, as these students were less likely to have A-Level or higher previous chemistry study.

University liberation networks were also specifically contacted to ensure inclusion of participants with marginalized identities. These groups were contacted and asked to promote the questionnaire via their Facebook groups, and Twitter platform if applicable. Specific targeting of marginalized groups' networks was key to achieving supported diverse and inclusive workshop spaces, as this ensured that more than 50% of workshop participants were members of a marginalized group (Table 2). Inverting minority/majority group dynamics avoided placing the burden of inclusion on marginalized individuals and promoted participant wellbeing and confidence.[106−109]

EVALUATION OF OUTREACH ACTIVITY

The outreach activities were evaluated using pre- and postworkshop questionnaires, thematic analysis of the transcripts of the recorded workshops, and autobiographical facilitator reflections.

Ethical Considerations

Ethical approval was granted by the Education Department Ethics Committee for data collection from questionnaires, educational activities, and for recording and transcription of the workshops. The survey was both voluntary and anonymous; participants gave informed consent for their participation and could exclude themselves or quit at any point

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Table 1. Demographic Data for the Recruitment Questionnaire and Workshop Participants

Recruitment Questionnaire	
Demographic Variable	Number of Participants (N = 68)[a]
Female	37
Male	18
Nonbinary	12
Trans	15
Cis	52
LGBQ+	21
Not LGBQ+	46
Disabled	22
Abled	37
GCSE Science	7
GCSE Chemistry	16
A Level	17
Undergraduate	19
PhD or higher	5
Workshop 1 Participants	
Demographic Variable	Number of Participants (N = 4)[a]
Male	3
Female	1
Nonbinary	0
LGBQ+	2
Not LGBQ+	1
Disabled	1
Abled	3
Workshop 2 Participants	
Demographic Variable	Number of Participants (N = 3)[a]
Male	0
Female	1
Nonbinary	2
LGBQ+	3
Not LGBQ+	0
Disabled	2
Abled	1

[a]Where the category values do not sum to the total, this is where participants have selected "other", "prefer not to say", or otherwise declined to state for a given characteristic. These participants have been omitted from the table accordingly.

Table 2. Outreach Activity Participants' Experiences of Marginalization

Workshop	MM[a] (%)	SM[b] (%)	NM[c] (%)
N_1 = 4	25	50	25
N_2 = 3	100	0	0

[a]MM = Multiply marginalized. [b]SM = Singly marginalized. [c]NM = Nonmarginalized.

during the survey or workshop. All data were collected and included in the analysis.

LIMITATIONS

The most significant limitations of this study was the small sample size and related to this the diversity of the participants; men and Black, Asian, and Minority Ethnic Group individuals were underrepresented. Recording the experiences of a greater number of participants could provide broader insight into the diversity of individual experiences. Importantly, we did not set out to identify generalizable conclusions of the experiences of marginalized individuals; their experiences are individual. Studies of the experiences of individuals from marginalized groups often have smaller sample sizes and provide qualitative evidence, rather than quantitative conclusions.[110] It is important that the voices of individuals with marginalized identities are heard. However, the sample size does limit the reliability of quantitative evaluation of participants' reduction in chemophobia score. Included in the supplementary are the workshop materials and surveys used in the evaluation, we hope that readers will be able to use these to deliver and evaluate further workshops.

WORKSHOP FACILITATOR PERSONAL REFLECTION

"Personal lens" is a way to consider how an individual's intersecting identities and experiences affect their perception of the world around them. Information regarding the individual providing an autobiographical reflection provides valuable context. The following autobiographic reflection was conducted by author AP, a final-year integrated Masters in Chemistry student with lived personal experience of marginalized identity and minority status.

This was a novel challenge; as a student with no formal teaching experience, organizing and running workshops induced some anxiety. There was also the difficulty of striking a balance between keeping the discussion focused and running to time while not attempting to position self-as an authority, in line with the critical theory frameworks utilized for this research. However, the workshops were exciting and enjoyable to conduct, both for instructor and participants. The intended aim of promoting an inclusive space for collaborative discussion was achieved; all participants were enthusiastic, engaged with material, and contributed to discussion.

The workshops could be developed further by adapting for remote synchronous delivery. This could allow a broader range of interested individuals to participate in a workshop, as several interested participants could not attend for scheduling reasons.

In addition, a key area for development would be working in partnership with a Black, Asian, or minority ethnic facilitator to support inclusion and effective recruitment from the BAME community. Better promotion of the questionnaire could have improved participation from BAME respondents, and additional relevant student and staff racial equality groups could have been engaged.

PRE- AND POSTWORKSHOP QUESTIONNAIRE

Questionnaire Methodology

The recruitment questionnaire was designed to explore variations in reported chemophobia. Eight questions in the questionnaire were used or adapted, with permission, from the authors of *Public Attitudes to Chemistry*; a further eight were original, in similar style and format.[41] These questions provide an indicative quantitative assessment of chemophobia by asking respondents to rate their agreement on a 10-point scale with statements either endorsing or refuting alternative conceptions linked to chemophobia, e.g., "All chemicals are man-made". Some statements had reversed ratings, where agreement would indicate lower chemophobia, e.g., agreement with "Everything is made of chemicals". Ratings for these "reverse" statements were inverted (11 − answer). Ratings were then averaged across questions to obtain a mean chemophobia score.

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Table 3. Core Themes, Subthemes, and Examples Arising from Qualitative Data Collection in Recruitment Questionnaire

Core theme	Subtheme	Example
Thinking process	Gaps in knowledge	"Sodium and... calcium" [in reference to NaCl]
	Hazard analysis	"I'd have said that is more dangerous than that, because..."
	Reflecting on assessment structure	"We've got a Venn diagram, so there must be things in the middle"
	Intuitive and unjustified	"That feels chemical, I do not know why though"
	Subject knowledge	"Salt dissolving in water, there's no chemical change, but there is change in bonding interactions"
	Preconceptions	"Ultimately it is [water] a safe thing..."
	Alternative explanation	"...from my perspective that is more an indicator that autism can strike at any stage in development..."
	Impact of limited criticality	"It means you have to take things at face value..."
	Critical evaluation	"...something like this is a great scapegoat, is not it?"
Emotional response	Assessment	"I feel like it is to mark us"
	Hesitation	"I do not—I do not know if this could go in..."
	General	"I had never heard the like, actual this-is-the-steps thing, it is... wild."
Context and concepts	Micro vs macro	"Physical can be a change in the properties of the thing, whereas chemical is a change in what's there"
	Chemical change	"We start with two things and get a different chemical, that is a chemical change"
	Considering extraction process	"I think extraction implies chemical"
	Hazard/precaution content	"There shouldn't be anything that ignites it, and if you have the protection then you should be fine"
	Relevant examples of content/context	"They used lots of unreplicable results"
	Discussion of wider context	"Conflating diagnosis with how many people have autism"

The reliability was assessed by calculating Cronbach α score, $\alpha = 0.761$; this measures the internal consistency of a questionnaire and how inter-related its questions are, where α closer to 1 indicates greater internal consistency.[111,112] Questionnaires are an established method of determining chemophobia, and of studying alternative conceptions more broadly, in the literature.[45]

The questionnaire also provided qualitative data from responses to two open-text questions; these questions allowed participants to justify and expand on their responses. The first question asked respondents to describe factors influencing chemistry reporting in the media, to gauge respondents' criticality. The second open-text question asked respondents to describe factors influencing their engagement with chemistry; this was included as marginalized individuals in STEM often report a "chilly climate" and feelings of isolation.[113−115]

Comparison of Pre- and Postworkshop Questionnaires

The mean reduction in chemophobia score following the workshops was calculated as 9% ($n = 7$, $p = 0.085$); this provided an indication of the efficacy of the session. This was consistent with participants' feedback, where they described a desire to "*re-educate*" themselves after finding that the workshops could "*reignite*" their enjoyment of chemistry.

Participants also described factors influencing their engagement with chemistry, with some reflecting that they felt women were not encouraged or represented in chemistry. Others noted that memorization of reagents and conditions was challenging for individuals whose disability impacted memory and could preclude further chemistry study.

■ THEMATIC ANALYSIS OF WORKSHOP TRANSCRIPTS

Workshops were audio-recorded, transcribed, and thematically analyzed using three core themes, and several subthemes. Key subthemes were initially identified using open coding from their prevalence in transcripts, then grouped into "core" themes (see Table 3).[116] Coding consistency was checked between authors to ensure reliable analysis of transcript data.

Development of Thinking Process

In the early stages of the workshop, the key themes were grouped around confusion, suggesting limited confidence or uncertainty. However, participants were focused on subject knowledge and relevant questions, indicating that while their subject knowledge may have been fragmented, they retained key self-evaluation skills.

As the workshop progressed, the main theme of participant's thinking process became their existing conceptual frameworks, centered on their judgment of hazards and risk mitigation. Participants typically used their own judgment in addition to hazard information supplied, indicating their understanding of context in assessing risk.

In the final part of the workshop, evaluative thinking processes were the main theme, with participants identifying and deconstructing aspects of poor scientific reporting/methodology. Individuals were able to consider and evaluate claims based on evidence provided alongside existing knowledge, and concepts discussed were based in their social context, with participants describing potential consequences of limited criticality and poor chemical literacy.

Reduced incidence of hesitation themes indicates a clearer understanding of workshop expectations, concurrent with progression to more open content where activity was less structured and it was clear that there were no "wrong" answers.

Participant Experience and Engagement

Workshop participants generally perceived the activity as positive, with questionnaire responses describing it as "*well put together*" and "*enjoyable*". Others noted that they were now more enthused about chemistry, with some intending to follow up with further reading. This positive response indicates that the aim of delivering an effective outreach activity run by and for marginalized individuals was achieved.

During the workshops, all participants enthusiastically took part in detailed discussion about the potential effects of chemophobia and limited chemical literacy, with individuals explaining a wide range of possible impacts. This ability to recognize and critically consider information would suggest

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that our first aim of creating an outreach activity to challenge negative alternate conceptions was met, and that our efforts to be inclusive were successful.

Chemophobia and Alternative Conceptions

Using diagrammatic representations can assist in constructing accurate conceptual frameworks.[56,117,118] This links to the third aim of supporting individuals reporting alternate conceptions and considering methods to support them so that they continue to progress in chemical study. However, poor diagrams can also induce alternative conceptions, as learners can overemphasize superficial features and miss necessary information.[119−121] For educators, diagrams used should be clear and provide an appropriate level of detail; checking learners' understanding may also assist in identifying and countering alternative conceptions. Workshop participants noted that drawing diagrams had assisted and that discussing chemophobia in a supportive space helped them to "*get it straight in my head*" and work through their alternative conceptions.

Participants were able to identify and critically analyze chemophobic attitudes in text and in their own perceptions. On discussing the removal of thiomersal, a mercury-containing compound, from vaccines, one participant remarked that "*as soon as you put that up, I saw the mercury*", assuming that discussion would relate to the dangers. They were surprised when it did not, and later commented that "*that's a personal bias there, that I've identified that as dangerous*".

Recommendations for Practitioners

- Facilitate nonjudgmental discussions around chemophobia where all participants feel able and comfortable to share their views and ideas, as demonstrated here for university students and by Belenguer-Sapiña et al. for high school students.[47]
- We recommend working with local liberation groups and staff/student networks to aid recruitment of participants and advertising outreach activities in order to improve the diversity of potential participants.
- Highlight the steps you are taking to promote accessibility and inclusivity when advertising outreach activities and recruiting participants rather than leaving the burden on potential participants to make enquiries about whether their needs would be accommodated.
- We observed that inverting traditional group dynamics by ensuring that typically minoritized participants were not in the minority in the workshop groups and using small group sizes were effective approach in creating safe, inclusive, and effective learning environments.
- We felt it was important that the facilitator assumed a supportive rather than an authoritative role in the workshops.
- We found that the lived experience of the facilitator was highly valuable and would recommend practitioners without lived experience of belonging to a marginalized group to consider cofacilitating with someone with relevant lived experience to your target group(s).

CONCLUSION

The workshops described here challenged chemophobia by scaffolding the development of critical thinking and evaluative skills in a chemistry context. The first paired card-sort activity, identifying and describing chemical and physical changes, prompted participants to consider their existing conceptual frameworks and identify where their conceptions originated.

The second paired activity, placing cards on a risk matrix, engaged participants to identify hazards and analyze the risk associated with a given activity. This section was designed to encourage participants to think about the wider context in which activities were conducted, and to think critically about the limitations of the safety data provided.

The final activity, conducted as individual reading followed by group discussion, asked participants to critically evaluate a newspaper article on a chemistry topic. In this activity participants considered the claims made and evaluated these based on the evidence provided and described and challenged the implicit chemophobic bias in the article. This discussion, and the subsequent discussion regarding the wider potential impacts of chemophobia, were student-led, with critical theory underpinning facilitation and participants' analysis and evaluation.

Individuals in marginalized groups are best placed to identify the support their community needs, hence listening to and uplifting their voices must be the core of any attempts to diversify outreach activities. The diverse lived experiences of the authors were fundamental in designing, facilitating, and evaluating an inclusive outreach activity to challenge chemophobic attitudes and develop critical thinking skills. The facilitator and the participants perceived the workshop activities to be effective and enjoyable, and comparison of the pre-/postworkshop questionnaires indicated a reduction in the measured level of chemophobia for this small sample. We hope that readers will use the resources provided to expand on this study.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.1c00400.

Recruitment and Postworkshop Questionnaires (PDF)
Teaching Notes (PDF) (DOCX)
Workshop Resources (PDF)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) *Diversity Landscape of the Chemical Sciences*; The Royal Society of Chemistry, 2018.
(2) *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2019; NSF 19–304*; National Science Foundation, Directorate for Social, Behavioral and Economic Sciences, National Center for Science and Engineering Statistics, 2019. https://ncses.nsf.gov/pubs/nsf19304/ (accessed on October 2020).
(3) *Diversity Data Report*; The Royal Society of Chemistry, 2020.
(4) McGee, E. O.; Martin, D. B. You Would Not Believe What I Have to Go Through to Prove My Intellectual Value!" Stereotype Management Among Academically Successful Black Mathematics and Engineering Students. *American Educational Research Journal* **2011**, *48* (6), 1347–1389.
(5) Ginther, D. K.; Schaffer, W. T.; Schnell, J.; Masimore, B.; Liu, F.; Haak, L. L.; Kington, R. Race, Ethnicity, and NIH Research Awards. *Science* **2011**, *333* (6045), 1015.
(6) Bullock, E. C. Only STEM Can Save Us? Examining Race, Place, and STEM Education as Property. *Educ. Stud.* **2017**, *53* (6), 628–641.
(7) Vakil, S.; Ayers, R. The racial politics of STEM education in the USA: interrogations and explorations. *Race Ethnicity and Education* **2019**, *22* (4), 449–458.
(8) *Tackling Racial Harassment: Universities Challenged*; Equality and Human Rights Commission, 2019.
(9) Whitcomb, K. M.; Singh, C. Underrepresented minority students receive lower grades and have higher rates of attrition across STEM disciplines: A sign of inequity? *Int. J. Sci. Educ.* **2021**, *43*, 1–36.
(10) Bhopal, K.; Henderson, H. Competing inequalities: gender versus race in higher education institutions in the UK. *Educational Review* **2021**, *73* (2), 153–169.
(11) Joice, W.; Tetlow, A. *Baselines for Improving STEM Participation: Ethnicity STEM data for students and academic staff in higher education 2007/08 to 2018/19*; The Royal Society, 2021.
(12) *Experiences surrounding gender equality in the physical sciences, and their intersections with ethnicity and disability*; Equality Challenge Unit, 2016.
(13) Joice, W.; Tetlow, A. *Disability STEM Data for Students and Academic Staff in Higher Education 2007/08 to 2018/19*; The Royal Society, 2021.
(14) *Exploring the Workplace for LGBT+ Physical Scientists*; Institute of Physics, Royal Astronomical Society and Royal Society of Chemistry, 2019.
(15) Sinton, M. C.; Baines, K. N.; Thornalley, K. A.; Ilangovan, V.; Kurt, M. Increasing the visibility of LGBTQ+ researchers in STEM. *Lancet* **2021**, *397* (10269), 77–79.
(16) Royal Society of Chemistry LGBT+ Toolkit. https://www.rsc.org/new-perspectives/talent/inclusion-and-diversity/resources/lgbt-toolkit/ (accessed on January 2021).
(17) Cech, E. A.; Waidzunas, T. J. Systemic inequalities for LGBTQ professionals in STEM. *Sci. Adv.* **2021**, DOI: 10.1126/sciadv.abe0933.
(18) *Exploring the Relationship between Socioeconomic Status and Participation and Attainment in Science Education*; The Royal Society, 2008.
(19) Crawford, C. *Socio-economic Gaps in HE Participation: How Have They Changed over Time? IFS Briefing Note BN133*; Institute for Fiscal Studies, 2012. DOI: 10.1920/bn.ifs.2012.00133
(20) Olga, T. Examining the relationship between student's engagement and socioeconomic background in higher education. *Stud. Engagement Higher Educ. J.* **2021**, *3* (2), 141–157.
(21) Crenshaw, K. In *Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics*; University of Chicago Legal Forum: Chicago, 1989.
(22) Van Dusen, B.; Nissen, J.; Talbot, R. M.; Huvard, H.; Shultz, M. A QuantCrit Investigation of Society's Educational Debts Due to Racism and Sexism in Chemistry Student Learning. *J. Chem. Educ.* **2022**, *99*, 25.
(23) McGee, E. O.; Bentley, L. The Troubled Success of Black Women in STEM. *Cognition and Instruction* **2017**, *35* (4), 265–289.
(24) Wilson-Kennedy, Z. S.; Payton-Stewart, F.; Winfield, L. L. Toward Intentional Diversity, Equity, and Respect in Chemistry Research and Practice. *J. Chem. Educ.* **2020**, *97* (8), 2041–2044.
(25) Comarú, M. W.; Lopes, R. M.; Braga, L. A. M.; Batista Mota, F.; Galvåo, C. A bibliometric and descriptive analysis of inclusive education in science education. *Stud. Sci. Educ.* **2021**, *57*, 241.
(26) Santos-Díaz, S.; Towns, M. H. Chemistry outreach as a community of practice: investigating the relationship between student-facilitators' experiences and boundary processes in a student-run organization. *Chemistry Education Research and Practice* **2020**, *21* (4), 1095–1109.
(27) Santos-Díaz, S.; Towns, M. H. An all-female graduate student organization participating in chemistry outreach: a case study characterizing leadership in the community of practice. *Chem. Educ. Res. Pract.* **2021**, *22*, 532.
(28) Morales-Doyle, D. Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education* **2017**, *101* (6), 1034–1060.
(29) Michalopoulou, E.; Shallcross, D. E.; Atkins, E.; Tierney, A.; Norman, N. C.; Preist, C.; O'Doherty, S.; Saunders, R.; Birkett, A.; Willmore, C.; Ninos, I. The End of Simple Problems: Repositioning Chemistry in Higher Education and Society Using a Systems Thinking Approach and the United Nations' Sustainable Development Goals as a Framework. *J. Chem. Educ.* **2019**, *96* (12), 2825–2835.
(30) Brown, D. R.; Brydges, S.; Lo, S. M.; Denton, M. E.; Borrego, M. J. A Collaborative Professional Development Program for Science Faculty and Graduate Students in Support of Education Reform at Two-Year Hispanic-Serving Institutions. *In Best Practices in Chemistry Teacher Education* **2019**, *1335*, 119–134.
(31) Goethe, E. V.; Colina, C. M. Taking Advantage of Diversity within the Classroom. *J. Chem. Educ.* **2018**, *95* (2), 189–192.
(32) Gonzales, L. D.; Hall, K.; Benton, A.; Kanhai, D.; Núñez, A.-M. Comfort over Change: a Case Study of Diversity and Inclusivity Efforts in U.S. Higher Education. *Innov. Higher Educ.* **2021**, *46*, 445.
(33) Bancroft, S. F.; Fowler, S. R.; Jalaeian, M.; Patterson, K. Leveling the Field: Flipped Instruction as a Tool for Promoting Equity in General Chemistry. *J. Chem. Educ.* **2020**, *97* (1), 36–47.
(34) White, K. N.; Vincent-Layton, K.; Villarreal, B. Equitable and Inclusive Practices Designed to Reduce Equity Gaps in Undergraduate Chemistry Courses. *J. Chem. Educ.* **2021**, *98* (2), 330–339.
(35) Broman, K.; Ekborg, M.; Johnels, D. Chemistry in crisis? Perspectives on teaching and learning chemistry in Swedish upper secondary schools. *Nordic Studies in Science Education* **2012**, *7* (1), 43–53.
(36) McGregor, S. Towards a rationale for integrating consumer and citizenship education. *Journal of Consumer Studies & Home Economics* **1999**, *23* (4), 207–211.
(37) Aikenhead, G. S. *Science Education for Everyday Life: Evidence-Based Practice*; Teachers College Press, 2006.
(38) Reid, A.; Jensen, B. B.; Nikel, J.; Simovska, V. Participation and learning: Developing perspectives on education and the environment, health and sustainability. In *Participation and Learning*; Springer, 2008; pp 1–18.
(39) *Science and the Public: A Review of Science Communication and Public Attitudes to Science in Britain*; Office of Science and Technology and the Wellcome Trust Report, 2000.
(40) Allchin, D. From Science Studies to Scientific Literacy: A View from the Classroom. *Science and Education* **2014**, *23* (9), 1911–1932.
(41) Fu, E.; Fitzpatrick, A.; Connors, C.; Clay, D.; Toombs, B.; Busby, A.; O'Driscoll, C. *Public Attitudes to Chemistry*; The Royal Society of Chemistry, 2015.
(42) Yacoubian, H. A. Scientific literacy for democratic decision-making. *International Journal of Science Education* **2018**, *40* (3), 308–327.
(43) Plutzer, E.; Hannah, A. L. Teaching climate change in middle schools and high schools: investigating STEM education's deficit model. *Climatic Change* **2018**, *149* (3–4), 305–317.

(44) MacKinnon, D. Chemophobia. *Chem. Eng. News* **1981**, *59* (29), 5.
(45) Eddy, R. M. Chemophobia in the College Classroom: Extent, Sources, and Student Characteristics. *J. Chem. Educ.* **2000**, *77* (4), 514.
(46) Francl, M. How to counteract chemophobia. *Nat. Chem.* **2013**, *5* (6), 439−440.
(47) Belenguer-Sapiña, C.; Briz-Redón, Á.; Domínguez-Sales, M. C. Do Social Chemophobic Attitudes Influence the Opinions of Secondary School Students? *J. Chem. Educ.* **2021**, *98*, 2176.
(48) Browne, M.; Thomson, P.; Rockloff, M. J.; Pennycook, G. Going against the herd: Psychological and cultural factors underlying the 'vaccination confidence gap'. *PLoS One* **2015**, *10* (9), 1−14.
(49) Ward, P. R.; Attwell, K.; Meyer, S. B.; Rokkas, P.; Leask, J. Understanding the perceived logic of care by vaccine-hesitant and vaccine-refusing parents: A qualitative study in Australia. *PLoS One* **2017**, *12* (10), 1−15.
(50) Siegrist, M.; Bearth, A. Chemophobia in Europe and reasons for biased risk perceptions. *Nat. Chem.* **2019**, *11* (12), 1071−1072.
(51) Özmen, H.; Demircioğlu, H.; Demircioğlu, G. The effects of conceptual change texts accompanied with animations on overcoming 11th grade students' alternative conceptions of chemical bonding. *Comput. Educ.* **2009**, *52* (3), 681−695.
(52) Wang, C.-Y.; Barrow, L. H. Exploring conceptual frameworks of models of atomic structures and periodic variations, chemical bonding, and molecular shape and polarity: a comparison of undergraduate general chemistry students with high and low levels of content knowledge. *Chemistry Education Research and Practice* **2013**, *14* (1), 130−146.
(53) Hashweh, M. Z. Toward an explanation of conceptual change. *European Journal of Science Education* **1986**, *8* (3), 229−249.
(54) Taber, K. S. Shifting sands: a case study of conceptual development as competition between alternative conceptions. *Int. J. Sci. Educ.* **2001**, *23* (7), 731−753.
(55) Taber, K. S. Alternative Conceptions and the Learning of Chemistry. *Isr. J. Chem.* **2019**, *59*, 1−21.
(56) Taber, K. S. Concepts in Chemistry. In *Chemical Misconceptions—Prevention, Diagnosis and Cure; Vol. I: Theoretical Background*; Osborne, C.; Pack, M.; Osborne, C.; Pack, M., Eds.; The Royal Society of Chemistry: London, 2002; pp 19−20.
(57) Brown, K. F.; Long, S. J.; Ramsay, M.; Hudson, M. J.; Green, J.; Vincent, C. A.; Kroll, J. S.; Fraser, G.; Sevdalis, N. UK parents' decision-making about measles-mumps-rubella (MMR) vaccine 10 years after the MMR-autism controversy: A qualitative analysis. *Vaccine* **2012**, *30* (10), 1855−1864.
(58) Motta, M.; Callaghan, T.; Sylvester, S. Knowing less but presuming more: Dunning-Kruger effects and the endorsement of anti-vaccine policy attitudes. *Social Science & Medicine* **2018**, *211*, 274−281.
(59) Yaqub, O.; Castle-Clarke, S.; Sevdalis, N.; Chataway, J. Attitudes to vaccination: A critical review. *Social Science & Medicine* **2014**, *112*, 1−11.
(60) Sjöström, J. The discourse of chemistry (and beyond). *HYLE - Int. J. Phil. Chem.* **2007**, *13* (2), 83−97.
(61) Smit, R. Towards a clearer understanding of student disadvantage in higher education: problematising deficit thinking. *Higher Education Research & Development* **2012**, *31* (3), 369−380.
(62) Grant, M. J.; Mottet, A. L.; Tanis, J.; Harrison, J.; Herman, J. L.; Keisling, M. *Injustice at Every Turn: A Report of the National Transgender Discrimination Survey*; National Center for Transgender Equality and National Gay and Lesbian Task Force, 2011.
(63) Green, D.; Pulley, T.; Jackson, M.; Martin, L. L.; Fasching-Varner, K. J. Mapping the margins and searching for higher ground: examining the marginalisation of black female graduate students at PWIs. *Gender and Education* **2018**, *30* (3), 295−309.
(64) Giroux, H. A. Critical theory and the politics of culture and voice: Rethinking the discourse of educational research. *J. Thought* **1986**, 84−105.
(65) Crenshaw, K.; Gotanda, N.; Peller, G.; Thomas, K. *Critical Race Theory: The Key Writings That Formed the Movement*; The New Press: New York, 1995; pp 276−291.
(66) Delgado-Bernal, D. Critical Race Theory, Latino Critical Theory, and critical raced-gendered epistemologies: Recognizing students of color as holders and creators of knowledge. *Qualitative Inquiry* **2002**, *8* (1), 105−126.
(67) Blake, N.; Masschelein, J. Critical theory and critical pedagogy. *In The Blackwell guide to The Philosophy of Education* **2007**, 38.
(68) Kellner, D. Toward a critical theory of education. *Democracy & Nature* **2003**, *9* (1), 51−64.
(69) Bodner, G. M.; Orgill, M. K. *Theoretical Frameworks for Research in Chemistry/Science Education*; Pearson Prentice Hall, 2007.
(70) Campbell, F. A. K. Exploring internalized ableism using critical race theory. *Disability & Society* **2008**, *23* (2), 151−162.
(71) Schenkel, K.; Calabrese Barton, A. Critical science agency and power hierarchies: Restructuring power within groups to address injustice beyond them. *Science Education* **2020**, *104* (3), 500−529.
(72) Mayo, P. M. *Critical Theory: Theoretical Frameworks for Research in Chemistry/Science Education*; Bodner, G. M., Orgill, M., Eds.; Pearson Prentice Hall: Upper Saddle River, NJ, 2007; Chapter 14, pp 243−261.
(73) Piaget, J.; Cook, M. *The Origins of Intelligence in Children*; International Universities Press: New York, 1952; Vol. *8*.
(74) Piaget, J. Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching* **1964**, *2* (3), 176−186.
(75) Herron, J. D. Piaget for Chemists. *J. Chem. Educ.* **1975**, *52*, 146.
(76) Bunce, D. M. Does Piaget Still Have Anything to Say to Chemists? *J. Chem. Educ.* **2001**, *78*, 1107.
(77) Taber, K. S. Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice* **2013**, *14* (2), 156−168.
(78) Cooper, M. M.; Stowe, R. L. Chemistry Education Research—From Personal Empiricism to Evidence, Theory, and Informed Practice. *Chem. Rev.* **2018**, *118* (12), 6053.
(79) Sweller, J. Cognitive load during problem solving: Effects on learning. *Cognitive Science* **1988**, *12* (2), 257−285.
(80) Johnstone, A. H. Why is science difficult to learn? Things are seldom what they seem. *Journal of computer assisted learning* **1991**, *7* (2), 75−83.
(81) Meyer, A.; Rose, D. H.; Gordon, D. T. *Universal Design for Learning: Theory and Practice*; CAST Professional Publishing, 2014.
(82) Dinmore, S. P. The Case for Universal Design for Learning in Technology Enhanced Environments. *International Journal of Cyber Ethics in Education (IJCEE)* **2014**, *3* (2), 29−38.
(83) Meyer, I. H. Prejudice, Social Stress, and Mental Health in Lesbian, Gay, and Bisexual Populations: Conceptual Issues and Research Evidence. *Psychological Bulletin* **2003**, *129* (5), 674−697.
(84) Budge, S. L.; Domínguez, S.; Goldberg, A. E. Minority Stress in Nonbinary Students in Higher Education: The Role of Campus Climate and Belongingness. *Psychology of Sexual Orientation and Gender Diversity* **2020**, *7* (2), 222−229.
(85) Mahaffy, P. The future shape of chemistry education. *Chemistry Education Research and Practice* **2004**, *5* (3), 229−245.
(86) Sjöström, J. Towards Bildung-Oriented Chemistry Education. *Science & Education* **2013**, *22* (7), 1873−1890.
(87) Vásquez-Levy, D. Bildung-centred Didaktik: a framework for examining the educational potential of subject matter. *Journal of Curriculum Studies* **2002**, *34* (1), 117−128.
(88) Mahaffy, P. Moving Chemistry Education into 3D: A Tetrahedral Metaphor for Understanding Chemistry. Union Carbide Award for Chemical Education. *J. Chem. Educ.* **2006**, *83* (1), 49.
(89) Bloom, B. S. *Taxonomy of Educational Objectives: The Classification of Educational Goals*; Longman McKay: London, New York, 1956.

(90) Haak, D. C.; HilleRisLambers, J.; Pitre, E.; Freeman, S. Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science* **2011**, *332* (June), 1213−1216.
(91) Cook-Sather, A. Increasing inclusivity through pedagogical partnerships between students and faculty. *Divers. Democr.* **2019**, 22.
(92) Cook-Sather, A. Respecting voices: how the co-creation of teaching and learning can support academic staff, underrepresented students, and equitable practices. *Higher Education* **2020**, *79* (5), 885−901.
(93) Fink, A.; Frey, R. F.; Solomon, E. D. Belonging in general chemistry predicts first-year undergraduates' performance and attrition. *Chemistry Education Research and Practice* **2020**, *21* (4), 1042−1062.
(94) Mayer, R. E. Multimedia learning. In *Psychology of Learning and Motivation*; Elsevier, 2002; Vol. *41*, pp 85−139.
(95) Chandler, P.; Sweller, J. The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology* **1992**, *62* (2), 233−246.
(96) Irby, S. M.; Phu, A. L.; Borda, E. J.; Haskell, T. R.; Steed, N.; Meyer, Z. Use of a card sort task to assess students' ability to coordinate three levels of representation in chemistry. *Chem. Educ. Res. Prac.* **2016**, *17*, 337−352.
(97) Krieter, F. E.; Julius, R. W.; Tanner, K. D.; Bush, S. D.; Scott, G. E. Thinking Like a Chemist: Development of a Chemistry Card-Sorting Task to Probe Conceptual Expertise. *J. Chem. Educ.* **2016**, *93* (5), 811−820.
(98) Galloway, K. R.; Leung, M. W.; Flynn, A. B. Patterns of reactions: a card sort task to investigate students' organization of organic chemistry reactions. *Chem. Educ. Res. Prac.* **2019**, *20* (30), 30−52.
(99) Ruge, B. In *Risk Matrix as Tool for Risk Assessment in the Chemical Process Industries, Probabilistic Safety Assessment and Management, Berlin*; Spitzer, C., Schmocker, U., Dang, V. N., Spitzer, C., Schmocker, U., Dang, V. N., Eds.; Springer: London, 2004; pp 2693−2698.
(100) Ni, H.; Chen, A.; Chen, N. Some extensions on risk matrix approach. *Safety Science* **2010**, *48* (10), 1269−1278.
(101) Siegrist, M.; Wallquist, L.; Visschers, V. H. M. Impact of Knowledge and Misconceptions on Benefit and Risk Perception of CCS. *Environ. Sci. Technol.* **2010**, *44* (17), 6557−6562.
(102) Cullipher, S.; Sevian, H.; Talanquer, V. Reasoning about benefits, costs, and risks of chemical substances: Mapping different levels of sophistication. *Chemistry Education Research and Practice* **2015**, *16* (2), 377−392.
(103) Mio, M. J.; Benvenuto, M. A. The Unsafe Lab Practical. *J. Chem. Educ.* **2021**, *98* (1), 243−245.
(104) Goldfeld, D. J.; Schott, J. H. Extracurricular Student Groups: The Final Frontier of Undergraduate Safety. *J. Chem. Educ.* **2021**, *98* (1), 15−18.
(105) Saleh, R.; Bearth, A.; Siegrist, M. Chemophobia" Today: Consumers' Knowledge and Perceptions of Chemicals. *Risk Anal.* **2019**, *39* (12), 2668−2682.
(106) Gayle, B. M.; Cortez, D.; Preiss, R. W. Safe Spaces, Difficult Dialogues, and Critical Thinking. *Int. J. the Scholar. Teach. Learn.* **2013**, DOI: 10.20429/ijsotl.2013.070205.
(107) Panelli, R.; Welch, V. R. Teaching research through field studies: a cumulative opportunity for teaching methodology to human geography undergraduates. *Journal of Geography in Higher Education* **2005**, *29* (2), 255−277.
(108) Elliott, K. O. Queering student perspectives: gender, sexuality and activism in school. *Sex Education* **2016**, *16* (1), 49−62.
(109) McGlashan, H.; Fitzpatrick, K. LGBTQ youth activism and school: challenging sexuality and gender norms. *Health Education* **2017**, *117* (5), 485−497.
(110) Okazaki, S.; Sue, S. Methodological issues in assessment research with ethnic minorities. In *Methodological Issues and Strategies in Clinical Research*; Kazdin, A. E., Ed.; American Psychological Association, 2016; pp 235−247.
(111) Cronbach, L. J. Coefficient Alpha and the Internal Structure of Tests. *Psychometrika* **1951**, *16*, 297.
(112) Tavakol, M.; Dennick, R. Making sense of Cronbach's alpha. *International Journal of Medical Education* **2011**, *2*, 53−55.
(113) Blickenstaff, J. C. Women and science careers: Leaky pipeline or gender filter? *Gender Educ.* **2005**, *17* (4), 369−386.
(114) Archer, L.; Dewitt, J.; Osborne, J. Is science for us? Black students' and parents' views of science and science careers. *Science Education* **2015**, *99* (2), 199−237.
(115) Hughes, B. E. Coming out in STEM: Factors affecting retention of sexual minority STEM students. *Sci. Adv.* **2018**, *4* (3), 1−6.
(116) Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qualitative Research in Psychology* **2006**, *3* (2), 77−101.
(117) Hilton, A.; Nichols, K. Representational Classroom Practices that Contribute to Students' Conceptual and Representational Understanding of Chemical Bonding. *International Journal of Science Education* **2011**, *33* (16), 2215−2246.
(118) Linenberger, K. J.; Bretz, S. L. Generating cognitive dissonance in student interviews through multiple representations. *Chem. Educ. Res. Prac.* **2012**, *13*, 172−178.
(119) Taber, K. S. Chemistry lessons for universities?: a review of constructivist ideas. *Univ. Chem. Educ.* **2000**, *4* (2), 63−72.
(120) Coll, R. K.; Treagust, D. F. Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching* **2003**, *40* (5), 464−486.
(121) Coll, R. K.; Taylor, N. Alternative Conceptions of Chemical Bonding Held by Upper Secondary and Tertiary Students. *Research in Science & Technological Education* **2001**, *19* (2), 171−191.

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