Chemistry Education Research and Practice

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal | View Issue

Cite this: *Chem. Educ. Res. Pract.*, 2026, **27**, 864

Chemistry experiences that matter: understanding self-identified influential experiences at different academic stages

Devin Pontigon * and Vicente Talanquer

This exploratory qualitative study examines the chemistry-related experiences that individuals at different academic stages describe as influential to their current academic and professional positioning within chemistry. Rather than eliciting predefined categories of experiences, participants were invited to share the moments, interactions, and contexts they deemed important, which were primarily situated within chemistry-related settings. Using these participant-selected narratives as the primary data source, transcripts were analyzed with a coding framework that characterized each experience by affective tone (positive, negative, neutral), role positioning (being a student or being a professional), and emergent experience type (curricular, co-curricular, extracurricular). Analysis revealed patterned differences in how participants described influential chemistry experiences across contexts, affective framings, and role positioning. Curricular experiences were more prominently described using frustration, challenge, or neutrality and were often framed through a student role, whereas co-curricular experiences, such as research and internships, were associated with mixed affective tones of uncertainty and empowerment and relatively more professional positioning. Extracurricular experiences were primarily described as sites of social connection and emotional support, particularly in early undergraduate stages, supporting persistence within coursework rather than disciplinary contribution. Taken together, these analyses trace how affective, contextual, and positional dimensions come together in the chemistry experiences participants interpreted as significant. By comparing participants within different academic stages, the study examines how chemistry-related experiences are framed as influential and highlight the importance of designing learning environments that account for differences in how participants engage with, frame, and prioritize chemistry-related experiences.

Received 15th December 2025,
Accepted 25th February 2026

DOI: 10.1039/d5rp00465a

rsc.li/cerp

Introduction

Understanding what shapes individuals' engagement with chemistry requires attention not only to achievement or instructional practices but to the lived experiences that accumulate across educational and professional contexts. Early work on STEM attrition framed persistence primarily as an outcome of ability, performance, or pedagogical structure (Seymour and Hunter, 2019). Although informative, these perspectives offered limited insight into how individuals experience chemistry and how those experiences are interpreted and narrated across contexts. More recent chemistry education research has emphasized the importance of examining emotional, social, and intellectual dimensions of experience as they are articulated within diverse settings (Villafañe and Lewis, 2016; Xu *et al.*, 2021). This shift reflects a broader move toward understanding engagement in chemistry as situated and experiential, rather than solely as an outcome of performance or persistence.

Dewey's (1938) Theory of Experience provides a generative foundation for this perspective by conceptualizing education as a continuous reconstruction of experience through the interaction of individuals and their environments. From this view, the quality of any experience, its emotional tone, its contextual features, and the individual's understanding of their role within it, shapes how future experiences are interpreted and enacted. Contemporary STEM frameworks extend these ideas by identifying mechanisms through which experiences contribute to identity formation, participation, and long-term engagement. Science identity frameworks (Carlone and Johnson, 2007; Hazari *et al.*, 2010) highlight how recognition, competence, and performance shape how individuals understand their participation within scientific contexts. Belonging and motivational perspectives underscore the affective and relational qualities of interaction that signal inclusion or alienation within disciplinary spaces (Goodenow, 1993; Walton and Cohen, 2007).

Department of Chemistry and Biochemistry, University of Arizona, Tucson, AZ 85721, USA. E-mail: dpontigon@arizona.edu

Situated learning and Communities of Practice (Lave and Wenger, 1991) further emphasize participation in social practices; such as classrooms, research groups, and teaching environments, as contexts in which individuals negotiate their roles as learners or professionals. Consistent with Dewey's view of experience as situated, relational, and inseparable from context, this study treats experiences as units of analysis shaped by interaction and interpretation.

Yet three notable gaps remain. First, most studies focus on a single academic position: undergraduate, graduate, or faculty, limiting comparative insight into how experiences are framed and interpreted among different academic roles. Second, research often centers on one type of setting (*e.g.*, coursework or research) rather than examining how experiences across multiple contexts are described and situated in relation to one another. Third, while affect positioning is acknowledged as an important component of experience, few studies systematically analyze how the emotional tone of experiences and an individual's positioning as a student or professional shape how those experiences are interpreted across academic contexts.

The present study addresses these gaps by examining the chemistry-related experiences that participants at different academic stages describe as influential to their current academic and professional positioning. Rather than prompting participants about specific settings, the study invited participants to describe the experiences they viewed as important, primarily situated in chemistry-related contexts. This experiential approach foregrounds how individuals interpret and frame their experiences in chemistry, offering insight into recurring patterns of interaction, role positioning, and context at different academic stages. Together, these analyses provide a comparative account of how chemistry-related experiences are described and situated within the discipline.

Literature review

In recent years, questions about what drives students' engagement in chemistry have expanded beyond achievement to include the experiences within the discipline. Early work on STEM attrition characterized persistence primarily as a function of ability, performance, or pedagogy (Seymour and Hunter, 2019; Chen and Soldner, 2013). While influential, these approaches often treated persistence as an outcome to be explained, offering limited insight into how individuals describe and interpret their experiences in chemistry. More recent research has emphasized that engagement is shaped not only by instructional design or academic success, but also by the affective, social, and contextual qualities of learners' interactions across educational settings. Drawing on Dewey's (1938) view of experience as situated and relational, this body of work foregrounds how individuals interpret experiences, respond emotionally within them, and connect interactions to their sense of participation in disciplinary contexts.

Traditional classroom environments; lectures, discussions, and course-embedded laboratory components constitute many students' first sustained interactions with chemistry strongly shape how they experience participation, belonging, and agency within the discipline. These settings, while central to disciplinary training, have often been described as rigid, hierarchical, and performance-driven (Galloway and Bretz, 2015; Ferrell *et al.*, 2016). Students frequently report feelings of detachment or competitiveness in such contexts (Seymour and Hunter, 2019), reflecting environments that prioritize correctness and evaluation over curiosity and collaboration. Reform efforts that integrate inquiry, reflection, and peer interaction have demonstrated how altering the structure of experience can promote engagement and self-concept. Cooper *et al.* (2018) showed that student-centered instructional design, whether implemented in the lecture hall or the laboratory, helps learners perceive themselves as active participants rather than passive recipients of information. Similarly, studies of affect and motivation in chemistry classrooms (Villafañe and Lewis, 2016; Xu *et al.*, 2021) reveal that emotions, from curiosity to anxiety, mediate students' confidence, control, and willingness to engage with chemistry. Broad-scale analyses of active learning (Freeman *et al.*, 2014) demonstrate improved student achievement and reduced failure rates in STEM courses. From a Deweyan perspective, these classroom and laboratory encounters highlight how the emotional and structural qualities of experience shape how learning situations are interpreted, positioning chemistry as either inviting or alienating for students within formal educational contexts.

Beyond formal coursework, co-curricular experiences such as research and internships, are frequently described as sites where disciplinary learning becomes personally relevant and socially situated. Prior work has often framed these experiences in developmental terms. For example, Hunter *et al.* (2007) offered a comprehensive examination of undergraduate research as a developmental process, documenting how students learned to navigate uncertainty, design experiments, and present findings. These experiences fostered self-efficacy and belonging by combining cognitive challenge with collaboration and recognition. Similarly, Aikens *et al.* (2017) empirically showed that mentoring relationships among undergraduates, graduate students, and faculty provide layered access to expertise and social capital, supporting students' participation and sense of belonging within scientific communities. Empirical studies of course-based undergraduate research experiences and applied internships further document how authentic inquiry, iteration, and dissemination support students' confidence and engagement (Brownell *et al.*, 2016). Complementing this empirical evidence, Corwin *et al.* (2015) offer a framework for understanding how such experiences function as sites of identity-relevant participation rather than as isolated instructional interventions. Collectively, this body of work highlights research and applied experiences as contexts in which intellectual challenge, social interaction, and affective engagement intersect.

As students move into graduate and early professional stages, teaching and mentoring experiences become prominent contexts for participation in chemistry-related work. Graduate

teaching assistantships, for example, often act as transitional spaces in which individuals negotiate their dual roles as learners and professionals. Mutambuki and Schwartz (2019) found that structured professional-development programs for chemistry GTAs fostered pedagogical confidence and agency, allowing participants to view teaching as integral to their identity rather than peripheral to research. Similarly, Goodwin *et al.* (2021) described how recognition, feedback, and collaboration within research groups shaped graduate students' evolving sense of belonging and legitimacy. Together, these studies illustrate how teaching and mentoring experiences provide opportunities for role negotiation and participation within academic communities of practice (Lave and Wenger, 1991; Wenger-Trayner and Wenger-Trayner, 2015).

Chemistry learning and identity-related experiences also occur in co-curricular and extracurricular spaces that foster community, belonging, and shared purpose. When students participate in mentoring networks, outreach initiatives, or disciplinary organizations, they encounter chemistry as a social practice situated within larger communities. Hernandez *et al.* (2018) showed that informal mentoring networks among women in STEM created spaces of affirmation and shared identity, helping participants imagine themselves as scientists within supportive communities. Wilson *et al.* (2015) similarly found that participation in student organizations strengthened belonging and academic integration by connecting interpersonal relationships to disciplinary commitment. Extending these insights, Otero *et al.* (2020) demonstrated that inclusive learning communities in physics empowered underrepresented students to sustain confidence and interest through collective support. Together, these studies suggest that experiences of community beyond coursework cultivate the social and emotional continuity essential for identity formation in chemistry, reminding us that engagement in STEM is not only intellectual but deeply relational.

Across educational and professional contexts, prior research has often framed engagement in chemistry and related academic work in developmental or longitudinal terms. Austin and McDaniels (2006) described graduate socialization as an apprenticeship through which observation, mentoring, and practice foster readiness for academic and professional roles. Similarly, research on faculty work suggests that professional fulfillment is shaped through ongoing negotiation of roles, values, and practices within departmental and disciplinary communities rather than through the completion of a fixed developmental trajectory. Günter *et al.* (2023a,2023b), for instance, show how university instructors construct intelligible professional identities by aligning their teaching practices, values, and self-presentations with collectively recognized norms in their academic communities. Overall, this literature emphasizes experience as situated and relational, emphasizing how influence arises through interaction with context.

Collectively, this body of research portrays chemistry education as constituted by a range of experiential contexts in which participation, reflection, and connection shape how individuals engage with the discipline. Across classrooms, laboratories, research settings, internships, and mentoring relationships, experiences provide opportunities for individuals to negotiate identity, agency, and belonging within specific situations. What remains less understood, however, is how individuals in undergraduate, graduate, and faculty roles describe and frame these experiences, and what patterns emerge in how experiences are discussed across academic contexts. The present study builds upon this foundation by examining chemistry-related experiences through their contexts, affective qualities, and role framings, offering a comparative account of how individuals describe and position their participation in chemistry at different academic stages.

Theoretical and conceptual framework

This study is grounded in John Dewey's (1938) Theory of Experience, which provides a philosophical foundation for understanding how chemistry-related experiences are situated within particular settings and roles. This study draws on Dewey's principles of interaction and continuity to emphasize the situated and relational nature of experience. Interaction highlights the dynamic relationship between the individual and their environment, recognizing that the impact of an experience emerges through engagement with specific contexts, activities, and social arrangements. Continuity, as used in this study, refers to how participants link and reference experiences within their narratives, rather than to developmental progression over time.

Although the emphasis on person-environment interaction is shared across multiple theoretical traditions, Dewey's Theory of Experience offers a distinct analytic orientation. Rather than focusing on motivation, preference alignment, or predictive outcomes, Dewey conceptualizes experience as a process through which individuals engage with and respond to their environments through ongoing interaction. This perspective foregrounds how individuals retrospectively make sense of their experiences, whether routine, emotionally neutral, or transformative, without assuming stable values or linear developmental trajectories. For the present study, Dewey's framework is particularly generative because it treats experience itself as the unit of analysis, allowing participants' narrated accounts to be examined as interpretive acts shaped by current roles, contexts, and relationships.

Contemporary frameworks in STEM education extend Dewey's attention to experience by articulating how experiences are interpreted, recognized, and positioned within disciplinary contexts. Science identity frameworks (Carlone and Johnson, 2007; Hazari *et al.*, 2010), for example, emphasize competence, performance, and recognition as key dimensions through which participation in science is made intelligible. Rather than treating persistence as the cumulative outcome of experiences over time, this work examines how participants describe experiences as supportive or challening in relation to one's role within the discipline.

Identity also can be understood as situationally constructed, in which individuals draw on past experiences, anticipated

futures, and normative expectations to present a coherent sense of self in a given context (Holmegaard *et al.*, 2014). From this perspective, identity is continuously reconstructed in response to changing circumstances, even as individuals experience and narrate it as stable and enduring. To further account for the dimensions of identity and recognition, Holland *et al.*'s (1998) concept of figured worlds provides a useful lens. Figured worlds describe socially and culturally constructed realms of activity in which particular roles, values, and forms of participation are recognized as legitimate. From this perspective, identities are not fixed traits but are enacted and made intelligible through participation in normative practices, helping explain how individuals present a coherent sense of self while navigating different chemistry-related contexts. Recent work has applied this framework to science and higher education contexts, illustrating how individuals position themselves relative to collectively valued norms while navigating tensions between expectation and practice (Günter *et al.*, 2023a,2023b). In this view, identity is shaped not only by personal experience but by alignment with, or resistance to, the norms that define intelligible participation within disciplinary spaces. Importantly, these norms provide a shared backdrop against which individuals' identity claims become recognizable and credible, even as participants experience their identities as coherent and stable. Identity narration can be understood as a form of situated self-presentation shaped by disciplinary norms of recognizability (Goffman, 1986; Gee, 2000), through which individuals construct accounts that appear coherent and legitimate within a given community.

These perspectives emphasize that science identity is not formed in isolation but is enacted and recognized within social contexts shaped by shared norms and expectations. Building on this view, science identity frameworks further highlight recognition and competence as central dimensions of participation, constructs that are inherently social because opportunities for recognition depend on the quality of individuals' interactions with others. Theories of belonging make this social and affective dimension explicit by linking motivation and engagement to students perceived inclusion within their learning environments. Goodenow (1993) described belonging as the feeling of being accepted, valued, and supported in a classroom or disciplinary community, a construct that strongly predicts motivation and academic effort. Later work by Walton and Cohen (2007) demonstrated that even brief interventions designed to affirm belonging can produce lasting improvements in achievement and persistence among underrepresented students in STEM. Within a Deweyan framework, belonging can thus be understood as a manifestation of the interaction principle: the emotional and relational quality of an individuals engagement with their environment. Feelings of inclusion, recognition, or exclusion reflect the quality of those interactions, reinterpreting Dewey's notion of ''quality of experience'' as a social and affective construct; where positive affect signals inclusion and growth, and negative affect signals alienation or belonging uncertainty. Similarly, situated learning and Communities of Practice (Lave and Wenger, 1991) offer a complementary lens by emphasizing participation in social practices as a defining feature of learning contexts. Chemistry laboratories, research groups, and teaching environments can be viewed as communities in which participation, interaction, and role negotiation are made visible. Dewey's emphasis on experience as relational and contextual resonates with this view of learning as socially situated and practice-based.

These complementary perspectives position Dewey's Theory of Experience as a generative and integrative framework for examining how chemistry-related experiences are interpreted, valued, and situated within disciplinary contexts. Dewey's principles of continuity and interaction provide the philosophical grounding that links individual experience to social environment. Extensions from science identity and belonging frameworks highlight how recognition, competence, and affective inclusion shape how experiences are framed as affirming or alienating within chemistry. Situated learning and Communities of Practice perspectives further clarify the social organization of these experiences, framing laboratories, classrooms, and research groups as sites of participation in shared practices where roles and expectations are negotiated. Together, these perspectives support an analytic focus on experience as relational, contextual, and interpretive.

While Dewey conceptualized continuity and interaction philosophically, he did not specify how these principles are enacted across different academic contexts or how they are reflected in individuals' descriptions of disciplinary experience. The present study extends Dewey in three ways.

First, by operationalizing experiences through context, affect, and role positioning, this study translates Dewey's abstract principles into analyzable dimensions that capture how individuals interpret their participation within chemistry. Second, while Dewey articulated continuity philosophically, it has rarely been examined empirically as a relational construct among different academic roles. By comparing accounts from undergraduates, graduate students, and faculty, this study highlights differences in how experiences are described across academic contexts. Third, although Dewey acknowledged the emotional qualities of experience, he did not specify how affect might be analytically examined. This study treats neutral, positive, and negative affect as indicators of experiential quality, illustrating how emotional tone shapes how experiences are interpreted as affirming or alienating within chemistry. Together, these contributions position Dewey's Theory of Experience as an analytic framework for examining how chemistry-related experiences are interpreted, valued, and situated within disciplinary contexts.

The present study operationalizes Dewey's framework across four analytic dimensions: context, capturing curricular, co-curricular, and extracurricular environments where interaction occurs; affect, reflecting the emotional connection of experiences as positive, negative, or neutral; role, examining how individuals position themselves as students or professionals; and academic stage, used to compare how experiences are framed among undergraduate, graduate, and faculty roles (Fig. 1).

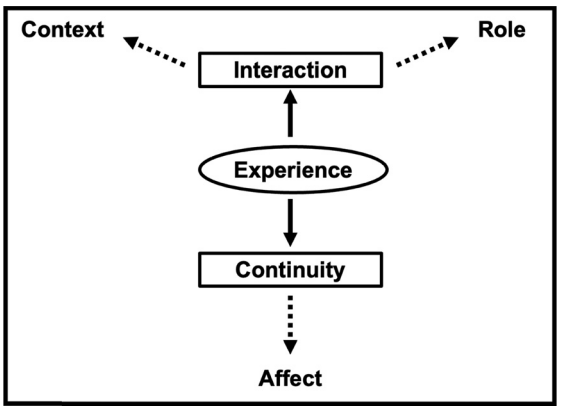

Fig. 1 Conceptual framework connecting Dewey's theory of experience to the present study.

In this study, the term experience is used in two related but distinct ways. At the empirical level, experience refers to participants' narrated accounts of events, activities, or situations they identified as influential. At the analytic level, these narrated accounts are interpreted through Dewey's (1938) conception of experience as a process defined by interaction between individuals and their environments. While participants describe experiences in a colloquial sense, Dewey's framework provides a theoretical lens for attending to how experiences are framed, interpreted, and valued within specific contexts, without assuming temporal sequencing or developmental linkage among them.

Research goals and questions

This study sought to characterize influential chemistry-related experiences that participants among different academic stages identified as significant. Rather than assuming specific contexts or outcomes, participants were invited to describe the experiences they viewed as important within educational and professional contexts. Using semi-structured interviews and an experience-based coding framework, this study examined how these participant-selected experiences varied in their context (curricular, co-curricular, extracurricular), affective framing (positive, negative, neutral), and role positioning (being a student or being a professional). By analyzing these dimensions among undergraduate, graduate, and faculty roles, the study aimed to trace patterns in how individuals describe their participation across academic and professional contexts. While participants span multiple academic stages, this study adopts a cross-sectional, narrative design. Accordingly, comparisons across stages are not used to infer developmental trajectories, but to examine how chemistry-related experiences are narrated and made influential from different institutional positions. Guided by this experiential framing, the study addressed the following research questions:

1. What chemistry-related experiences do participants at different academic stages describe as influential to their current academic and professional positioning within chemistry?

2. How do the chemistry-related experiences participants identify as influential vary among different academic stages, and what patterns emerge in how these experiences are described?

3. How do participants position themselves within the chemistry-related experiences, and how does this positioning vary at different academic stages?

Methods

Context and participants

This investigation was conducted at a large public research university in the southwestern United States. Participants represented three populations within the chemistry community: undergraduate chemistry/biochemistry majors (N = 18), chemistry graduate students (N = 8), and chemistry faculty (N = 3). Recruitment occurred through departmental listserv announcements, physical flyer invitations, and course announcements.

Due to the difficulty of recruiting individuals to participate in interview-based studies, especially among various academic stages, all individuals who expressed interest were included in the study. Although we initially aimed for balanced representation across groups, the final numbers reflect both the voluntary nature of participation and the practical constraints of recruiting within a single department. All participants received a small compensation, as a gift card, as an acknowledgment of their time and contribution. Compensation was provided only after the interview was completed.

Undergraduate participants included students from early and advanced stages of their majors, graduate students represented a mix of early and late-stage doctoral researchers, and faculty included both tenure track and non-tenure track instructors (Table 1). Across all participant groups, individuals represented a range of identities. All identifying information was anonymized, and to protect participant confidentiality, pseudonyms were replaced with stage-based labels (*e.g.*, Freshman 1, Sophomore 2, Graduate Student 3), which are used solely for organizational clarity and do not imply ranking or progression.

The sample size for this study was guided by qualitative methodological standards emphasizing analytic depth and conceptual saturation rather than numerical representation. For undergraduates, a larger sample (N = 18) ensured variability between academic years (freshman-senior) and provided sufficient breadth to examine early-stage experiential differences in coursework, research access, and affective framing. Graduate

Table 1 Participant distribution by academic stage and gender

Academic stage	Female	Male	Total
Freshman			
Sophomore	1	4	5
Junior	2	5	7
Senior	1	5	6
Graduate	2	6	8
Faculty	2	1	3

students (N = 8) represent a smaller departmental population, and this number aligns with recommendations for semi-structured interview studies aimed at identifying developmental patterns within a relatively homogeneous group. Faculty participants (N = 3) were intentionally fewer, as their inclusion was not intended to represent faculty populations, but to incorporate a faculty institutional perspective that complements student accounts. Including faculty enabled examination of how chemistry-related experiences are framed from a faculty role, providing analytic contrast among institutional positions rather than population-level comparison.

In addition to gender, participants were asked to self-report their ethnicity during the informed consent process. The sample included students and faculty who identified as White, Hispanic/Latinx, Asian, Black/African American, Multiracial. These data were collected to ensure awareness of the diversity represented in the study; however, demographic variables were not used as analytic categories, as the purpose of this project was to examine experiential patterns at different academic stages rather than to conduct intersectional or demographic-comparative analyses. Since recruitment across all academic levels was challenging, the demographic distribution reflects voluntary participation rather than purposive demographic sampling. Future work will build on these findings by integrating a more explicit intersectional analysis of lived experiences within chemistry.

Ethical considerations

This study was approved by the UA Institutional Review Board (IRB) (IRB Protocol #: STUDY00003737) and adhered to all ethical guidelines for research involving human subjects. Informed consent was obtained from all participants prior to data collection, ensuring their voluntary participation and the confidentiality of their responses. All data were anonymized to protect participant privacy, and no identifying information was included in the analysis or reporting of results.

Data collection

Data for this study were collected through semi-structured interviews designed to elicit participants' experiences within chemistry across educational and professional contexts. Interviews were chosen as the primary data source because they allowed participants to reconstruct their experiences and reflect on important moments within academic and professional contexts.

The interview protocol (see SI) included prompts oriented toward past, present, and anticipated experiences in order to support participants in recalling a broad range of chemistry-related experiences. These temporal prompts were used solely as elicitation tools and were not treated as analytic categories. Each interview began with a broad, open-ended invitation (*e.g.*, "Can you tell me about your journey in chemistry so far?") and was followed by targeted questions that prompted reflection on specific experiences within curricular, co-curricular, and extracurricular settings. Participants were asked to describe what these experiences involved, how they felt during them, and how they understood their relevance to their engagement with chemistry at the time of the interview.

Follow-up questions invited clarification and elaboration on specific events or contexts, such as classroom or research settings, collaborative projects, or extracurricular activities. The goal was to capture the range and character of experiences participants considered influential rather than to elicit predefined categories. Affective tone, role positioning, and experience type were not directly prompted but were instead identified later through analysis of participants' narratives and language use.

Interviews were conducted one-on-one by the lead researcher between Spring and Summer 2024 semesters. Each session lasted approximately 45–75 minutes and was held *via* Zoom. All interviews were audio-recorded with consent and transcribed verbatim. Immediately following each session, the interviewer composed brief analytic notes to capture impressions, and non-verbal observations.

This design allowed participants to narrate a broad range of experiences they considered influential, rather than responding to isolated or predefined events. The combination of open reflection and targeted prompts produced detailed descriptions of affective, contextual, and relational aspects of participants' chemistry experiences, providing a rich foundation for subsequent coding and analysis.

Data analysis

Analysis proceeded through iterative coding cycles designed to capture how participants described their chemistry experiences across different academic and professional contexts. A structured coding framework was applied that combined both deductive and inductive approaches. Deductive codes were informed by Dewey's Theory of Experience, particularly his notion of interaction, understood as the reciprocal relationship between individuals and their environments and continuity as the ways experiences were framed and valued within participants' accounts. Inductive insights emerged through close reading of interview transcripts, allowing patterns in context, affect, and role positioning to surface from participants' narratives.

In this study, the unit of analysis was a participant-described experience, defined as any event, interaction, or moment that individuals identified as influential. Experiences were identified by segmenting transcripts at points where participants shifted to describing a specific incident, using linguistic markers such as temporal cues ("there was this one time…"), evaluative statements ("that really helped me…"), or contextual anchors ("in my lab course…"). Each experience included what occurred, the context in which it occurred, how the participant felt about it, and how they positioned themselves (as a student or a professional). Defining the experience in this way allowed us to analyze each unit across the three dimensions reflected in our research questions.

Coding was conducted through a structured, multi-step process, refined through constant comparative analysis to ensure internal coherence. Each participant account was segmented into discrete experiences, which were then coded by activity type, affective framing, and role positioning.

1. *Activity type*: each experience was categorized as curricular (C), co-curricular (Co), or extracurricular (EC) to differentiate between formal coursework, adjacent learning environments (such as research or workshops), and broader community-based or personal engagements.

Curricular experiences included formal, credit-bearing components of chemistry education such as lectures, recitations, and laboratory courses. These experiences were typically structured by institutional requirements and were often described as routine, evaluative, or foundational. Examples included completing assignments, attending lectures, and performing laboratory experiments as part of course sequences.

Co-curricular experiences encompassed research involvement, internships, mentoring programs, conferences, teaching assistantships, and workshops, settings adjacent to coursework that provided authentic disciplinary participation. These experiences often involved autonomy, collaboration, or professional recognition.

Extracurricular experiences included outreach events, student organizations, clubs, athletics, and informal study groups. While some of these activities were directly connected to chemistry (*e.g.*, outreach or discipline-related organizations), others were not. Regardless of disciplinary focus, participants described these experiences as influential to their experiences as students because they provided community-based engagement and affective support outside formal academic structures. These contexts contributed to experiences of belonging, motivation, and coping strategies and were therefore included as influential experiences within participants' accounts, particularly among undergraduates.

2. *Affective framing*: each described experience was assigned an affective tone, positive, negative, or neutral, based on the participant's evaluative language and emotional descriptors. This step provided insight into the emotional valence of chemistry participation among academic stages.

Neutral affect was operationalized as descriptions of experiences in which participants did not convey any clear positive or negative emotional evaluation. Linguistically, neutral affect was identified through matter-of-fact phrasing, routine descriptions (''*I went to lecture*,'' ''*I completed the assignment*''), or statements framed as structural requirements rather than emotionally influential moments. Neutrality was distinguished from low-intensity positive or negative affect through coder discussion: if participants assigned any evaluative tone, even subtly, the experience was coded as positive or negative. Coding neutrality allowed the analysis to capture experiences participants described as stable, routine, or obligatory, without presuming the absence of relevance or importance.

Positive affect included experiences described with enthusiasm, accomplishment, or confidence (*e.g.*, ''*I finally felt like a chemist*,'' ''*I loved that project*''). Negative affect captured experiences characterized by frustration, discouragement, confusion, or alienation (*e.g.*, ''*I felt lost in lecture*,'' ''*Research made me doubt myself at first*''). Coding positive and negative affect provided insight into how participants emotionally interpreted chemistry experiences and how affective appraisal varied across academic contexts.

3. *Role positioning*: experiences were also coded for how participants positioned themselves relative to the discipline, as being a student (BS) or being a professional (BP), revealing moments of agency, growth, or dependency in their experience.

BS (Being a Student) codes were applied when participants positioned themselves as learners operating within structured instructional contexts, emphasizing dependence, guidance, or externally defined expectations. The term student was used intentionally to reflect this role-based positioning rather than as a general descriptor of learning, as learner would not capture the institutional constraints and power relations implied in these accounts. Linguistic indicators included phrases like ''*I had to*,'' ''*I was learning*,'' or ''*I didn't know what I was doing yet*.'' Student positioning often appeared in descriptions of coursework, early laboratory work, or unfamiliar research tasks. BS coding highlighted experiences characterized by dependence, guided participation, or structural constraint.

BP codes were applied when participants described themselves as contributing members of the chemistry community, acting with autonomy, expertise, or responsibility. Indicators included references to mentoring others, leading research tasks, presenting at conferences, teaching, or making decisions independently. Statements such as ''*I felt like a real chemist*,'' ''*I trained new students*,'' or ''*I contributed something new*'' signaled enactment of a professional role within chemistry-related contexts. BP codes captured moments in which participants described participation characterized by agency, contribution, and disciplinary belonging.

The distinction between Being a Student and Being a Professional was intentionally framed as a role-based, institutionally grounded contrast rather than a learner–expert distinction. While all participants continue to learn at different academic stages, the student role captures a particular institutional positioning characterized by externally defined expectations, evaluation, and limited authority. In contrast, the professional role reflects participation marked by autonomy, contribution, and responsibility within disciplinary communities. This role-based framing allowed the analysis to attend to how participants positioned themselves relative to institutional structures and normative expectations, rather than to their epistemic status as learners.

When participants' accounts reflected both student and professional role framings within a single experience, both codes were applied. Coding decisions were guided by participants' linguistic emphasis and evaluative framing, with attention to whether the experience was narrated primarily as compliance with instruction or as contribution and agency. This approach preserved the complexity of role negotiation while allowing aggregate patterns in role positioning to be examined at different academic stages.

All data were organized and analyzed in MAXQDA qualitative software, which facilitated hierarchical code organization, cross-tabulation, and data visualization. A subset of transcripts (7 of 29; approximately 24%) was independently coded by another researcher to ensure consistency and interpretive reliability. Discrepancies were discussed collaboratively until

consensus was achieved, leading to refinement of code definitions and increased alignment across coders.

All interview transcripts were coded using an interpretive, consensual coding approach. An initial subset of transcripts was independently coded by two members of the research team to support coder familiarization and calibration with the coding framework. Coding differences were then discussed in regular analytic meetings, during which code definitions were refined and applications were negotiated until consensus was reached.

Following this calibration process, the remaining transcripts were coded using the refined codebook, with ongoing discussions used to address ambiguities and ensure consistency in interpretation. Coding decisions were thus finalized through consensus rather than through numerical measures of agreement.

After initial coding, pattern analysis was conducted to explore how context, affective tone, and role positioning intersected among participant groups (undergraduates, graduate students, and faculty). Comparative matrices were constructed to identify points of convergence and divergence among groups. These results were visualized through bar graphs representing the relative frequency and distribution of codes among participant groups, providing a descriptive overview of trends in affect, role positioning, and context. For each academic group, values are reported as percentages representing the average proportion of coded experiences within the academic group, rather than the percentage of participants who mentioned a given experience type, or raw counts of experiences. This normalization was used to account for variation in the total number of experiences described by individual participants and to support comparison between groups of different sizes. Accordingly, the visualizations are intended to illustrate patterns in experiences across contexts, rather than to represent population-level prevalence or developmental change. Although the number of participants in each group was small, the proportional analyses reflect distributions across hundreds of coded experience segments within each group, allowing for comparison of patterned narrative emphasis rather than population-level prevalence.

Results

Findings are organized around three analytic dimensions: (1) the context and nature of chemistry experiences, (2) their affective framing, and (3) participants' role positioning. Each dimension integrates quantitative patterns with qualitative narratives to capture systematic trends alongside how participants framed experiences as influential across contexts, affective tones, and role positionings. Quantitative summaries illustrate how coded experiences were distributed between participant groups, while interview excerpts provide depth and context by showing how participants interpreted those experiences within specific contexts. This integrated presentation allows patterns in context, affect, and role positioning to be examined alongside participants' own accounts.

Context and nature of experiences

Among all groups, participants described a wide range of chemistry experiences spanning curricular, co-curricular, and extracurricular contexts. Quantitative coding revealed that curricular experiences, such as lecture and laboratory coursework, dominated within all academic stages but was less common among more advanced academic stages (Fig. 2). For early undergraduates, nearly 70% of all coded experiences were situated within formal coursework and course based laboratories, reflecting a learning environment structured primarily by institutional requirements. This proportion dropped to roughly 50% among graduate students and faculty, indicating a shift toward more autonomous and professionally oriented forms of engagement.

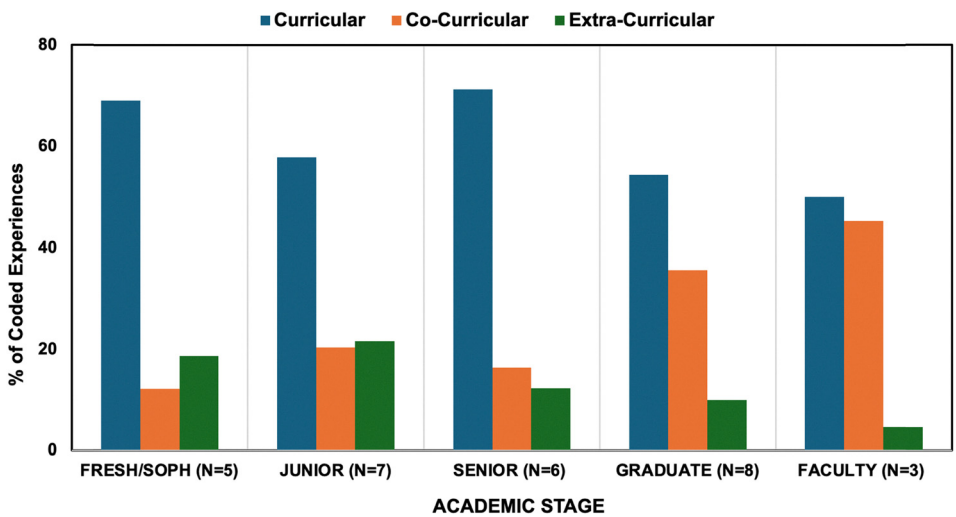

Fig. 2 Distribution of experience contexts at academic stages. Values represent the percentage of coded experiences within each academic group assigned to each context.

Fig. 2 illustrates these patterns, showing how the relative frequency of curricular, co-curricular, and extracurricular experiences varied at different academic stages. Among participant groups, curricular contexts were referenced less often among faculty than among undergraduates, while co-curricular experiences, particularly research and internship, were emphasized more often.

While non-laboratory curricular experiences were more prominent (Fig. 3), participants often characterized them as passive or routine:

"Lecture was something to sit through; I was there to take notes and hope I passed." (Sophomore, 2)

Laboratories were often described as stressful but occasionally rewarding, as one student reflected that:

"The labs stressed me out a ton, like every week I was nervous I'd mess something up. But when it actually worked, it was like, 'Oh wow, okay, I did that.' It felt like a real win." (Junior, 3)

Graduate students often described laboratory contexts as spaces where both learning and contribution occurred, emphasizing responsibilities related to training and mentorship. One graduate student reflected:

"*Helping new students in lab was the first time I felt like I was teaching chemistry*." (Graduate Student, 5)

Faculty reflected on these settings retrospectively, contrasting their own negative student experiences with efforts to make their current teaching more engaging.

"*I remember sitting in those huge lectures as an undergrad and just... hating it. So now I really try to make my own classes more interactive because I don't want my students feeling the way I did.*" (Faculty, 2)

In contrast, co-curricular experiences, including research and internships, showed the greatest variation in frequency and emphasis among different participant groups (Fig. 4). These experiences began as infrequent mentions among early undergraduates (below 20%) but became more frequent among juniors and seniors, peaking near 40% among graduate participants. Juniors and seniors more commonly described research as their first exposure to authentic scientific practice and articulated these experiences as influential in how they

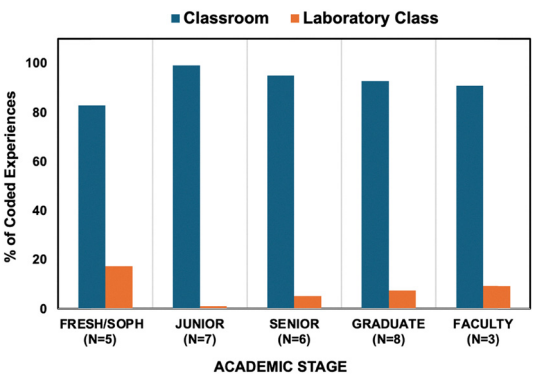

Fig. 3 Distribution of curricular subcontexts at academic stages. Values represent the percentage of coded curricular experiences within each academic group assigned to each subcontext.

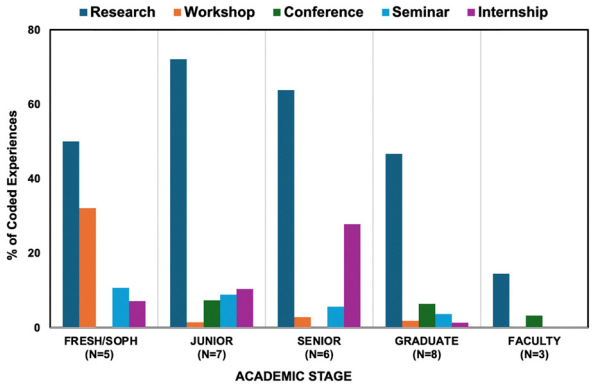

Fig. 4 Distribution of co-curricular subcontexts at academic stages. Values represent the percentage of coded co-curricular experiences within each academic group assigned to each subcontext.

positioned themselves within the field. Graduate students emphasized research and conferences as central to their professional recognition and belonging, with one participant noting that "*presenting at ACS wasn't just about my poster it was about realizing I belonged in the field*." For faculty participants, co-curricular experiences involved activities such as supervising research, conference participation, and professional service, that shaped their engagement with chemistry outside the classroom.

Internship experiences were referenced more often by juniors and seniors than by earlier cohorts, highlighting differences in engagement with applied and career-oriented contexts within participant groups. These findings indicate that co-curricular experiences function as vital sites of participation outside formal coursework, where participants described opportunities for contribution, recognition, and connection to chemistry-related practice.

Extracurricular experiences, though less common overall, consistently contributed to participants' involvement in the chemistry community. Undergraduates described outreach, student organizations, and even athletics as spaces that fostered connection beyond coursework (Fig. 5). One participant shared that "the chemistry club was my space to feel connected outside of class." For several students, these activities evolved into opportunities for leadership and mentorship, as one undergraduate reflected that "running the club made me realize I could organize and support others in chemistry." Graduate students and faculty mentioned outreach primarily as a form of professional service, highlighting a shift from social involvement to disciplinary contribution. A graduate student explained:

"Teaching chemistry to high school students made me feel like I was really giving back as a chemist." (Graduate student, 4)

The reduced emphasis on extracurricular experiences among faculty reflects differences in the types of activities participants described when discussing their engagement with chemistry-related communities. This pattern may also reflect the timing of the interviews, as faculty participants were less likely to be actively involved in extracurricular activities at the

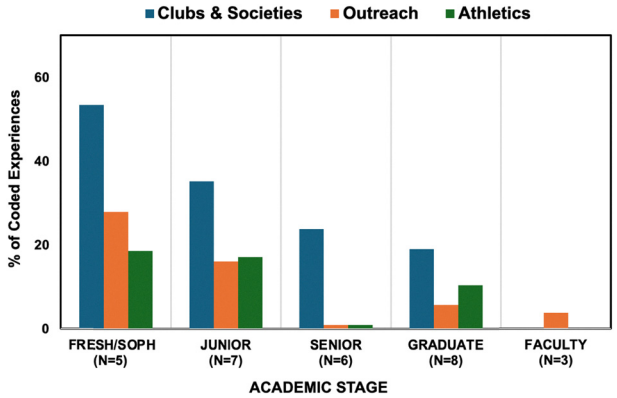

Fig. 5 Distribution of extracurricular subcontexts at academic stages. Values represent the percentage of coded extracurricular experiences within each academic group assigned to each subcontext.

time of data collection, given the demands and structure of their professional roles.

Accounts from undergraduates frequently highlighted classroom-based coursework, while participants in graduate and faculty roles more often described co-curricular and professionally situated engagements such as research, mentoring, and service. From a Deweyan perspective, these patterns highlight the principle of interaction, emphasizing how the environments participants described shaped the kinds of chemistry experiences that were related within their accounts. The findings illustrate how different institutional contexts structured opportunities for engagement with chemistry at different academic stages.

Affective framing of experiences

The distribution of affective framing (positive, negative, and neutral) across curricular, co-curricular, and extracurricular experiences is shown in Fig. 6 (curricular), Fig. 7 (co-curricular), and Fig. 8 (extracurricular). Curricular experiences were more frequently associated with neutral or negative affect among undergraduates, while participants in graduate and faculty roles more often described these experiences in positive terms. Co-curricular

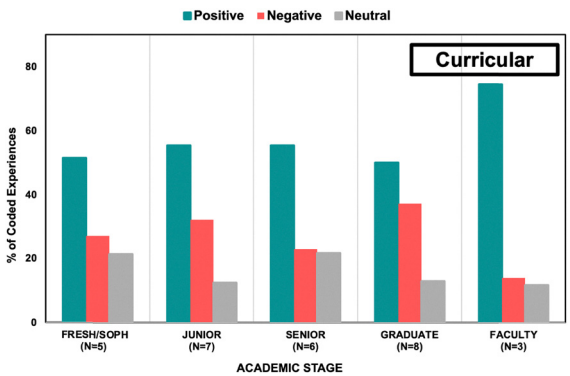

Fig. 6 Distribution of positive, negative, and neutral curricular experiences at academic stages. Values represent the average percentage of coded curricular experiences within each participant group.

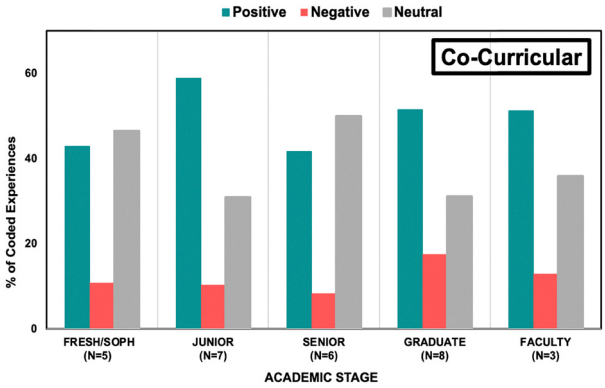

Fig. 7 Distribution of positive, negative, and neutral co-curricular experiences at academic stages. Values represent the average percentage of coded co-curricular experiences within each participant group.

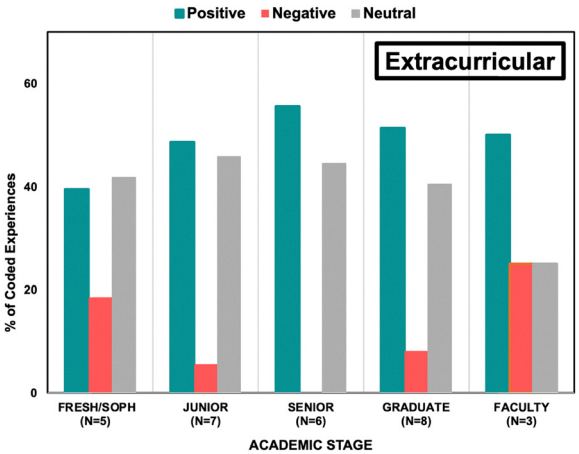

Fig. 8 Distribution of positive, negative, and neutral extracurricular experiences at academic stages. Values represent the average percentage of coded extracurricular experiences within each participant group.

experiences were characterized by a wider range of affective framing between participant groups; research and internship were described as emotionally engaging and affirming, but also as sources of stress or uncertainty within participants' accounts. Extracurricular experiences, though referenced less frequently among advanced participants, were consistently described in positive or neutral terms, often in relation to community, support, or personal grounding.

Affective framing was not evenly distributed across experience types, with clear differences emerging by context and participant group. Curricular experiences were more prominently described with positive affect, although negative affect was more prominent among graduate students, who often characterized coursework as stressful, detached, or procedural (Fig. 6). One graduate student summarized, "It was just something I had to push through." Yet many participants also described coursework as routine and expected rather than explicitly negative, reflecting a steady presence of neutral affect that persisted throughout different academic stages. These experiences, completing assignments, attending lectures,

preparing for exams, were often recounted as necessary steps toward progression rather than as influential learning moments. Positive affective moments were more frequent and were often transformative; as one junior explained:

"*Finally understanding spectroscopy made me feel like I was actually good at chemistry*." (Junior, 2)

highlighting how even isolated successes could influence confidence.

Negative affect was less common among later academic stages, for instance a faculty, reframed earlier struggles as productive in hindsight, with one recalling:

"*At the time, organic chemistry felt brutal, but looking back, I see how it prepared me for everything else*." (Faculty, 3)

Turning a negative experience into one that has an overall positive effect.

In contrast, co-curricular experiences, including research and internships, were characterized by greater variability in affective framing, with a more balanced distribution of positive and neutral affect (Fig. 7). Juniors and seniors described research as both demanding and empowering, emotionally charged but also marked by periods of neutrality associated with the repetitive or technical nature of lab work. One senior noted:

"Over time it became the place I felt like a real scientist," (Senior 3)

Other participants described stretches of "routine data collection" or "waiting for reactions to work". Graduate students echoed this duality, portraying research and conferences as spaces of recognition and belonging while also acknowledging uncertainty early in their graduate career. As one graduate student reflected:

"*Working with my advisor made me realize I could contribute something new, that was exciting*." (Graduate Student, 1)

yet elsewhere described feeling "numb" during cycles of failed experiments. Among faculty, co-curricular activities such as research and professional service were framed as deeply fulfilling but often routine, reflecting how neutral affect signified comfort and stability in established professional roles. This balance of affective tones highlights how co-curricular participation encompasses a range of emotional experiences, from excitement and engagement to routine professional involvement.

Extracurricular experiences were less frequent but consistently positive, particularly for undergraduates who found community and enjoyment through outreach, clubs, and athletics (Fig. 8). One student shared:

"*The chemistry club was where I met people who cared about the subject*". (Freshman, 2)

Even here, however, neutral affect appeared in the form of social familiarity, activities described as "fun," "regular," or "just part of my week." For graduate students and faculty, extracurricular engagement declined as professional commitments grew, yet those who continued outreach described it as both steady and affirming. A graduate student explained, "Working with younger students reminded me why I chose chemistry, it reconnected me to the joy of discovery" illustrating how routine service became an emotionally sustaining element.

When comparing academic stages, neutral affect functioned as an important marker of continual participation representing neither disengagement nor enthusiasm, but rather stability and sustained participation within chemistry. Positive affect was commonly associated with accounts of accomplishment or satisfaction, while negative affect appeared in narratives describing difficulty or challenge. Neutral affect was frequently used to describe routine or taken-for-granted experiences at different academic stages.

From a Deweyan perspective, these affective patterns illustrate how emotion functions as a qualitative feature of experience, shaped by the interaction between individuals and the contexts in which participation occurs. Neutral affect often reflected routine or obligatory engagement, while positive and negative affect marked moments of heightened emotional salience within participants' accounts. Overall, affective framing varied across experience contexts, with curricular, co-curricular, and extracurricular settings supporting different emotional interpretations.

Role positioning: student *vs.* professional

Taking all participants narratives into account, the participant groups positioned themselves differently in relation to chemistry-related experiences. Undergraduate participants more commonly described their experiences through a Being a Student (BS) lens, emphasizing structured learning environments, guidance, and compliance with external expectations. In contrast, upper-division undergraduates, graduate students, and faculty more frequently articulated experiences through a Being a Professional (BP) lens, highlighting autonomy, contribution, and engagement in disciplinary practices. These differences reflect variation in role positioning associated with participants' institutional roles.

Fig. 9 presents the distribution of Being a Student (BS) and Being a Professional (BP) framings among participant groups. BS positioning was most prominent among first- and second-year undergraduates, while BP positioning was more frequent in graduate student and faculty narratives. In particular, BP framings emphasized autonomy, contribution, and mentorship, whereas BS framings emphasized structured learning and externally defined expectations.

Although graduate students and faculty demonstrated the highest relative proportion of Being a Professional (BP) framings, Being a Student (BS) framings remained prevalent even at advanced stages. This pattern indicates that professional participation does not replace student positioning but coexists with it at different academic contexts.

By context, BS and BP codes indicate the relative prevalence of student and professional framing across experience types (Fig. 10). In curricular contexts, student positioning remained most prominent, particularly in coursework and laboratory instruction, although professional framings appeared more often when participants described instructional or mentoring responsibilities such as teaching assistantships or discussion leadership. In co-curricular contexts, including research, conferences, and internships, participants mainly framed their

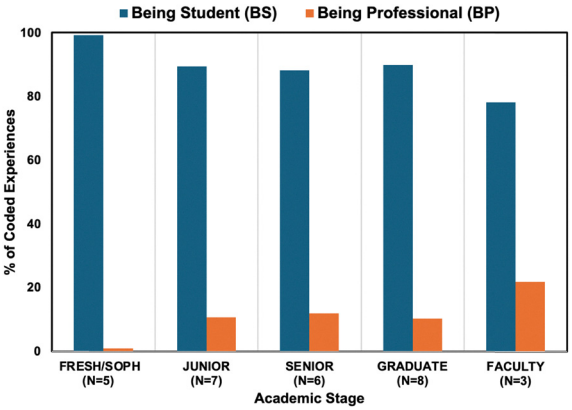

Fig. 9 Distribution of student (BS) and professional (BP) role framings at academic stages. Values represent the percentage of participants' coded experiences within each academic group.

experiences in professional terms. These environments were described as providing opportunities for autonomy, recognition, and contribution within chemistry-related practice. One graduate student described this transition vividly:

"*Leading a workshop for new students was the first time I realized I wasn't just learning chemistry, I was helping shape how others learn it.*" (Graduate Student, 5)

In contrast, extracurricular contexts, such as clubs, outreach, or athletics, were more prominently referenced in undergraduate accounts and were commonly framed in relation to student identity and community belonging. Graduate student and faculty participants referenced these experiences less often; however when present, they were typically described retrospectively as sources of connection and support rather than as sites of professional participation.

Undergraduate participants consistently anchored their accounts in the student role, particularly within coursework and laboratory settings. One sophomore explained, "I was there to learn and get through the material, not to add anything new." In contrast, upper-division undergraduates more frequently described experiences in which they positioned themselves in professional terms, particularly in research and presentation contexts. A senior reflected, "Presenting at the regional conference felt like stepping into the role of a chemist, not just a student taking classes." These accounts illustrate variation in role positioning across contexts, with research and presentation settings more often associated with professional framing than classroom-based activities.

Graduate students exhibited more fluidity in role positioning, often toggling between student and professional identities depending on the context. Within coursework and teaching assistant roles, participants reverted to student-like framings, describing themselves as "still figuring things out" or "learning how to teach." Yet in research or mentoring, their accounts focused on professional self-concepts. One participant remarked, "In my research group, I felt like a real chemist contributing something new, but in class I was just another student trying to keep up." This oscillation between learning and expertise highlights how graduate participants described navigating both student and professional role expectations within chemistry-related contexts.

Faculty's accounts of professional framing involved, leadership, mentorship, and contribution to the discipline. However, many referenced their own student experiences as touchstones for guidance. One faculty member recalled, "I remember being completely overwhelmed as an undergrad, so I try to make sure my students feel supported in ways I didn't." These reflections illustrate how faculty participants drew on student-centered experiences when describing their mentoring practices, linking personal recollections to their current approaches to supporting others. Faculty commonly referenced prior undergraduate or graduate experiences when describing moments that shaped their current professional roles. In these cases, Being a Student functioned as a narrative lens through which participants interpreted their present professional identity. While some faculty described ongoing learning in their professional roles, these accounts were typically framed as professional growth rather than institutional studenthood.

Overall, the results illustrate variation in how participants positioned themselves across different contexts and at various institutional roles. Professional framings were more commonly articulated in co-curricular settings such as research, mentoring, and conferences, while student framings remained prominent in coursework and instructional environments. Rather than tracing a developmental continuum, the findings show how different chemistry contexts supported distinct ways of

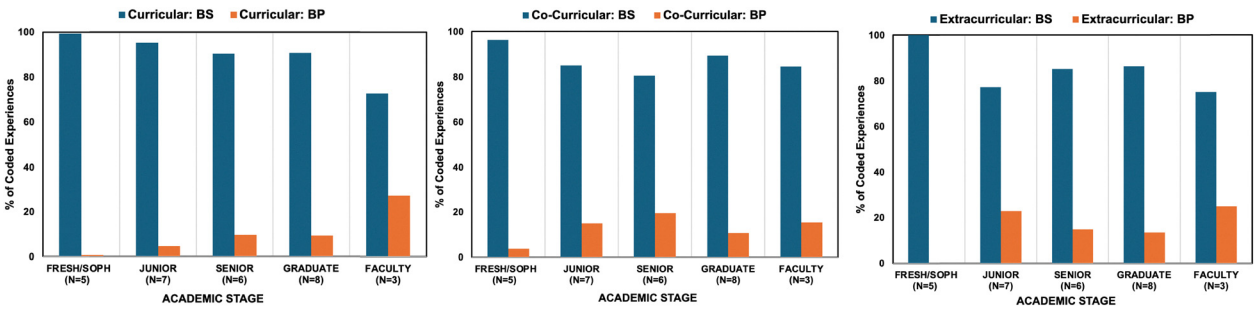

Fig. 10 Distribution of student (BS) and professional (BP) role framings within curricular, co-curricular, and extracurricular experiences at academic stages. Values represent the percentage of coded experiences within each context and academic group assigned to each role category.

participating, contributing, and making sense of one's place within the discipline.

Discussion

This study explored how individuals at different academic stages in chemistry; undergraduates, graduate students, and faculty, described and interpreted chemistry-related experiences they identified as influential to their current academic and professional positioning. By examining the contexts of these experiences, affective framings, and role positionings, the analysis highlighted differences in how chemistry participation was described across settings.

The patterns observed support Dewey's contention that the importance of experience emerges through the interaction between individuals and their environments, while extending his framework by specifying affect and role positioning as analytically useful dimensions for examining chemistry-related experiences. Although Dewey emphasized the quality of experience, he did not articulate how emotional tone or disciplinary role shape how experiences are interpreted and remembered. In this study, positive, negative, and neutral affect functioned as indicators of experiential quality, aligning with prior work showing that emotion mediates engagement, control, and persistence in chemistry learning environments (Villafañe and Lewis, 2016; Xu *et al.*, 2021). Similarly, distinctions between student and professional role positioning resonate with identity frameworks that emphasize recognition, competence, and performance as described by Carlone and Johnson (2007) and Hazari *et al.* (2010), while adding analytic depth by illustrating how role positioning varied across contexts. In this way, the study complements prior research on undergraduate research participation (Aikens *et al.*, 2017) and graduate socialization (Austin and McDaniels, 2006) by foregrounding experience as an interpretive unit of analysis rather than as evidence of developmental progression.

When comparing between academic stages, experiences varied in degree of structure, autonomy, and professional alignment. Early undergraduate accounts were dominated by curricular contexts, which were often characterized as procedural, evaluative, or disconnected from broader participation in chemistry, findings consistent with prior work documenting student detachment in traditional chemistry courses (Galloway and Bretz, 2015; Ferrell *et al.*, 2016). At the same time, these structured environments were described as providing sustained exposure to disciplinary practices and expectations. Rather than serving as developmental precursors, curricular experiences functioned as stable contexts against which participants later interpreted more autonomous and professionally framed engagements (Goodwin *et al.*, 2021).

Co-curricular experiences, including research, conferences, and internships, were consistently described as influential at different academic stages, but were framed differently depending on participants' academic position, ranging from tentative exposure among undergraduates to sites of contribution, recognition, and mentoring among graduate students and faculty. Prior work has shown that undergraduate research and authentic inquiry support confidence, belonging, and professional identity formation (Hunter *et al.*, 2007; Corwin *et al.*, 2015). The present study extends this literature by illustrating how participants occupying different roles in chemistry described these experiences in distinct ways. Undergraduates often framed research as tentative participation and exposure to disciplinary practice, graduate students emphasized recognition and contribution, and faculty highlighted mentoring, service, and stewardship of the discipline. Extracurricular experiences such as outreach and clubs were primarily discussed in relation to community and emotional support, particularly by undergraduates, and were less frequently referenced by graduate students and faculty, reflecting differences in institutional roles and forms of engagement. From a Communities of Practice perspective (Lave and Wenger, 1991; Wenger-Trayner and Wenger-Trayner, 2015), these patterns demonstrate how participation is shaped by context and role positioning.

Affective patterns among participants' accounts illustrate how emotional tone varied across chemistry-related experiences and contexts. Curricular contexts were more often described using frustration, anxiety, or neutral affect, reflecting tensions between external expectations and constrained agency. Rather than indicating disengagement, neutral affect often characterized experiences participants viewed as routine, stable, or obligatory. This interpretation aligns with work showing that challenge and struggle are common features of chemistry learning environments and are not inherently detrimental when situated within supportive instructional contexts (Goodwin *et al.*, 2021). Neutrality in this study appeared to signal sustained engagement within structured practices rather than absence of importance. Attending to neutral affect therefore expands existing affective models in chemistry education, which have largely emphasized high-arousal emotions such as interest, anxiety, or frustration (Villafañe and Lewis, 2016; Xu *et al.*, 2021).

Co-curricular environments elicited the most varied emotional patterns in participants' accounts. Research and internship experiences were described as both empowering and uncertain, reflecting the inherent ambiguity of authentic scientific practice. These affective dualities align with prior work on scientific self-efficacy, confidence, and belonging in research and applied settings (Aikens *et al.*, 2017; Hernandez *et al.*, 2018). Undergraduates often emphasized uncertainty and exposure, whereas graduate students and faculty more commonly framed similar experiences in terms of contribution, responsibility, and support of others.

Differences in Being a Student (BS) and Being a Professional (BP) framing captured how participants positioned themselves in relation to chemistry across contexts. Undergraduates predominantly framed themselves as students navigating structured expectations, though moments of professional alignment emerged through research participation, presentations, and peer mentorship. Graduate students oscillated between student and professional framings, consistent with literature on their

liminal identity status (Austin and McDaniels, 2006). This interpretation is consistent with work by Bhattacharyya (2008) and Bhattacharyya and Bodner (2014), who showed that professional identity in chemistry emerges through engagement with disciplinary epistemic practices rather than through the attainment of fixed roles, with even advanced practitioners continuing to position themselves as learners as they encounter new problems, methods, and expectations. While faculty participants exhibited a relatively higher proportion of professional framings than student groups, they nonetheless continued to describe many experiences using student-oriented language. Faculty narratives more commonly referenced their own student experiences when discussing mentoring and teaching, illustrating how BS and BP framings coexist within professional roles and how past student experiences inform current approaches to supporting others.

The relatively low proportion of professional role framings among graduate students and faculty may appear counterintuitive at first glance. However, this pattern reflects the situational and institutional nature of role positioning rather than a lack of professional identity. Participants narrated experiences in which they were learning new practices, responding to evaluation, or navigating externally imposed expectations, conditions that elicited student framings even at advanced stages. From this perspective, Being a Student does not signify novice status but an institutional positioning marked by accountability, constraint, and ongoing learning. This finding aligns with sociocultural accounts of identity as contextually enacted rather than cumulatively acquired, where individuals draw on different role framings depending on the demands of the situation. Thus, the persistence of student framings among faculty and graduate participants highlights the fluidity of professional identity and underscores that participation in chemistry involves continual movement between learning and expertise.

When comparing groups, participants drew on recognizable ways of speaking about competence, struggle, contribution, and belonging, reflecting expectations about what it means to present oneself as a chemist. This interpretation aligns with life-story and narrative approaches to identity, which emphasize that identities are constructed and reconstructed through storytelling in relation to figured worlds and normative expectations (Gonsalves *et al.*, 2016, 2019). From this perspective, participants' accounts do not transparently reflect developmental trajectories but instead represent situated identity work, through which individuals present themselves as coherent and intelligible members of a discipline despite changing roles and circumstances.

Taken together, the findings position chemistry education as an experiential system in which identity, emotion, and participation are shaped through individuals' interactions with disciplinary environments. By examining how participants at different academic stages described their chemistry experiences, this study shows that disciplinary engagement is reflected not in isolated moments of success, but in how experiences across coursework, research, mentoring, and extracurricular contexts are framed and prioritized. Identifying affective framing and role positioning as central analytic dimensions extends Dewey's Theory of Experience by specifying how the quality of experience can be examined empirically within chemistry education. In particular, recognizing neutral affect as an important mode of participation challenges common assumptions that engagement must be emotionally intense to be productive. Together, these insights offer a framework for thinking about chemistry learning environments that support sustained participation, belonging, and interpretation of experience, emphasizing learners' ongoing relationships with the discipline.

Implications

Findings from this study offer several implications for chemistry curriculum design, departmental structures, and mentoring practices. First, the predominance of curricular experiences among early undergraduates highlights the need to reimagine how coursework fosters influential engagement. Prior research has shown that traditional lecture and lab environments can promote performance-oriented rather than meaning-oriented participation (Galloway and Bretz, 2015; Ferrell *et al.*, 2016). Consistent with calls for inquiry-based and student-centered practices (Cooper *et al.*, 2018), instructors can embed opportunities for agency and reflection, such as reflective writing, design-based lab tasks, or problem-based mini-projects, to help students connect coursework to authentic scientific practice.

Second, the prominence of co-curricular experiences among participant groups highlights their central role in supporting influential engagement with chemistry. Empirical studies of undergraduate research and internship participation demonstrate that authentic scientific involvement is associated with increased self-efficacy, belonging, and identity-related outcomes (Hunter *et al.*, 2007; Aikens *et al.*, 2017). Complementing this empirical work, Corwin *et al.* (2015) offer a conceptual framework for understanding how undergraduate research experiences may function as contexts for identity negotiation and participation within scientific communities. Rather than positioning these opportunities as merely supplemental, this perspective highlights their potential role in shaping how students interpret and position themselves within the discipline. Expanding structured mentorship programs, providing equitable access to research experiences, and scaffolding conference participation may therefore support earlier and more sustained engagement with disciplinary communities.

Third, the affective findings highlight the importance of designing learning environments that attend to the emotional dimensions of chemistry participation. Emotions such as anxiety, frustration, and uncertainty, long documented in early chemistry coursework (Villafañe and Lewis, 2016) should not be interpreted merely as barriers but as elements of learning that require contextual support. Departments can support students by creating mentoring networks, peer discussion groups, and reflective activities that help normalize the emotional complexities of scientific work. When instructors share their own formative experiences, including moments of struggle or

uncertainty, they can help students contextualize difficulty as part of the learning process and help students build belonging and confidence (Hernandez *et al.*, 2018; Goodwin *et al.*, 2021).

Ultimately, these results suggest that chemistry education should be viewed not simply as a sequence of isolated instructional experiences, but as a dynamic system. One in which identity, emotion, and participation evolve through the interplay of structured environments, authentic practice, and social connection. Designing for continuity, by integrating research, mentoring, and reflective practice at different stages, can help learners move not just through chemistry, but into it, as full and enduring members of the disciplinary community. These insights call for chemistry programs to intentionally design curricula, co-curricular opportunities, and mentoring structures that support long-term growth rather than short-term performance outcomes.

Limitations

Several limitations should be considered when interpreting the findings of this study. Although participants represented three academic stages, the sample was drawn from a single institutional context, limiting the generalizability of findings to other types of institutions, disciplinary cultures, or demographic groups. Future research should include participants from a wider range of universities and subdisciplines to capture broader variability in how chemistry experiences are described and interpreted.

This study is limited in its ability to examine how gender, race, class, or other positionalities shape the experiences described. Although participants represented diverse backgrounds, the sample size and analytic focus did not support systematic comparisons across demographic groups. As a result, the findings speak to broad patterns in how chemistry experiences are described at different academic stages and across various academic contexts, rather than to how structural inequities or identity-based dynamics shape access to, interpretation of, or participation in chemistry experiences. Future research should purposefully center positionality by using larger, more demographically balanced samples or study designs that foreground intersectional experiences.

Since the study relied on retrospective, self-reported interview data, participants' accounts reflect how experiences were interpreted and narrated at the time of the interview. These accounts were shaped by memory, current perspective, and personal framing, and may differ from how the same experiences would be described at another point in time. Participants often blended past and present perspectives, which may have introduced selective emphasis or omission. Future research could integrate longitudinal or multi-method approaches, such as repeated interviews, reflective journaling, or observational data, to examine how interpretations of chemistry experiences focus on moments of reflection.

Additionally, the cross-sectional design limits claims about developmental causality. The patterns observed at different stages represent comparisons between participants at different points in their trajectories rather than within-person change over time. Longitudinal approaches would allow for deeper insight into how affect, role positioning, and contextual engagement unfold through continuity of lived experience.

Finally, while the coding framework captured major dimensions of experience (context, affect, role positioning), it may not have captured all nuances in participants' narratives. Expanding future frameworks to include additional relational or epistemic dimensions, or incorporating participant validation, could enhance interpretive depth and validity.

Concluding remarks

This study examines how individuals at different academic stages in chemistry describe and interpret experiences they identify as influential. By examining experiences through affective framing, contextual features, and role positioning, the findings highlight that participation in chemistry extends beyond coursework to include research engagement, mentoring, and community involvement. These findings emphasize interaction between individuals and their environments, showing how the quality of participation was shaped by the contexts in which experiences occurred and the roles participants enacted within them. Taken together, the study suggests that chemistry learning environments that foster connection, reflection, and opportunities for participation across contexts may better support sustained engagement with the discipline. Addressing the limitations identified here and extending this work can further inform how chemistry educators design environments that support influential participation among academic stages.

Author contributions

Devin Pontigon contributed to the investigation through study conceptualization, data collection and analysis, as well as writing the original draft. Vicente Talanquer contributed to study conceptualization, project supervision, and writing (reviewing and editing).

Conflicts of interest

There are no conflicts to declare.

Data availability

Due to ethical confidentiality requirements, the recorded data have not been made publicly available. Our research participants have consented to share their data only with the researchers directly involved in this project.

Supplementary information (SI) includes the full interview protocol, coding framework, and additional example quotes supporting each thematic category. See DOI: https://doi.org/10.1039/d5rp00465a.

Acknowledgements

The authors would like to thank all participants who generously shared their experiences and insights for this study. We also thank Ben Augustine for his collaboration during the data analysis process, particularly in supporting the development of interrater reliability procedures. We are grateful for the guidance and feedback provided throughout the project by colleagues in the Chemistry Education research community.

References

Aikens M. L., Robertson M. M., Sadselia S., Watkins K., Evans M., Runyon C. R., Eby L. T. and Dolan E. L., (2017), Race and gender differences in undergraduate research mentoring structures and research outcomes, *CBE Life Sci. Educ.*, **16**(2), ar34.

Austin A. E. and McDaniels M., (2006), Preparing the professoriate of the future: graduate student socialization for faculty roles, *High. Educ.: Handbook Theory Res.*, **21**, 397–456.

Bhattacharyya G., (2008), Who am I? What am I doing here? Professional identity and the epistemic development of organic chemists, *Chem. Educ. Res. Pract.*, **9**(2), 84–92.

Bhattacharyya G. and Bodner G. M., (2014), Culturing reality: How organic chemistry graduate students develop into practitioners, *J. Res. Sci. Teach.*, **51**(6), 694–713.

Brownell S. E., Hekmat-Scafe D. S., Singla V., Chandler Seawell P., Conklin Imam J. F., Eddy S. L., Stearns T. and Cyert M. S., (2016), A high-enrollment CURE improves student conceptions of scientific thinking and attitudes about science, *CBE—Life Sci. Educ.*, **15**(2), ar21.

Carlone H. B. and Johnson A., (2007), Understanding the science experiences of women of color: science identity as an analytic lens, *J. Res. Sci. Teach.*, **44**(8), 1187–1218.

Chen X. and Soldner M., (2013), *STEM attrition: College students' paths into and out of STEM fields*, Washington, DC: National Center for Education Statistics.

Cooper M. M., Stowe R. L. and Brownell S. E., (2018), Restructuring traditional chemistry labs to support engagement and agency, *Chem. Educ. Res. Pract.*, **19**(3), 841–856.

Corwin L. A., Graham M. J. and Dolan E. L., (2015), Modeling course-based undergraduate research experiences: an agenda for future research and evaluation, *CBE—Life Sci. Educ.*, **14**(1), es1.

Dewey J., (1938), *Experience and education*, Macmillan.

Ferrell B., Phillips M. M. and Barbera J., (2016), Connecting achievement motivation and performance in general chemistry. *Chem. Educ. Res. Pract.*, **17**(4), 1054–1066.

Freeman S., Eddy S. L., McDonough M., Smith M. K., Okoroafor N., Jordt H. and Wenderoth M. P., (2014), Active learning increases student performance in STEM, *Proc. Natl. Acad. Sci. U. S. A.*, **111**(23), 8410–8415.

Galloway K. R. and Bretz S. L., (2015), Measuring meaningful learning in the undergraduate general chemistry laboratory, *J. Chem. Educ.*, **92**(2), 200–211.

Gee J. P., (2000), Chapter 3: Identity as an Analytic Lens for Research in Education, *Rev. Res. Educ.*, **25**(1), 99–125.

Goffman E., (1986), *Stigma: Notes on the Management of Spoiled Identity*, Touchstone.

Gonsalves A. J., Danielsson A. and Pettersson H., (2016), Masculinities and experimental practices in physics: the view from three case studies, *Phys. Rev. Phys. Educ. Res.*, **12**(2), 020120.

Gonsalves A. J., Silfver E., Danielsson A. and Berge M., (2019), ''It's not my dream, actually'': Students' identity work across figured worlds of construction engineering in Sweden, *Int. J. STEM Educ.*, **6**(1), 13.

Goodenow C., (1993), The psychological sense of school membership among adolescents: scale development and educational correlates, *Psychol. Schools*, **30**, 79–90.

Goodwin L., McConnell M. and Cooper M. M., (2021), Negotiating identity and belonging in the chemistry laboratory: graduate student perspectives, *Chem. Educ. Res. Pract.*, **22**(4), 1047–1061.

Günter K. P., Ahnesjö I. and Gullberg A., (2023a), ''I try to encourage my students to think, read, and talk science'' intelligible identities in university teachers' figured worlds of higher education biology, *J. Res. Sci. Teach.*, **60**(6), 1195–1222.

Günter K. P., Bussière L. F. and Gromes R., (2023b), Dedicating, faking, and surviving: disclosing tensions in how three women university students negotiate collectively celebrated norms across European contexts, *Int. J. Sci. Educ.*, **45**(12), 1032–1052.

Hazari Z., Sonnert G., Sadler P. M. and Shanahan M.-C., (2010), Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice, *J. Res. Sci. Teach.*, **47**(8), 978–1003.

Hernandez P. R., Bloodhart B., Barnes R. T., Adams A. S., Burt M., Clinton S. M., Pollack I., Godfrey E. and Fischer E. V., (2018), Promoting professional identity, motivation, and persistence: benefits of an informal mentoring network for women in STEM, *CBE—Life Sci. Educ.*, **17**(3), ar36.

Holland D., Lachicotte W. Jr., Skinner D. and Cain C., (1998), *Identity and Agency in Cultural Worlds*, Cambridge: Harvard University Press.

Holmegaard H. T., Ulriksen L. M. and Madsen L. M., (2014), The Process of Choosing What to Study: A Longitudinal Study of Upper Secondary Students' Identity Work When Choosing Higher Education, *Scandinavian J. Educ. Res.*, **58** (1), 21–40.

Hunter A.-B., Laursen S. L. and Seymour E., (2007), Becoming a scientist: the role of undergraduate research in students' cognitive, personal, and professional development, *Sci. Educ.*, **91**(1), 36–74.

Lave J. and Wenger E., (1991), *Situated learning: Legitimate peripheral participation*, Cambridge University Press.

Mutambuki J. M. and Schwartz R., (2019), We don't get any training, they expect us to teach: graduate teaching assistants' experiences teaching chemistry, *Chem. Educ. Res. Pract.*, **20**(3), 540–552.

Otero V., Pollock S. and Finkelstein N., (2020), A physics learning community for underrepresented groups, *Phys. Rev. Phys. Educ. Res.*, **16**(1), 010137.

Seymour E. and Hunter A. B., (2019), *Talking about leaving revisited: Persistence, relocation, and loss in undergraduate STEM education*, Springer.

Villafañe S. M. and Lewis J. E., (2016), Exploring a measure of science attitude for different groups of students enrolled in introductory college chemistry, *Chem. Educ. Res. Pract.*, **17**, 731–742.

Walton G. M. and Cohen G. L., (2007), A brief social-belonging intervention improves academic and health outcomes of minority students, *Science*, **331**, 1447–1451.

Wenger-Trayner E. and Wenger-Trayner B., (2015), *Learning in landscapes of practice: Boundaries, identity, and knowledge-ability in practice-based learning*, Routledge.

Wilson D., Jones D., Bocell F., Crawford J., Kim M. J., Veilleux N., Floyd-Smith T., Bates R. and Plett M., (2015), Belonging and academic engagement among undergraduate STEM students: a multi-institutional study, *Res. High. Educ.*, **56**(7), 750–776.

Xu X., Lewis J. E. and Lopez J. L., (2021), Examining chemistry anxiety as a barrier to student success in general chemistry, *Chem. Educ. Res. Pract.*, **22**(2), 410–421.

