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Course-Based Undergraduate Research Experiences (CUREs) in Chemistry Education: Characteristics, Implementation, and Impact

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Abstract: Course-Based Undergraduate Research Experiences (CUREs) have gained increasing prominence as an innovative pedagogical model that integrates authentic research into the undergraduate curriculum. While extensive research has highlighted the general benefits of CUREs across STEM fields, a focused synthesis of their implementation and impact specifically within chemistry education remains underexplored. This narrative review addresses this gap by analyzing ten recent, peer-reviewed studies indexed in Scopus to characterize how CUREs are designed, implemented, and evaluated in undergraduate chemistry contexts. The findings demonstrate that CUREs shift traditional laboratory instruction toward inquiry-based, authentic research experiences that foster critical thinking, increase student engagement, and enhance retention in STEM, especially within inclusive learning environments. However, challenges such as faculty workload, scalability, and research output persist. By consolidating insights across current literature, this review contributes a field-specific understanding of CUREs in chemistry education and offers implications for curriculum design, institutional support, and future research directions. In doing so, it fills a critical gap in the literature and underscores the evolving role of CUREs in preparing the next generation of chemists through evidence-based, research-intensive teaching practices.

Keywords: Characteristics; Chemistry education; Course-based undergraduate research experiences; Impact; Implementation

Introduction

In recent years, Course-Based Undergraduate Research Experiences (CUREs) have emerged as a transformative pedagogical model aimed at democratizing access to authentic research experiences in undergraduate STEM education. Traditionally, undergraduate research was confined to mentored, one-on-one lab apprenticeship opportunities, typically limited by faculty bandwidth and institutional resources. In contrast, CUREs allow entire classes of students to engage in genuine research projects embedded within the curriculum, significantly expanding participation in research and reshaping the undergraduate learning environment (Auchincloss et al., 2014; Dolan, 2016).

CUREs are particularly impactful in the field of chemistry, where they offer students hands-on engagement with scientific inquiry, from hypothesis development and experimental design to data interpretation and communication. This model not only enhances content mastery and laboratory skills but also

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promotes key affective outcomes, such as increased science identity, motivation, and persistence in STEM fields (Buchanan & Fisher, 2022; Corwin, Graham, & Dolan, 2015). Additionally, chemistry-focused CUREs offer unique opportunities to align course content with interdisciplinary and socially relevant challenges, such as materials science, sustainability, and drug discovery (Heemstra et al., 2017; Watts & Rodriguez, 2023).

The integration of CUREs into chemistry education poses both opportunities and challenges. While studies demonstrate increased student engagement and equity in access to research (Ballen et al., 2017; DeChenne-Peters et al., 2023), the logistical complexities of scaling and assessing these experiences across diverse institutional contexts remain significant. As such, understanding the design characteristics, implementation strategies, and measurable impacts of chemistry-based CUREs is critical for advancing evidence-based curriculum reform.

Despite a growing body of literature on CUREs, there remains a notable gap in comprehensive, chemistry-specific analyses that integrate theoretical models, instructional practices, and outcome evaluations. Much of the foundational work on CUREs has focused on biology (Brownell & Kloser, 2015; Lopatto et al., 2014), with chemistry often treated as a secondary context (Auchincloss et al., 2014; Brownell & Kloser, 2015). This review is novel in its targeted synthesis of chemistry CUREs, bridging the divide between educational theory and practical implementation in this discipline. By providing an integrative, up-to-date examination of chemistry-specific CURE models, this work addresses an urgent need for discipline-centered insights that can guide faculty, departments, and policymakers in designing effective and sustainable research-integrated curricula (Watts & Rodriguez, 2023). Moreover, the findings have implications for promoting inclusivity, retention, and workforce readiness among undergraduate chemistry students (Ballen et al., 2017; Buchanan & Fisher, 2022).

This review synthesizes current literature on CUREs in chemistry education, with a focus on their structural features, pedagogical underpinnings, and documented outcomes. By critically examining implementation models and their effects on student learning and development, this work aims to inform future directions for integrating research into the undergraduate chemistry curriculum in a sustainable and inclusive manner.

Method

This study employed a qualitative literature review approach, guided by principles of thematic synthesis and content analysis (Elo & Kyngäs, 2008; Thomas & Harden, 2008). The aim was to identify, analyze, and interpret the characteristics, implementation, and impact of CUREs. A comprehensive literature search was conducted from the Scopus database. The search terms were constructed using Boolean operators and keyword combinations, such as: TITLE-ABS-KEY(course pre/0 based pre/0 undergraduate pre/0 research pre/0 experience) AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (OA,"all")) AND (LIMIT-TO (SUBJAREA,"CHEM")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English")). From the initial search results, a total of 17 articles were identified. After a screening process based on the relevance of the title and abstract, and a full-text review based on the inclusion criteria, which focused on the impact of CURE in chemistry education, a total of 10 articles were finally selected for further analysis.

Result and Discussion

Key Characteristics of CUREs in Chemistry

Essential Components and Design Elements

According to Auchincloss et al., (2014) five central elements consistently define CUREs: engagement with broadly relevant research questions, the application of authentic scientific methods, iterative experimental design, collaboration among students, and the pursuit of novel discovery. These components have been widely adopted as a theoretical framework for evaluating and designing CUREs across disciplines.

Research has emphasized that the integration of research into the formal curriculum is one of the most important design decisions influencing both scalability and inclusivity. Unlike traditional undergraduate research, which typically occurs outside the classroom under faculty mentorship, CUREs embed research within credit-bearing courses. This structure enhances accessibility for students who might otherwise be excluded due to time, financial, or institutional constraints (Bangera & Brownell, 2014; Karukstis, 2008; Kruis, McLean, Bish, & Rakhmatullaev, 2023). Studies consistently highlight that such integration reduces barriers to participation, particularly for first-generation students, working students, and those from historically excluded backgrounds.

Despite these advantages, several reviews have noted that CURE implementation in early undergraduate coursework remains uneven. While upper-level courses in biology and chemistry increasingly incorporate research experiences, first-year students often lack similar access. Doble et al. (2024) observed that institutional hesitancy frequently stems from concerns about students' preparedness, lab resource limitations, and curriculum rigidity.

Nonetheless, evidence suggests that early research exposure is correlated with stronger science identity development, increased persistence in STEM majors, and improved learning outcomes (Buchanan & Fisher, 2022; Corwin et al., 2015).

The literature also underscores the pedagogical value of iteration and collaboration in the CURE model. Corwin et al. (2018) demonstrated that opportunities to repeat, revise, and troubleshoot experiments promote a sense of project ownership, which in turn predicts positive attitudes toward science careers. Similarly, team-based inquiry, another hallmark of CUREs, has been associated with gains in scientific communication, critical thinking, and interpersonal skills (Auchincloss et al., 2014). These findings align with national priorities to equip undergraduates with both technical and soft skills needed for a modern STEM workforce.

Inclusivity and Accessibility Features

CUREs are becoming recognized as a successful method for involving students in research at the onset of their college education (Wang, 2024). CUREs provide numerous benefits compared to conventional courses and research internships. They engage numerous undergraduates in scientific study simultaneously, and all students enrolled in a course are permitted to participate.

CUREs are crucial for providing students, particularly those from underprivileged backgrounds, with early engagement in STEM research during their undergraduate studies, hence enhancing retention rates. CUREs have continuously demonstrated the ability to engage students in the scientific process, augment retention, and enhance learning outcomes within a course. (Fields et al., 2019).

CUREs have gained prominence not only for their pedagogical innovation but also for their potential to advance equity and accessibility in STEM education. Unlike traditional research internships or faculty-mentored research opportunities, often limited by availability, selective admission, or student schedules, CUREs are embedded within the curriculum, allowing all enrolled students to participate in authentic research as part of a credit-bearing course (Auchincloss et al., 2014; Wang, 2024). This structural integration eliminates many of the logistical and social barriers historically associated with undergraduate research, including limited lab space, restricted funding, and implicit gatekeeping (Bangera & Brownell, 2014).

Recent literature has emphasized that CUREs are especially impactful for students from underrepresented or underserved backgrounds. By democratizing access to research experiences, CUREs offer early exposure to scientific practices for students who may not have the resources, social capital, or time to participate in competitive extracurricular research (Bangera & Brownell, 2014; Karukstis, 2008; Kruis et al., 2023). This broad participation model aligns with institutional goals to reduce opportunity gaps in STEM and contributes to the diversification of the scientific workforce.

Multiple studies have shown that participation in CUREs enhances students' academic self-efficacy, sense of scientific identity, and persistence in STEM majors, all of which are key predictors of long-term retention and success (Indorf et al., 2019; Miller et al., 2023). Fields et al., (2019) reported that CURE implementation in chemistry significantly improved student retention rates and course-level learning outcomes, with pronounced benefits observed among students from marginalized groups.

Moreover, early engagement is a critical feature of inclusive research models. Embedding CUREs in first- or second-year courses not only normalizes research as a standard component of science education but also cultivates interest and belonging in scientific fields from the outset of a student's academic journey (Buchanan & Fisher, 2022; Wang, 2024). In this context, CUREs function as both a pedagogical innovation and an equity intervention, bridging access gaps while enhancing engagement, skill development, and identity formation.

Authentic Research Integration

A core objective of CUREs is to replicate the authenticity of professional scientific research within an academic course setting. One of the defining attributes of authentic research in CUREs is the production of data or knowledge that is genuinely needed, either by the scientific community, an instructor, or an external stakeholder. Frederick et al. (2025) provide an illustrative case in which students conducted technical analyses on curated objects, where their findings directly informed broader research questions posed by museum curators. The structure of such experiences reflects a key dimension of authenticity: student work contributes meaningfully to real-world inquiries, not merely to pedagogical exercises.

Authentic research integration is further strengthened when students are granted agency in shaping the research process. Studies have shown that giving students control over hypothesis formulation, experimental design, and interpretation fosters deeper engagement and mirrors the decision-making responsibilities they would encounter in actual laboratory environments (Auchincloss et al., 2014; Corwin et al., 2015). These opportunities for ownership and creativity are central to what distinguishes CUREs from more structured or confirmatory laboratory exercises.

Moreover, the incorporation of open-ended, problem-solving tasks within CUREs has been associated with the development of scientific reasoning, resilience, and collaborative skills. These features not only enrich the educational experience but also simulate the uncertainties and complexities inherent in both academic and industrial research settings (Corwin et al., 2015; Hanauer et al., 2022). Authenticity, therefore, is not solely defined by research output, but also by the alignment of student roles and responsibilities with those encountered in professional scientific environments

Implementation Strategies and Approaches

Curriculum Integration Models

Various unique implementation models have arisen within diverse chemical subdisciplines. The majority of chemical CUREs are executed in classes designed for second-year students and higher, including Organic, Analytical, Biochemistry, Physical, and Inorganic chemical. Nonetheless, there is increasing acknowledgment that if students are not exposed to the research process until these courses, it may prolong their identification as scientists (Doble et al., 2024).

The integration of CUREs into the chemistry curriculum has taken diverse forms across subdisciplines, reflecting both pedagogical opportunities and disciplinary constraints. A growing body of literature reports successful CURE implementation in upper-division courses, particularly in Organic, Analytical, Biochemistry, Inorganic, and Physical Chemistry (Frederick et al., 2025; Heemstra et al., 2017). These advanced-level courses often provide the disciplinary depth and lab infrastructure necessary to support authentic, inquiry-driven research projects. As such, many chemistry CUREs are situated in the second year or beyond, when students have acquired sufficient content knowledge and technical competencies to engage in meaningful scientific inquiry.

However, recent scholarship has raised concerns about the implications of delaying research exposure until upper-level coursework. Doble et al. (2024) argue that postponing engagement with the research process may limit early identity formation as scientists and restrict access for students who may exit STEM pathways before reaching advanced courses. Early exposure to research, particularly in the first year of undergraduate study, has been associated with increased persistence, improved self-efficacy, and greater academic engagement (Corwin et al., 2015). This has led to a growing movement toward incorporating CUREs into introductory-level courses, despite challenges related to content scaffolding, student preparedness, and course structure (Buchanan & Fisher, 2022; Dolan, 2016).

The literature further suggests that flexible curriculum models, such as vertically integrated CURE sequences, modular approaches embedded within existing lab courses, and interdisciplinary project frameworks, may offer viable strategies for expanding research access without overburdening instructors or displacing essential content (Wang, 2024). These integration models are being increasingly adopted to scaffold research skills longitudinally and to ensure that students across all academic levels benefit from authentic research engagement.

Structured Course Design

The successful implementation of CUREs often relies on well-structured course designs that intentionally scaffold both research competencies and disciplinary knowledge. Structured CURE models typically divide the course into clearly delineated phases, commonly including preparatory, investigative, and dissemination components, each aligned with specific learning objectives and skill development (Auchincloss et al., 2014; Corwin et al., 2015). This sequencing ensures that students acquire foundational knowledge incrementally while engaging with increasingly complex research tasks.

Frederick et al. (2025) exemplify this approach in their chemistry CURE, which was organized into two distinct but interrelated segments: a literature-intensive phase followed by a laboratory-based experimental phase. Each seven-week segment emphasized different yet complementary skill sets, analytical reading, hypothesis formulation, and chemical experimentation with scaffolding embedded throughout the course. This model provided students with a coherent progression of competencies, thereby reducing cognitive overload and increasing student confidence and autonomy.

The literature strongly supports the use of instructional scaffolding in CUREs, particularly when courses integrate interdisciplinary content or are aimed at early-career undergraduates. In Frederick et al.'s case, the research questions required engagement with both scientific literature and humanities-based sources, such as art history and anthropology. To support students in navigating this interdisciplinary terrain, the course incorporated targeted sessions on research strategies, database usage, and discipline-specific information literacy. Librarians with expertise across domains played an active role in guiding students, highlighting the value of cross-departmental collaboration in CURE execution.

Such structured instructional support is consistent with broader findings that emphasize the importance of research skill development within CUREs. Studies suggest that students benefit most when given explicit instruction in tasks often assumed to be intuitive, such as literature search techniques, data analysis, and scientific writing (Buchanan & Fisher, 2022; Dolan, 2016). Scaffolding also plays a critical role in ensuring equity in research education, as it accounts for variability in student preparation and background, particularly in courses that serve nonmajors or interdisciplinary cohorts.

Partnership and Collaboration Models

Collaborative partnerships with external organizations have emerged as a valuable strategy for enhancing the authenticity, relevance, and impact of CUREs. These partnerships can bridge the gap between classroom learning and real-world applications, providing students with opportunities to engage in research that extends beyond academic settings and contributes to ongoing societal, cultural, or scientific efforts.

Doble et al. (2024) document a CURE model in which chemistry undergraduates conducted applied research on biochar, a carbon-rich material derived from biomass, through a collaboration with a local environmental research center. This partnership provided students with access to authentic datasets, specialized instrumentation, and mentoring from professional researchers, thus elevating both the scientific rigor and perceived value of the course-based research. Such community-engaged models are increasingly recognized for their potential to integrate experiential learning with pressing environmental and sustainability challenges.

Similarly, Frederick et al. (2025) describe CURE implementations in which chemistry students collaborate with regional art museums to generate technical data on cultural artifacts. These collaborations are particularly well-suited for analytical chemistry education, as they require students to apply a wide array of spectroscopic, microscopic, and chemical analysis techniques commonly taught in the undergraduate laboratory curriculum. In this context, museums function as authentic research partners, offering interdisciplinary research opportunities that blend scientific analysis with cultural heritage preservation.

The literature broadly supports the integration of external partnerships as a high-impact practice in undergraduate education. Collaborative CUREs enhance student motivation and scientific identity by demonstrating the societal relevance of classroom learning (Corwin et al., 2015; Hanauer et al., 2022). Furthermore, such models often facilitate access to resources, instrumentation, and mentoring networks that may not be available within a single institution. When executed thoughtfully, these partnerships promote interdisciplinary thinking, community engagement, and scalable avenues for embedding real-world research into undergraduate curricula.

Faculty Development and Multi-institutional Networks

Multiple studies highlight the flexible implementation pathways available to faculty when integrating Course-Based Undergraduate Research Experiences (CUREs) into chemistry curricula. Wolfe & Steed (2023) describe four common models: (1) independently designed CUREs not directly tied to faculty research, (2) CUREs developed from ongoing faculty research agendas, (3) participation in multisite CURE networks such as the Malate Dehydrogenase CURE Community (MCC), and (4) the adoption of pre-developed CUREs from curated repositories like CUREnet or CourseSource. This structural adaptability has been widely recognized as a key enabler for broader institutional adoption, particularly in settings with limited research infrastructure or faculty bandwidth (Dolan, 2016).

The flexibility in CURE design also extends to curricular scale, ranging from single-term laboratory modules to multi-semester research sequences. Such customization allows institutions to tailor CUREs to their unique constraints and pedagogical objectives. For example, community colleges and teaching-focused universities may favor short, modular CUREs, while research-intensive institutions are more likely to implement vertically integrated CUREs aligned with faculty research priorities.

Furthermore, Vater et al. (2021) categorize CUREs into two structural models based on geographic and organizational scale. National-level CUREs, such as SEA-PHAGES and the Genomics Education Partnership, are unified by common scientific frameworks and shared infrastructure, enabling collaborative learning across institutions. In contrast, local CUREs are typically developed and managed at the departmental level, allowing for greater curricular flexibility and contextual relevance, often tailored to local community or environmental needs.

Educational Impacts and Outcomes

Student Learning and Skill Development

CUREs have been widely recognized for their substantial contributions to cognitive and conceptual learning in undergraduate science education. Empirical studies consistently demonstrate that CUREs promote deep engagement with disciplinary content, enhance students' research competencies, and foster higher-order thinking skills across STEM fields, including chemistry (Auchincloss et al., 2014; Corwin et al., 2015).

Wang (2024) observed significant gains in students' research skills following participation in a chemistry-focused CURE, particularly in their ability to interpret experimental data and relate it to complex chemical systems. These findings align with a broad consensus in the literature, which suggests that CUREs foster the integration of theoretical frameworks with hands-on practice, leading to improved conceptual understanding and scientific reasoning (Dolan, 2016; Hanauer et al., 2016).

Students involved in such experiences also demonstrate marked improvement in critical thinking and problem-solving skills. Fields et al. (2019) report that CURE participants showed enhanced ability to formulate testable hypotheses, design and conduct experiments, and interpret results using both biochemical and analytical methods. The iterative and inquiry-driven nature of CUREs provides repeated opportunities for students to engage in authentic scientific decision-making, which reinforces metacognitive development and intellectual autonomy.

Furthermore, early exposure to research within a contextual and structured framework appears to strengthen students' ability to apply scientific thinking in novel settings. Wang (2024) emphasizes that engaging students with research tasks early in their undergraduate careers cultivates transferable thinking skills that extend beyond the classroom. These include logical reasoning, evidence-based argumentation, and the ability to draw connections between abstract concepts and practical applications, skills essential for success in both graduate education and scientific careers.

Taken together, the literature suggests that CUREs function as high-impact educational practices that support not only content mastery but also cognitive development, by immersing students in the processes of scientific inquiry and evidence-based reasoning from the outset of their academic trajectories.

Student Engagement and Satisfaction

Student engagement and satisfaction are widely recognized as essential indicators of the success and educational impact of CUREs. A growing body of research highlights that students participating in CUREs report higher levels of motivation, involvement, and perceived learning than those in traditional laboratory settings (Auchincloss et al., 2014; Corwin et al., 2015). These positive perceptions are often reflected in both quantitative evaluations and qualitative feedback, underscoring the perceived authenticity and relevance of CURE activities.

Frederick et al. (2025) document high levels of student engagement in a chemistry CURE, as evidenced by self-reported time investment and consistently strong scores on course evaluation forms. Students expressed a deep sense of involvement in the research process and reported that the course provided a meaningful educational experience. These findings are consistent with the literature showing that CUREs foster a heightened sense of ownership, autonomy, and scientific identity, all of which contribute to greater academic persistence and satisfaction (Estrada et al., 2018; Hanauer et al., 2016).

Similarly, in a study focused on computational chemistry, Alexander et al. (2021) found that students met all stated learning objectives and provided overwhelmingly positive evaluations of their experience. Participants reported a deeper understanding of computational chemistry techniques and expressed confidence in their ability to conduct research using digital tools and databases. Such outcomes support previous research suggesting that when students engage in research perceived as authentic and aligned with real-world scientific practices, their cognitive and affective gains are significantly enhanced (Olimpo et al., 2016).

These observations affirm the pedagogical value of CUREs not only as vehicles for developing technical competencies but also as transformative educational experiences that enhance students' confidence, satisfaction, and commitment to scientific learning. The literature consistently recommends that CURE intentionally prioritize opportunities for student agency, iterative learning, and meaningful feedback in order to maximize these affective benefits (Buchanan & Fisher, 2022).

Scientific Communication and Professional Development

In addition to fostering technical skills and research competencies, CUREs have been consistently linked to improvements in students' scientific communication and professional development. A central component of the CURE model involves disseminating research findings through oral and written formats, which provides students with critical opportunities to practice articulating complex scientific ideas to both expert and non-expert audiences.

Frederick et al. (2025) document that students engaged in a chemistry-focused CURE were able to effectively present their research outcomes to curators, non-specialist stakeholders, demonstrating the ability to translate disciplinary knowledge into accessible language. These communication experiences were not limited to classroom contexts; subsequent discussions and question-and-answer sessions further developed students' capacity for real-time scientific dialogue and critical reflection.

The value of CUREs in preparing students for professional environments is also reflected in post-course activities. In the study by Frederick et al. (2025), one student group successfully presented their research findings at an international scientific conference (PittCon), where they received commendations for scientific merit and clarity of presentation. Such experiences are not uncommon in well-structured

CUREs, where students often produce work of publishable or presentable quality (Heemstra et al., 2017; Wolfe & Steed, 2023).

Beyond academic dissemination, CURE participation has been shown to contribute to career readiness and self-efficacy (Newell & Ulrich, 2022). Senior students frequently report referencing their CURE projects during job interviews or graduate school applications, citing the experience as evidence of research experience, problem-solving ability, and collaborative skill (Olimpo et al., 2016). These outcomes align with broader literature suggesting that engaging undergraduates in authentic research environments promotes professional identity formation and confidence in scientific roles (Estrada et al., 2018; Hanauer et al., 2016).

Collectively, the literature affirms that scientific communication is not only a byproduct but a pedagogical cornerstone of CUREs. These experiences advance students' ability to engage diverse audiences, navigate scholarly discourse, and position themselves as competent contributors to scientific communities, key capacities in both academic and professional trajectories.

Retention and STEM Persistence

A growing body of evidence suggests that CUREs offer many of the same long-term benefits traditionally associated with mentored undergraduate research, particularly in promoting student retention and persistence in STEM disciplines. These benefits include increased academic engagement, stronger identification with the scientific community, and enhanced interest in pursuing graduate education (Auchincloss et al., 2014; Frederick et al., 2025). Because CUREs are integrated into the required curriculum and accessible to entire classes, they extend these gains to a broader and more diverse student population.

Frederick et al. (2025) report that students who participate in CUREs often exhibit a heightened sense of belonging in scientific contexts, which has been repeatedly linked to improved academic outcomes. The development of a science identity, an internalized sense of being a "science person," has emerged in the literature as a critical predictor of persistence, particularly among students from historically marginalized backgrounds (Estrada et al., 2018). CUREs provide frequent opportunities for scientific ownership, problem-solving, and peer collaboration, all of which contribute to the formation of that identity.

Quantitative studies have substantiated the link between CURE participation and degree completion. In a large-scale, multi-institutional study, Stovall, Huynh, Engelman, & Ellington, (2019) found that students engaged in CUREs experienced a 17% increase in six-year graduation rates and a 23% greater likelihood of earning a STEM degree, compared to matched peers who did not participate in CUREs. These findings support the argument that CUREs serve not only as instructional innovations but also as strategic interventions for improving STEM degree attainment at the undergraduate level.

The literature further highlights that these positive effects are amplified when research experiences occur early in students' academic careers. Early exposure to authentic research enhances motivation, clarifies career goals, and increases the perceived value of science coursework, factors that collectively improve persistence and reduce attrition in STEM pathways (Hanauer et al., 2016). As such, embedding CUREs across multiple levels of the undergraduate curriculum can be a powerful mechanism for sustaining student interest and performance in scientific fields.

Faculty and Institutional Impacts

Research Benefits and Challenges

One of the frequently cited advantages of CUREs is their dual benefit: enhancing student learning while simultaneously advancing faculty research agendas. When CUREs are closely aligned with a faculty member's research program, they can serve as incubators for pilot studies, contribute to long-term projects, and, in some cases, yield publishable data. As Wolfe et al. (2023) argue, the integration of CUREs with faculty-led research can catalyze scholarly output by providing a structured setting in which to test hypotheses, refine methodologies, and generate preliminary findings.

Numerous faculty members have reported successfully translating CURE-generated data into academic publications, particularly in the chemical and life sciences (Corwin et al., 2018; Heemstra et al., 2017). These benefits are especially pronounced when CUREs are designed around novel, hypothesis-driven experiments that align with faculty expertise and institutional research priorities. In such contexts, students not only gain authentic research experience but also contribute meaningfully to scholarly productivity.

However, the literature also documents several persistent challenges associated with using CUREs as a source of publishable research. A primary concern is the discontinuity of student involvement, as undergraduate cohorts frequently change each semester, limiting the continuity needed for sustained data generation and long-term project development (Wolfe & Steed, 2023). This turnover complicates not only the collection of reproducible and robust datasets but also the manuscript preparation process, particularly when students are expected to co-author or contribute substantively to writing.

Another reported barrier is the time-intensive nature of data validation and publication preparation. Faculty members often face constraints related to the additional effort required to verify student-generated data, especially when research involves complex material or compound characterization. The need to ensure methodological rigor and analytical precision to meet peer-reviewed standards can delay or deter the publication process (Dolan, 2016).

Recommendations for Maximizing Impact

Optimizing the impact of CUREs requires intentional instructional strategies, collaborative teaching models, and thoughtful course design. The literature consistently emphasizes that CURE effectiveness is enhanced when faculty collaboration and interdisciplinary integration are built into the instructional structure. Wolfe et al. (2023) advocate for co-teaching approaches, whereby multiple faculty members jointly administer a CURE. This method distributes instructional labor, brings complementary disciplinary expertise into the classroom, and exposes students to a wider spectrum of scientific methodologies and perspectives.

Another frequently cited recommendation is the deliberate application of class-wide experimental design strategies that promote coherent data collection and synthesis across student teams. Designing CUREs to culminate in a unified dataset, rather than isolated or fragmented results, can facilitate more robust research findings, enhance opportunities for publication, and reinforce a sense of collective ownership among students (Corwin et al., 2018; Heemstra et al., 2017). Class-wide projects also encourage collaboration, reproducibility, and critical analysis of pooled results, thereby fostering scientific reasoning and communication skills.

Moreover, the strategic alignment of CURE projects with ongoing institutional research agendas or external partner needs has been identified as a mechanism for sustaining impact over time. When CUREs are situated within a broader research framework, students are more likely to perceive their work as consequential, which in turn contributes to deeper engagement and motivation (Hanauer et al., 2016).

Specialized Applications and Innovation

Computational Chemistry Integration

The integration of computational tools into undergraduate chemistry curricula has become increasingly prevalent, driven by both technological advancements and the growing significance of computational approaches in chemical research. Within CUREs, the inclusion of computational chemistry offers a valuable avenue for engaging students in modern scientific inquiry while addressing challenges such as limited lab resources and time constraints.

Alexander et al. (2021) emphasize the increasing adoption of computational methods by organic chemists and advocate for incorporating such approaches into undergraduate instruction to reflect contemporary research practices. Embedding computational research tasks within laboratory CUREs enables students to explore molecular modeling, reaction energetics, or structure–activity relationships, fostering a deeper conceptual understanding of chemical phenomena while simultaneously developing transferable data analysis and coding skills.

Several studies report that CUREs incorporating computational elements lead to enhanced educational outcomes, including improved conceptual mastery, increased scientific identity, and greater confidence with interdisciplinary tools (Buchanan & Fisher, 2022; Callejas et al., 2023; Sargent et al., 2020). Furthermore, computational CUREs provide unique opportunities to engage students in iterative research design, a hallmark of authentic research, without the logistical barriers often associated with traditional wet-lab experimentation (Dolan, 2016).

From a curricular perspective, computational integration is also seen as a means of broadening participation in research. Because simulations and modeling can often be conducted with open-source tools and remote access, they reduce the need for physical laboratory infrastructure, making CUREs more accessible and scalable across diverse institutional settings (Strubbe, 2024; Werth et al., 2022).

Overall, the literature supports the growing inclusion of computational chemistry within CUREs as a pedagogically sound and practically efficient strategy. By aligning undergraduate research experiences with evolving disciplinary practices, these integrations prepare students for the data-driven nature of contemporary chemical research while enhancing engagement and learning in the classroom.

Interdisciplinary Approaches

The expansion of Course-Based Undergraduate Research Experiences (CUREs) into interdisciplinary domains has garnered increasing attention for its potential to make research more accessible, inclusive, and relevant to students from diverse academic backgrounds. Integrating topics that transcend traditional disciplinary boundaries (food science, fermentation, and sensory chemistry) offers novel avenues for embedding research within everyday experiences while maintaining scientific rigor.

Sörensen (2023) highlights the use of flavor science and food fermentation as effective vehicles for interdisciplinary CURE development. These topics, while often underrepresented in standard STEM curricula, are grounded in chemical, biological, and microbiological principles, making them fertile ground for inquiry-based learning. Their inherent accessibility, cultural relevance, and applied focus create authentic research contexts that appeal to a broad spectrum of learners, including those who may not initially identify as scientists.

The interdisciplinary nature of such CUREs also encourages the integration of non-STEM perspectives, such as anthropology, cultural studies, and ethics, thereby enhancing students' ability to frame scientific problems in broader societal contexts. This pedagogical approach aligns with national calls to increase relevance and inclusivity in STEM education through the infusion of real-world, cross-disciplinary challenges (National Academies of Sciences and Medicine, 2018).

Moreover, interdisciplinary CUREs have been shown to cultivate transferable skills, including communication across disciplines, critical thinking, and creativity, that are increasingly valued in both academic and industry settings (Buchanan & Fisher, 2022; Pedwell et al., 2018). By situating scientific inquiry within culturally resonant themes, such models can also support greater student motivation and identity development, particularly among nontraditional or underrepresented students in STEM.

Thus, the integration of interdisciplinary topics such as food chemistry and fermentation into CUREs represents a promising strategy for broadening participation, deepening engagement, and fostering the development of well-rounded, socially aware scientific thinkers.

Advanced Technology Integration

The integration of advanced digital tools into CUREs has increasingly been recognized as a powerful strategy for enriching research authenticity and fostering data-driven inquiry. Among these tools, the Cambridge Structural Database (CSD) stands out as a particularly valuable resource for structural chemistry education. Housing over 1.25 million crystallographic structures, the CSD offers students unparalleled access to real-world molecular data and structural information that can be leveraged across a variety of chemical subdisciplines (Abourahma, 2024).

Abourahma, (2024) emphasizes that the CSD is highly adaptable for use across all tiers of the undergraduate chemistry curriculum, from general and organic to inorganic and materials chemistry. Within CURE contexts, it enables students to investigate molecular geometry, symmetry, hydrogen bonding, and reactivity patterns through authentic crystallographic data, thus aligning course activities with professional research practices. The use of such databases facilitates inquiry-based exploration, encourages student-generated hypotheses, and promotes computational and analytical literacy.

The educational benefits of integrating structural databases into CUREs are multifaceted. First, these tools expose students to large-scale data sets and sophisticated search algorithms, fostering familiarity with computational chemistry skills that are increasingly demanded in both academic and industrial settings (Vater et al., 2021). Second, they democratize access to high-quality experimental data, particularly in institutions where crystallographic instrumentation may be limited, allowing for broader participation in structure-based research. Third, they support interdisciplinary CURE designs, including applications in materials science, pharmacology, and supramolecular chemistry (Buchanan & Fisher, 2022).

Furthermore, Provost (2022) states that technological integration enhances student engagement by allowing for real-time interaction with curated scientific information and by enabling comparisons between experimental and theoretical models. These pedagogical advantages align with current trends toward data-centric, computation-enhanced learning environments in STEM education.

Overall, the incorporation of the CSD and similar digital infrastructures into CUREs represents a scalable and innovative approach to modernizing chemistry education. It equips students with relevant skills, fosters authentic scientific inquiry, and extends the scope of undergraduate research into realms traditionally reserved for advanced or graduate-level work.

Conclusion

This review highlights how CUREs are reshaping undergraduate chemistry education by integrating authentic research into the curriculum. By synthesizing ten recent Scopus-indexed studies, this review addresses a notable gap in the literature: the lack of field-specific analysis of CURE implementation in chemistry. The evidence demonstrates that CUREs promote significant educational gains, including enhanced conceptual understanding, critical thinking, STEM retention, and inclusive participation. Despite persistent challenges, such as faculty workload, scalability, and the need for sustainable research infrastructure, the pedagogical advantages for students are compelling. CUREs in chemistry not only foster scientific skills but also support broader educational goals such as equity, engagement, and scientific identity formation. Moving forward, strategic investments in curriculum design, faculty training, and institutional collaboration will be essential to sustaining and scaling these initiatives. As pedagogical innovation continues to evolve, CUREs are well-positioned to serve as a foundational model for cultivating the next generation of chemists through high-impact, research-intensive education.

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It is declared by the authors that there is no conflict of interest.

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