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Common Focus Area between CUREs and STEM Education

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Abstract: STEM education has transitioned from a model characterized by passive learning and strict laboratory exercises to one focused on active inquiry, student autonomy, and research involvement. Central to this educational transformation are Course-Based Undergraduate Research Experiences (CUREs), which integrate genuine research into the curriculum. This review synthesizes 15 current studies from Scopus to examine the common focus between cures and STEM education. CUREs and reformed STEM pedagogies integrate authentic scientific practice, student-centered learning, and inclusive access to improve persistence, equity, and workforce readiness. By embedding research with uncertain outcomes into coursework, these approaches broaden participation, remove barriers, and build critical thinking, problem-solving, and communication skills. They also enhance scientific identity and self-efficacy, particularly for underrepresented students, supporting retention and success in STEM. Scalable and supported by national initiatives, CUREs show that high-impact, research-rich learning can be delivered widely without losing depth, preparing a skilled and diverse scientific community for complex challenges.

Keywords: Common focus area; Course-based undergraduate research experiences; STEM education

Introduction

Over the past two decades, STEM education has undergone a fundamental transformation, evolving from a model dominated by passive learning and prescriptive laboratory exercises toward one centered on active inquiry, student agency, and sustained engagement with authentic research (Freeman et al., 2014). At the forefront of this shift are CUREs, which integrate genuine research practices directly into the curriculum (Auchincloss et al., 2014; Corwin et al., 2015). Unlike traditional undergraduate research programs that often serve a small and highly selected group, CUREs democratize access by embedding authentic scientific inquiry into the experiences of entire classrooms. This inclusive model helps address persistent inequities in representation by expanding opportunities to community colleges, minority-serving institutions, and other historically underrepresented contexts in STEM (Bangera & Brownell, 2014; Dunbar-Wallis et al., 2024). As a recognized high-impact practice, CURE participation has been shown to enhance academic performance, retention, and long-term persistence in STEM pathways (Kuh, 2008; Rodenbusch et al., 2016).

Understanding how and why CUREs succeed requires examining their key design features. Drawing from both empirical and theoretical literature, this review identifies eight interrelated focus areas that collectively shape CURE effectiveness and sustainability. At the core, Research Integration ensures that student projects generate outcomes with genuine

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scientific relevance, situating learners as contributors to their fields rather than passive observers (Auchincloss et al., 2014). This emphasis naturally connects to Student-Centered Learning Approaches, where inquiry, autonomy, and iterative problem-solving replace rote procedures (Brownell & Kloser, 2015). However, the benefits of these approaches can only be fully realized when coupled with Inclusive and Accessible Education, which incorporates culturally relevant contexts and equitable instructional design to reach diverse learners (Abrica et al., 2024; Asai, 2020).

The learning gains from CUREs also extend beyond disciplinary knowledge. Through Skills Development Beyond Content Knowledge, students acquire transferable competencies such as collaboration, scientific communication, and critical thinking (Linn et al., 2015; Lopatto, 2004). These skills directly reinforce the growth of Scientific Identity and Self-Efficacy, as students gain confidence in their abilities and a sense of belonging in scientific communities (Estrada et al., 2016). Such growth, in turn, supports Retention and Persistence Goals, ensuring that more students, especially those from underrepresented backgrounds, remain engaged in STEM pathways over the long term (Rodenbusch et al., 2016).

Yet, for CUREs to have a widespread impact, they must be implemented at scale without losing authenticity. Scalability and Broad Access addresses this challenge by exploring ways institutions can expand offerings across diverse settings, from large public universities to small liberal arts colleges, without diluting the research experience (Shortlidge et al., 2015). Central to maintaining quality during expansion is adherence to Authentic Scientific Practices, which immerse students in the complete research cycle, from hypothesis generation to dissemination of findings, mirroring the work of professional scientists (National Research Council, 2003).

The novelty of this review lies in its integrative synthesis of these eight focus areas into a unified analytical framework that considers pedagogical, equity-focused, and institutional dimensions together. Previous reviews have typically examined either programmatic outcomes (Corwin et al., 2015) or design principles in isolation (Auchincloss et al., 2014), but few have explicitly mapped how these elements interconnect to shape student outcomes and program sustainability. By bridging findings across disciplines, institutional types, and student populations, we reveal both shared mechanisms of effectiveness and underexplored leverage points for innovation, particularly in broadening participation while preserving research authenticity (Asai, 2020; Harrison et al., 2011). This holistic perspective offers a conceptual roadmap for researchers and a practical guide for institutions seeking to embed CUREs as a cornerstone of equitable, excellence-driven STEM education.

Method

This study employed a qualitative literature review approach, guided by principles of thematic synthesis and content analysis (Elo & Kyngäs, 2008; Thomas & Harden, 2008). 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((stem pre/0 (practic* or field or activiti* or project or education or model or approach or discipline or course or major or program or curricul*)) or (science pre/0 technology pre/0 engineering pre/0 math*)) AND TITLE-ABS-KEY(course pre/0 based pre/0 undergraduate pre/0 research pre/0 experience)) AND (LIMIT-TO (OA,"publisherfullgold")) AND (LIMIT-TO (DOCTYPE,"ar"))). From the initial search, 20 articles were identified. Following title and abstract screening, along with a full-text review using inclusion criteria that targeted the common focus between CUREs and STEM, 15 articles were ultimately retained for detailed analysis.

Result and Discussion

Research Integration

The integration of authentic research into undergraduate education is widely recognized in the literature as a foundational element of effective STEM pedagogy and a significant contributor to student persistence in science. According to Auchincloss et al. (2014), embedding research within coursework creates opportunities for students to engage in the authentic practices of science, thereby bridging the gap between classroom instruction and professional research environments. Bangera et al. (2014) argue that CUREs represent one of the most scalable and cost-effective strategies for broadening research participation, reaching students across diverse institutional types, including community colleges and minority-serving institutions. Similarly, Majka et al. (2021) emphasize that CUREs democratize access to research by removing traditional barriers that restrict participation to select groups.

The literature consistently identifies open-ended inquiry, uncertain outcomes, and iterative problem solving as defining features of research integration. Brownell et al. (2015) highlight that these elements promote deeper conceptual understanding and greater engagement than traditional laboratory exercises. Callejas et al. (2023) and Werth et al. (2023) report that such experiences allow students to navigate the complexities of real-world scientific problems, fostering adaptability and critical thinking. According to Crescencio et al. (2024), Diaz-Martinez et al. (2019), Waddell et al. (2021), and Wu et al. (2021), research integration also develops student agency by positioning learners as active contributors to the generation of knowledge, encouraging them to take intellectual risks and pursue novel ideas. Sommers et al. (2021) further contend that situating student research within environmental, technological, and societal contexts enhances its perceived relevance and value.

In addition to disciplinary skill development, research integration promotes interdisciplinary engagement. As Werth et al. (2023) note, students often apply tools and concepts from multiple STEM domains, including biology, mathematics, engineering, and technology, when addressing authentic research questions. Callejas et al. (2023) and Estrada et al. (2018) argue that these experiences also advance equity and inclusion by creating pathways for historically underrepresented students to build scientific identity and self-efficacy. Collectively, authors converge on the view that research integration is not only pedagogically effective but also socially transformative, serving as a unifying priority within both CURE design and broader STEM education reform efforts.

Student-Centered Learning Approaches

Student-centered pedagogical approaches are widely regarded as essential for fostering meaningful engagement, skill development, and long-term persistence in STEM fields. According to Auchincloss et al. (2014), CUREs offer an effective model for embedding authentic research experiences within courses, enabling students to make substantive contributions to ongoing scientific investigations. Sommers et al. (2021) similarly report that student-centered features within CUREs, such as open-ended inquiry, iterative problem-solving, and real-world application are key drivers of substantial learning gains. Within the broader context of STEM education, Freeman et al. (2014) and Felder et al. (2016) emphasize that student-centered learning approaches develop core competencies, including critical thinking, collaboration, and adaptability, which are essential for success in 21st-century scientific and technological careers.

The literature highlights active engagement as a central principle in both CUREs and modern STEM instruction. Freeman et al. (2014) provide meta-analytic evidence that students learn more effectively when actively involved in posing questions, designing investigations, analyzing data, and communicating findings. In CURE settings, students work on research projects with unknown outcomes, thereby mirroring the processes of professional science and reinforcing the value of their contributions to real-world inquiry (Auchincloss et al., 2014; Sommers et al., 2021). In parallel, STEM classrooms adopting inquiry-based learning place emphasis on learner autonomy, enabling students to take ownership of their intellectual development and to participate in constructing their own understanding of scientific concepts (Felder & Brent, 2016).

Student agency emerges as a recurring theme across both models. According to Wu et al. (2021), opportunities for learners to direct their own inquiry and collaborate with peers enhance confidence, deepen motivation, and strengthen scientific identity. Estrada et al. (2016) further link these outcomes to improved retention and achievement, particularly among students from historically underrepresented groups in STEM. Theobald et al. (2020) provide evidence that active, student-centered approaches reduce achievement gaps, demonstrating their equity-promoting potential. Additionally, both CUREs and student-centered STEM instruction integrate relevance and context into the learning process, enabling students to connect academic content to pressing societal and environmental challenges (Sommers et al., 2021). Finally, collaborative learning environments fostered in these settings help students develop critical communication, teamwork, and problem-solving skills necessary for professional success (Felder & Brent, 2016). Collectively, the literature underscores that student-centered pedagogy is a shared foundation underpinning the effectiveness of both CUREs and broader STEM instructional reforms.

Inclusive and Accessible Education

Promoting inclusive and accessible learning environments is a central priority in both CUREs and contemporary STEM education reform. According to Sommers et al. (2021), embedding authentic research into standard coursework enables broad participation by removing traditional barriers such as minimum GPA thresholds, exclusive faculty mentorship opportunities, and unpaid laboratory commitments. Auchincloss et al. (2014) contend that such integration opens research opportunities to entire classrooms, thereby expanding participation among historically underrepresented and marginalized students. Bangera et al. (2014) further argue that CUREs provide a more equitable alternative to apprenticeship-style research models by allowing all students to contribute to authentic investigations with outcomes of genuine scientific value, thus supporting a more diverse and sustained STEM pipeline.

Inclusive instructional practices are also foundational to equity-oriented STEM education. Theobald et al. (2020) report that active learning strategies, when applied intentionally, can reduce achievement gaps for students from underrepresented groups. According to authors such as Kang et al. (2019), culturally responsive pedagogy and the integration of community-relevant content foster greater student engagement by connecting academic material to learners' lived experiences. This aligns with the principles of Universal Design for Learning (UDL), which Felder et al. (2016) identify as a framework for designing instruction that accommodates diverse abilities, needs, and learning preferences. In both CUREs and inclusive STEM classrooms, these approaches collectively affirm that all students, regardless of background, ability, or identity, deserve meaningful engagement in scientific inquiry.

Evidence also points to the role of inclusive practices in fostering belonging, a critical predictor of persistence in STEM. Estrada et al. (2016) emphasize that participation in inclusive, collaborative environments supports the development of scientific identity and self-efficacy, especially for students from groups historically excluded from science. Corwin et al. (2015) note that the low-cost, course-based format of CUREs allows them to be integrated into required curricula, delivering high-impact educational experiences without the financial or logistical constraints associated with traditional research roles. Jones et al. (2023) argue that such models not only expand access but also align educational practices with the values of a diverse scientific community. Collectively, the literature suggests that CUREs and inclusive STEM education share a commitment to dismantling structural barriers, creating equitable opportunities, and fostering a more representative and empowered scientific workforce.

Skills Development Beyond Content Knowledge

The development of transferable skills beyond discipline-specific content knowledge is a shared priority in both CUREs and reformed STEM education. According to Felder et al. (2016), mastery of scientific concepts remains essential, but sustained success in the 21st-century scientific workforce depends equally on competencies such as problem-solving, collaboration, and communication. Auchincloss et al. (2014) emphasize that CUREs foster these skills through authentic research engagement, enabling students to address complex questions, work effectively in teams, and manage time in ways that traditional laboratory courses often fail to cultivate. Sommers et al. (2021) similarly argue that these experiences provide intentional scaffolding for the development of professional competencies that are underemphasized in many STEM programs.

The broader STEM education literature reflects parallel priorities. Freeman et al. (2014) note that active learning approaches nurture quantitative reasoning, interdisciplinary teamwork, and scientific communication, skills that are essential for both academic and industry careers. Within the CURE model, students develop these capabilities by engaging in the practices of professional science: formulating research questions, designing and troubleshooting experiments, analyzing complex datasets, and presenting results in both written and oral formats (Delventhal & Steinhauer, 2020). Such activities mirror authentic scientific workflows and bridge the gap between academic training and workplace demands.

According to Ballen et al. (2017) and Fisher et al. (2018), CUREs and active STEM curricula also foster iterative learning, where students reflect on challenges, adapt methodologies, and build resilience, critical attributes of scientific thinking and innovation. Communication emerges as a central focus. Delventhal et al. (2020) highlight that CURE participants learn to articulate scientific arguments, collaborate across disciplinary teams, and convey complex ideas to diverse audiences, enhancing both confidence and civic scientific literacy. Wang et al. (2020) further underscore that these non-content skills are deliberately embedded into course learning objectives and assessments, ensuring they are cultivated intentionally rather than incidentally. Collectively, the literature positions both CUREs and reformed STEM curricula as vehicles not only for knowledge acquisition but also for the development of adaptable, collaborative, and communicative professionals prepared for diverse scientific careers and lifelong learning.

Scientific Identity and Self-Efficacy

Fostering scientific identity and self-efficacy is a shared priority in both CUREs and broader STEM education reform, as these psychological constructs are strongly associated with persistence and success in science-related fields. According to Callejas et al. (2023) and Newell et al. (2022), scientific identity refers to the extent to which students see themselves as "science people" and feel a sense of belonging in the scientific community, whereas self-efficacy pertains to their confidence in performing scientific tasks and overcoming challenges. Shuster et al. (2019) emphasize that both constructs are significant predictors of STEM persistence, shaping students' motivation, academic performance, and long-term career aspirations. Estrada et al. (2016) further argue that these attributes are not peripheral outcomes but core determinants of equitable participation and advancement in science.

CUREs are particularly well-positioned to cultivate these outcomes. Auchincloss et al. (2014) note that by engaging students in authentic, discovery-driven research with uncertain outcomes, CUREs provide opportunities for ownership, intellectual contribution, and connection to the scientific enterprise. Corwin et al. (2018) add that such experiences validate students' roles as knowledge producers, reinforcing their sense of belonging in science. Similarly, student-centered STEM education that employs inquiry-based and active learning approaches offers repeated opportunities for students to strengthen self-efficacy through meaningful problem-solving, collaborative engagement, and iterative experimentation (Freeman et al., 2014; Theobald et al., 2020).

These environments are especially important for students from historically underrepresented groups, who may encounter systemic barriers and stereotype threat in traditional STEM pathways. Inclusive CUREs and reformed STEM instruction mitigate these challenges by creating supportive spaces in which all learners can develop a positive scientific identity and confidence in their ability to succeed (Callejas et al., 2023; Wang et al., 2020). As Newell et al. (2022) contend, nurturing scientific identity and self-efficacy is not merely an instructional aim but a critical equity strategy, one that strengthens persistence, retention, and the capacity for thriving in science careers.

Scalability and Broad Access

Scalability and broad access are central priorities in both CUREs and reformed STEM education, with the shared goal of extending meaningful research and learning opportunities to large and diverse student populations. According to Bangera et al. (2014), the traditional apprenticeship model of undergraduate research, while effective, reaches only a small, self-selected group of students who can secure faculty mentorship, access laboratory resources, and commit significant time. Auchincloss et al. (2014) argue that CUREs directly address this equity challenge by embedding authentic research experiences into existing course curricula, enabling entire classes, often across multiple sections or campuses, to participate in scientific inquiry simultaneously. This approach removes the exclusivity of traditional research, transforming it into an inclusive, course-integrated experience.

Several authors highlight the capacity of CUREs to scale without sacrificing research authenticity. Ballen et al. (2018) and Kay et al. (2023) note that these models involve entire student cohorts in investigating shared research questions within the context of a course, making them particularly effective in large introductory and non-major STEM classes. Brownell et al. (2015) emphasize that this scalability allows CUREs to reach students early in their academic trajectories, including those who might otherwise lack exposure to research. Corwin et al. (2015) further contend that this democratization of access dismantles structural barriers, such as GPA thresholds, limited faculty networks, and scheduling conflicts, that traditionally exclude underrepresented students from high-impact research experiences.

Scalability is also a defining feature of several national CURE initiatives. Jordan et al. (2014) and Lopatto et al. (2014) document the success of large-scale programs such as SEA-PHAGES and the Genomics Education Partnership, which have been implemented across research universities, minority-serving institutions, and community colleges. These initiatives provide compelling evidence that CUREs can be adapted to varied institutional contexts while producing measurable gains in persistence, identity formation, and equity outcomes. Parallel reforms in STEM pedagogy, such as active learning and peer-based instruction, similarly aim to transform large-enrollment lecture courses into interactive and inclusive spaces that scale engagement (Freeman et al., 2014). Collectively, the literature illustrates that scalability and inclusion are not opposing forces but mutually reinforcing goals, enabling the delivery of research-rich, transformative educational experiences at scale without compromising depth or quality.

Retention and Persistence Goals

Increasing student retention and persistence in STEM disciplines is a shared priority of both CUREs and reformed STEM education models, particularly given the persistent attrition observed during early undergraduate years and among students from underrepresented backgrounds. According to Bangera et al. (2014), the traditional apprenticeship model of undergraduate research, while beneficial, reaches only a small, selective group of students, thereby limiting its impact on retention at the institutional level. CUREs address this limitation by embedding research experiences into standard coursework, enabling a larger and more diverse student population to benefit from the positive outcomes traditionally associated with research participation.

Empirical evidence supports the link between CURE participation and predictors of STEM persistence. Rodenbusch et al. (2016) found that students who engaged in early course-based research demonstrated higher graduation rates and a greater likelihood of completing STEM degrees compared to peers in traditional courses. Corwin et al. (2018) reported that CUREs contribute to psychological constructs such as scientific self-efficacy, identity, and belonging, which are known to influence intentions to persist in science. Wachtell et al. (2023) further observed that these gains are particularly pronounced among students from historically marginalized groups, underscoring the equity potential of scalable research experiences.

Similar benefits are observed in reformed STEM teaching practices that incorporate active learning and inclusive pedagogy. Freeman et al. (2014) demonstrated that active learning reduces failure rates and narrows achievement gaps across demographic groups, while Corwin et al. (2015) noted that embedding research-oriented activities into coursework enhances student engagement and persistence. According to Esparza et al. (2023), such approaches do more than improve academic performance; they reinforce students' belief in their potential and their sense of belonging within the scientific community. By integrating high-impact, research-rich learning opportunities into standard curricula, both CUREs and modern STEM reforms provide equitable pathways for fostering commitment, persistence, and long-term success in scientific careers.

Authentic Scientific Practices

Engagement in authentic scientific practices is a central priority in both CUREs and reformed STEM education, reflecting a commitment to aligning student learning experiences with the processes used by practicing scientists. According to Auchincloss et al. (2014), authentic research in educational contexts encompasses generating hypotheses, designing experiments, interpreting data, engaging in peer review, and communicating findings, skills essential for fostering scientific reasoning and critical inquiry. Corwin et al. (2015) emphasize that these practices, when embedded in course-based research, transform students from passive recipients of knowledge into active participants in the construction of scientific understanding.

In CURE settings, students collaborate as part of a research team and investigate questions of broad scientific relevance, producing outcomes that contribute meaningfully to disciplinary knowledge (Kay et al., 2023; Majka et al., 2021). This stands in contrast to traditional laboratory courses, where experiments often have predetermined results and limited real-world application. Brownell et al. (2015) note that the unpredictability and iterative nature of authentic inquiry fosters adaptability, problem-solving, and evidence-based thinking, core competencies also emphasized in broader STEM curricular reform.

Reformed STEM curricula share this emphasis on inquiry-driven, student-centered environments that replicate the collaborative, interpretive, and iterative processes of professional science (Brownell & Kloser, 2015). These pedagogies not only develop technical competencies but also strengthen metacognitive awareness and scientific communication skills, which are increasingly vital in both academic and industry contexts. According to Esparza et al. (2023), the early involvement of students, particularly those from historically underrepresented backgrounds, in authentic and valued scientific activities can enhance scientific identity and self-efficacy, supporting long-term persistence in STEM.

Collectively, the literature positions CUREs as a practical implementation of broader STEM educational goals, operationalizing inclusive, research-based, and student-centered learning at scale. By blurring the line between learning about science and doing science, CUREs and modern STEM education create more relevant, empowering, and equitable pathways into the scientific community.

Conclusion

CUREs and reformed STEM pedagogies share a unified vision of integrating authentic scientific practice, student-centered learning, and inclusive access to foster persistence, equity, and workforce readiness. By embedding discovery-driven research with uncertain outcomes into coursework, these models democratize participation, dismantle traditional barriers, and cultivate critical thinking, problem-solving, and transferable skills such as collaboration and communication. They also strengthen scientific identity and self-efficacy, particularly among historically underrepresented students, contributing to improved retention and success in STEM. Scalable by design and supported by national initiatives, CUREs demonstrate that high-impact, research-rich learning can be delivered at scale without compromising depth or authenticity, ultimately preparing a more skilled, confident, and diverse scientific community equipped to address complex challenges.

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Conceptualization, A. M., Y. R. and A. K.; methodology, A. M., Y. R., and A. K.; resources, L. H.; data curation, L. H.; writing original draft preparation, L. H.; writing review and editing, L. H.; visualization, and A. M., Y. R., and A. K. All authors have read and agreed to the published version of the manuscript.

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