

Course-Based Undergraduate Research Experiences (CUREs) in STEM Higher Education: Global Trends, Benefits, and Prospects for Indonesian Physics Education

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ABSTRACT

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Course-based undergraduate research experience (CURE) is widely recognized as a transformative approach to advancing STEM education. However, their integration into physics, especially in Indonesian higher education, remains limited. This article presents a comprehensive bibliometric analysis of 500 Scopus-indexed CURE publications from 2015 to 2025. The analysis conducted with Excel for data filtering and visualizing with VOSviewer highlights trends, disciplinary disparities, and the unique potential of CUREs in physics. The study identifies critical challenges and opportunities in adopting CUREs in physics labs and curricula and draws comparisons with more established fields, such as the life sciences and chemistry. To contextualize the global findings from bibliometrics analysis, a quantitative survey with Likert scale scoring and open-ended questions was conducted with second-year physics education students at Universitas Sebelas Maret. The survey result reveals their strong enthusiasm and readiness for authentic, research-based learning, underscoring the relevance of integrating CUREs into Indonesia's STEM curriculum and educational priorities. The findings articulate the key benefits of CUREs, including enhancement of scientific identity, critical thinking, and research skills, while also outlining practical implementation strategies, such as curriculum design, faculty preparation, and scalable, low-cost research experiences. This article advocates for broader CURE adoption in Indonesian physics education to prepare students for the evolving demands of the modern workforce.

INTRODUCTION

The future of learning is defined by a shift towards flexible, personalized, technology-driven processes with a strong emphasis on lifelong learning, accessibility, and developing future-ready skills (Singh et al., 2024). Education systems and providers must adapt rapidly to ensure individuals and societies can thrive in a complex and dynamic world (Wang et al., 2023).

Course-based Undergraduate Research Experiences (CUREs) represent a transformative and innovative approach to STEM education that fundamentally enhances how undergraduate students engage with scientific research (Dillon et al., 2024). Contrary to conventional laboratory courses, which frequently employ "cookbook" experiments—wherein students meticulously obey step-by-step directives to attain predefined outcomes—CUREs involve entire classes in genuine scientific exploration (Wierzchowski & Wink, 2023). Students collaboratively tackle novel, open-ended research questions, contributing new knowledge to their scientific fields (Oliver, 2023). The undergraduate laboratory experience is shifted from passive replication of established experiments to active participation in the dynamic and iterative process of scientific discovery by this pedagogical innovation (Wiggins et al., 2021; Davishahl, 2024).

An authentic research experience is ensured by the systematic incorporation of nine essential elements by CUREs: relevance, scientific background, hypothesis

development, predictions and proposal, experiments (often involving teamwork and collaboration), reproducibility, data analysis and evidence-based conclusions, final research presentation, and peer review (Bell et al., 2025). Together, these elements foster a learning environment that replicates real-world scientific practice, encouraging deeper engagement and a thorough grasp of the scientific process.

The growing integration and improvement of CUREs in higher education is driven by several interconnected factors, reflecting a rising awareness of their distinctive advantages and adaptability (Fernandez, 2025). CUREs are more flexible and cost-effective than traditional, individualized research experiences (Fuentes & Entezari, 2020), allowing institutions to engage a large number of students in authentic research (Fernandez, 2024). This broad accessibility motivates institutions to provide high-impact practices to all students.

The adaptability and flexibility of CURE, contributes to their enhanced implementation. Duration of CUREs can range from short, modular components integrated into existing courses to full-semester projects (Dahlberg et al., 2019). This lets instructors start small, experiment with the pedagogy, and gradually expand their CURE offerings (Genné-Bacon et al., 2024). Along with that, institutional support and faculty development initiatives are crucial. Professional development programs that cover CURE pedagogy, active learning strategies, and practical management advice. Coupled with ongoing support and financial stipends, encourage faculty adoption and ongoing implementation (Dechenne-Peters & Scheuermann, 2022). CUREs can also be aligned with institutional priorities, such as preparing students for STEM careers, to ensure the necessary administrative support is gained.

Another key factor which encourages faculty and institutions to adopt CUREs, is the positive impact on student outcomes (Lo & Le, 2021). Improved understanding of course content and significant gains in technical skills (Bennie et al., 2025), such as computer modeling, statistical analysis, and various laboratory techniques, have been shown by students in CURE (Wang et al., 2022). These gains are comparable to or surpass those in traditional labs. CUREs also improve students' ability to design and interpret experimental data. Students show growth in many areas beyond just discipline-specific knowledge: writing and speaking, time management, organization, problem solving, and data and information literacy (Korkor & Darner, 2025). CURE participation increases student confidence and self-efficacy (Dunbar-Wallis et al., 2024), leading to more engagement in discussions and collaborations (Callahan et al., 2022).

CUREs are recognized as a high-impact educational practice associated with increased retention rates in STEM majors (Biazzo et al., 2024). Students who participate in CURE are more likely to graduate with a STEM degree and remain in STEM disciplines. This effect is beneficial for historically marginalized groups, narrowing demographic gaps in STEM persistence (Bradshaw et al., 2023). The authentic research experience provided by CUREs helps students identify their academic and professional goals, often leading to increased enrollment in STEM majors and pursuing graduate and professional schools.

CUREs provide an invaluable platform for training postdoctoral scientists and graduate students in instructional roles, offering opportunities for developing instructional materials, practicing active learning strategies, and cultivating their identity as educators (Kern & Olimpo, 2023). CUREs allow faculty to seamlessly integrate research and teaching missions, that lead to co-authored, peer-reviewed publications. Some instructors report improved relationships with students and increased job satisfaction when teaching with CUREs (Du et al., 2023).

RESEARCH METHOD

A systematic bibliometric review was used to examine the evolution, disciplinary distribution, and emerging trends of Course-Based Undergraduate Research Experiences (CUREs) in higher education. Bibliometric analysis is a recognized method for mapping research landscapes and identifying influential works, authors, and themes. The Scopus database was selected due to its coverage of peer-reviewed literature in education and the sciences. The search strategy targeted articles published between 2015 and 2025 using the query: TITLE-ABS-KEY ("Course-Based Undergraduate Research Experience") AND PUBDATE > 2014 AND PUBDATE < 2026. The inclusion of both STEM and non-STEM contexts relevant to CUREs was ensured by this approach.

A total of 501 articles were retrieved and screened for relevance based on their titles, abstracts, and keywords. The dataset was categorized by publication type (e.g., journal articles, conference proceedings, and reviews), disciplinary focus, and publication source. Bibliometric indicators such as annual publication trends, prolific authors, and journal distribution were analyzed using VOSviewer and Microsoft Excel. Keyword co-occurrence analysis was conducted to identify dominant research themes and their evolution over time (Donthu et al., 2021).

To contextualize global findings, a cross-sectional survey was conducted among second-year physics education students at Physics Education major at Universitas Sebelas Maret. The survey consisted of Likert-scale and open-ended questions exploring students' perceptions of CUREs, their readiness for research-based learning, and perceived alignment with STEM curriculum goals. The survey results were combined with bibliometric findings to develop recommendations for adopting CURE in physics education. The study integrates bibliometric and survey methods to provide a thorough, multi-level analysis of CURE implementation. This analysis offers global trends and local insights to guide future educational innovations in Indonesia.

RESULT AND DISCUSSION

Trends of CURE Implementation: a bibliometric review (2015 - 2025)
In order to comprehend the evolving terrain of Course-based Undergraduate Research Experiences (CUREs) in higher education, a bibliometric analysis was conducted on 501 articles retrieved from Scopus related to CUREs and Undergraduate Research Experiences (UREs). The queries used to compile the articles are {TITLE-ABS-KEY

("Course-Based Undergraduate Research Experience") AND PUBDATE > 2014 AND PUBDATE < 2026} to obtain articles about CURE between 2015 to 2025.

Over the past decade as shown in Figure 1, the field of CURE research has demonstrated significant and consistent growth in academic output. Published research reveals a marked increase in articles over time, indicating growing interest and expansion in CURE implementation and studies. This upward trajectory highlights the growing recognition of CUREs as a crucial pedagogical approach in higher education, especially in STEM disciplines. The bibliometric data clearly shows that approximately 94.81% of these publications focus on STEM contexts, highlighting the strong connection between CUREs and STEM education.

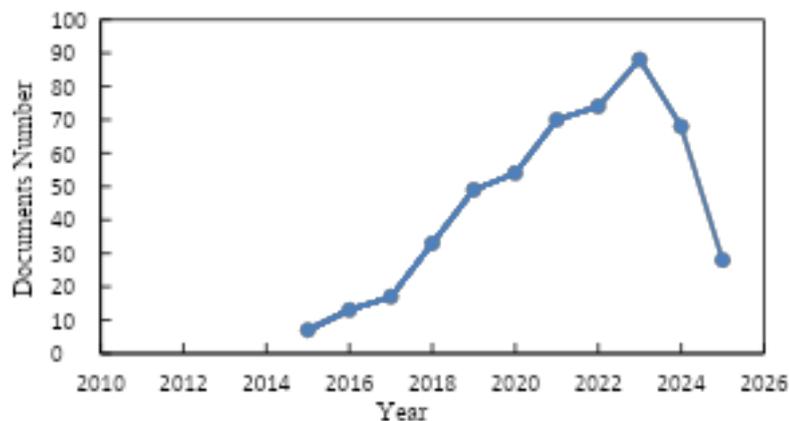


Figure 1. Publication trends by year

CUREs continue to gain recognition as an effective method of providing authentic research experiences to large, diverse student populations. This is driven by their ability to overcome the limitations of traditional one-on-one mentorship models. The pandemic significantly influenced CURE implementation, leading to a surge in online and hybrid CUREs. Numerous studies have reported successful transitions, demonstrating CUREs' adaptability to various learning environments (Sabel et al., 2021; Shamooun-Pour, 2022; Lopatto et al., 2023; Dubar-Wallis, 2024). A strong emphasis on CUREs being integrated into introductory-level courses (first- and second-year students) so that students can be engaged early in their academic careers and retention in STEM can be improved (Kruis et al., 2023; Watts & Rodriguez, 2023; Doble, 2024). Increased collaborations among students, instructors, and external partners are promoted by CURE, with real-world problems relevant to the community are frequently addressed (Doble, 2024; Nyutu et al, 2024; Patridge et al., 2025).

An analysis of keywords in Figure 2 reveals the most frequently explored themes within CURE literature. The most common author keywords are related to the subject, including "cure" and "undergraduate research" alongside pedagogical terms. Indexed keywords categorize the research into areas like "humans", "curriculum", "students", "education", and "research" often specifying disciplinary contexts.

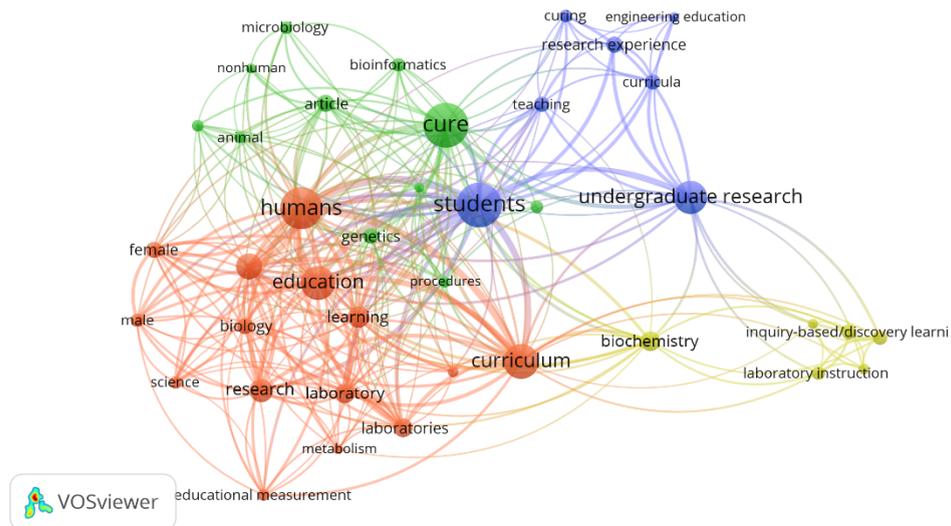


Figure 2 Keyword linking visualized in VOSviewer

In terms of scholarly contributions, several prolific authors have consistently shaped the discourse as shown in Figure 3. Notably, the top contributors include J.T. Olimpo (16 publications), S.E. Brownell (10 publications), and D. Lopatto (7 publications), whose extensive work has significantly contributed to the development and evaluation of CUREs.

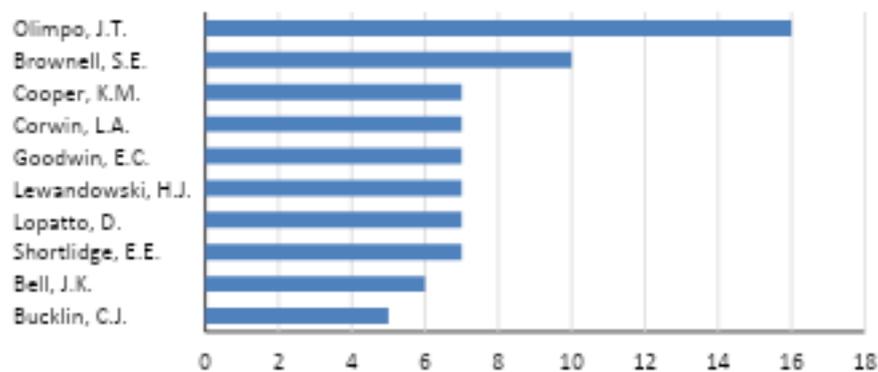


Figure 3. Top 10 prolific author in CURE topic (2015-2025)

Research on CUREs is mostly presented in specialized education journals within various scientific disciplines as shown in Table 1.

Table 1. 10 top source titles by publication count

Document Source	Number of Publications
Journal of Microbiology and Biology Education	69
Journal of Chemical Education	55
Biochemistry and Molecular Biology Education	50

CBE Life Sciences Education	46
Journal of College Science Teaching	19
ASEE Annual Conference and Exposition, Conference Proceedings	15
Frontiers in Microbiology	14
American Biology Teacher	14
Mathematics Enthusiast	11
ACS Symposium Series	9

This distribution is a highlight of the strong engagement of the life sciences and chemistry education communities in CURE research as shown in Table 2. Numerous chemistry CUREs have been reported, spanning analytical, biochemistry, inorganic, physical, and organic chemistry. These often involve synthesis, characterization, and real-world applications like water remediation or drug discovery (Dorn et al., 2021; Hanson & Stultz, 2022; Provost, 2022; Abourahma, 2024; Wurz et al., 2024). The emergence of CUREs in computer science is evident in research on generative AI in introductory programming classes and broader research methods (Lauren, 2024; Fernandez, 2025). In engineering, CUREs are being implemented in first-year engineering design and computing courses to promote research career pathways for transfer students (Yeo, 2021; Griffith & Rathore, 2023; Davishahl, 2024). Math CUREs are also being developed, often focusing on data analysis, statistics, and sports analytics (Deka et al., 2022; Goodman & Valster, 2022; Pardo, 2023).

Table 2. Frequent subject area in CURE research (2015-2025)

No	Subject Area	Document
1	Social Sciences	309
2	Biochemistry, Genetics and Molecular Biology	211
3	Agricultural and Biological Sciences	123
4	Immunology and Microbiology	95
5	Chemistry	76
6	Medicine	35
7	Engineering	33
8	Environmental Science	24
9	Computer Science	23
10	Mathematics	19
11	Chemical Engineering	17
12	Physics and Astronomy	15

It is suggested by the data from 501 articles about CURE that there is a potential area of growth for the physics education journal, as only 15 articles related to physics have been shown. Physics has been identified as a discipline where CUREs are less common compared to life sciences, prompting initiatives to develop frameworks and resources for their implementation. CUREs have been implemented in introductory physics labs (Oliver et al., 2023), computational physics (Strubbe, 2024), and engineering physics integration (Davishahl, 2024). Faculty views indicate barriers to implementing and

sustaining physics CUREs, but also highlight potential benefits and learning goal priorities (Kretchmer, 2024)

Compatibility and Potential of CURE Implementation in Physics Education in Indonesia

To gain insight into the perspective of students in higher education, a survey of second-year physics students at Universitas Sebelas Maret revealed a high demand for Course-Based Undergraduate Research Experiences (CUREs) within a STEM framework. This focused group offers insights into integrating research methods into physics education. Their overwhelming support for CUREs indicates a need for pedagogical innovation in physics education programs. The findings highlight students' strong recognition of the importance of integrated learning. All surveyed students affirmed that understanding the integration of science, technology, engineering, and mathematics (STEM) is crucial for their future as physics teachers. Furthermore, the students emphasized the need for guided, authentic research experiences as an integral part of their classroom learning. This collective recognition of STEM integration and direct research experience forms a fundamental basis for adopting STEM-CURE, which directly addresses a perceived gap in their educational journey.

The students perceive a high degree of feasibility and suitability of such innovative approaches within their specific academic context. All of the respondents believed that authentic, research-based learning could be applied to their physics education program. Their agreement that the STEM-CURE model is suitable for implementation in their learning environment further supports this belief. This strong perceived compatibility provides powerful internal encouragement for educational reform and curriculum enhancement in Indonesian physics higher education and suggests a receptive audience for the upcoming STEM-CURE integration.

Students articulated clear advantages and benefits beyond mere feasibility associated with STEM-CURE integration. They agreed that applying the STEM-CURE model, which emphasizes authentic research and 21st-century skills, would significantly increase their motivation and interest in learning and scientific research. Furthermore, they agreed that STEM-CURE could improve their ability to design and conduct physics experiments relevant to real-world contexts. These perceived improvements in cognitive, affective, and practical skills directly address the widely recognized goals of contemporary science education and align with the intended outcomes of the planned STEM-CURE implementation in the classroom.

In conclusion, the collective voice of the physics education students, as captured in this preliminary survey, signals a significant demand for STEM-CURE implementation. Their strong belief in the importance of STEM integration, expressed the need for authentic research experiences. This valuable student input is a critical first step in the process of preparing and systematically integrating STEM-CURE to meet the evolving needs and aspirations of future physics educators in Indonesia. Indonesia needs a skilled and innovative STEM workforce, particularly for Industry 4.0. CURE is a

relevant teaching approach (Nugroho et al., 2021). There is limited direct reporting on CURE implementation in higher education in Indonesia, but the emphasis on STEM education and related learning models makes it a good place for CURE adoption, especially in physics.

Indonesia's STEM curriculum aims to develop 21st-century skills, such as critical thinking, problem-solving, collaboration, and communication. CUREs are designed to develop these skills by engaging students in authentic research. The focus on applying STEM concepts to real-life situations aligns with CUREs' emphasis on problem-solving and real-world relevance. Despite fewer CUREs in physics literature compared to biology, successful physics implementations (Oliver et al., 2023) show physics concepts can be translated into real research experiences.

Physics education is often theoretical. CUREs provide hands-on, inquiry-based projects that apply theoretical concepts to novel problems, fostering deeper understanding and engagement (Oliver et al., 2023). Physics majors require strong experimental design, data analysis, and computational skills. CUREs offer structured opportunities to develop these, including using publicly available datasets or low-cost experimental setups for computational physics or experimental design (Oliver et al., 2023; Avramovska et al., 2024; Strubbe, 2024). By engaging in projects with unknown outcomes, students learn to troubleshoot, iterate, and adapt their approaches, mirroring the realities of scientific research and fostering an innovative mindset critical for Indonesia's development (Genné-Bacon, 2024). CUREs can provide a scalable, individualized research opportunity to ensure all physics majors gain valuable experience (Abrica et al., 2024).

Integrating Course-Based Undergraduate Research Experiences (CUREs) into Indonesian physics education requires a comprehensive understanding of the local higher education landscape. Challenges such as limited infrastructure, high student-to-faculty ratios, and restricted funding can hinder the adoption of CUREs, which are resource-intensive. However, the adaptability of the CURE model offers institutions flexibility to start small and scale up based on resources. Existing collaborations can also provide alternative avenues for authentic research experiences.

"CURE" programs in Indonesian higher education are not widely documented in academic literature, but related pedagogical approaches exist. The Research Team-Based Learning (RTBL) model has been used in environmental science courses, showing superiority in developing students' research skills compared to traditional methods. This model shares the core "CURE" principle of collaborative research. There is also Research-Based Learning (RBL) has been explored for improving research learning quality and access to facilities. These indicate a cultural and pedagogical readiness for more structured research integration, suggesting the value of integrating research into learning, which is essential for "CUREs." The absence of "CURE" case studies might be due to terminology or adoption differences.

Preparation for Implementing CUREs in Indonesia

Strategic preparation across several key areas is required for the successful implementation of CUREs in Indonesian higher education, particularly in physics. These areas include curriculum adaptation, faculty development and support, resource management and infrastructure, as well as assessment and evaluation.

Curriculum design and adaptation begins with clearly identifying the desired learning outcomes for the CURE. Then, appropriate assessment instruments are selected or developed. Finally, the course content and activities are designed to achieve those outcomes (Govindan et al., 2020). Adaptation involves fitting authentic research ideas to the classroom setting while considering practical constraints such as time, laboratory space, and equipment. In physics, this could entail computational projects using publicly available data or low-cost experimental setups enabling novel investigations (Avramovska et al., 2024; Strubbe, 2024).

Intentionally provide support to help students navigate new information and challenging tasks. This includes setting aside time for background literature research and experimental design as well as incorporating structured opportunities for brainstorming, peer review, and constructive feedback (Dechenne-Peters & Scheuermann, 2022). CURE's design embraces iteration, allowing students to repeat experiments and refine their approaches. This helps students understand that scientific progress often involves unexpected results and requires adaptability. Structured group work assignments and dedicated class discussions foster effective collaboration, mirroring real-world scientific practice (Govindan et al., 2020).

Faculty preparation starts with professional development programs covering CURE pedagogy, active learning strategies, and relevant technical expertise for research projects. This should include practical strategies for student group work, proposal development, and time management (Govindan et al., 2020). Systems should be in place for continuous support, such as monthly virtual meetings, email or phone assistance, and financial stipends for developing and implementing CUREs. Concerns like time constraints, workload, and finding projects should be acknowledged and addressed. These issues can be mitigated by modular CUREs or national network models (Genné-Bacon et al., 2024).

The resource management and infrastructure preparation initiated by securing funding through campus-level grants, national funding opportunities, or by incorporating CUREs into broader research proposals. Exploring how institutions can work together to share resources and reduce costs. Make use of lab equipment and infrastructure. Use "low-cost CUREs" that use publicly available datasets or simulations (Avramovska et al., 2024). This is especially important for physics education, as complex equipment can be a barrier. Invest in digital tools and training on digital platforms and tools like data analysis, collaboration, and communication (Delcher et al., 2025).

As for the assessment and evaluation the preparation needed for alignment with learning outcomes. Employing a backward design approach to assessment, ensuring that assessment instruments are directly aligned with the intended learning outcomes of the CURE (Shortlidge & Brownell, 2016). By utilizing a combination of quantitative

(e.g., surveys, direct assessment tools for scientific skills) and qualitative (e.g., interviews, reflective journals, open-ended prompts) methods, to capture the comprehensive impact of CUREs on student learning, skills, and attitudes. Collaboration with education experts, needed to effectively measure and evaluate affective gains such as self-efficacy, science identity, and attitudes toward science, which are crucial but often challenging to assess. Assessment data not only compiled to measure success but also to inform the continuous refinement and evolution of the CURE, creating a vital feedback loop for improvement.

CONCLUSION

Course-based undergraduate research experiences (CUREs) are a scalable, impactful strategy for improving STEM education at the undergraduate level worldwide. A bibliometric analysis confirms the existence of a substantial and growing body of research supporting CUREs. This body of research provides evidence that CUREs effectively improve student engagement, skill development, and retention, especially among historically marginalized groups. A focused group survey of students reveals strong readiness and demand for integrating CUREs into physics education. By aligning with national STEM curriculum objectives and addressing the need for practical, research-based learning, CUREs offer a promising path for educational innovation. Future efforts should focus on overcoming institutional barriers, expanding CUREs beyond traditional STEM fields, and systematically evaluating outcomes to maximize this potential.

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