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Undergraduate Research Experience Models: A systematic review of the literature from 2011 to 2021

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ABSTRACT

Undergraduate research experiences (UREs) impart a great deal of knowledge to undergraduate students, enhance the research capital of institutes, and authenticate the country's educational outcomes. To effectively assimilate these benefits, the URE designers have proposed many different learning models. However, there is little work done to assess and compare the effectiveness of these varying learning models being adopted in various disciplines. Hence, this article provides an educational research review on the effective pedagogical models in URE to enhance the research experiences of undergraduate students. We initially screened 331 articles and finally compared 67 studies between 2011 and 2021 ranging in different disciplines to understand and weigh out the influence of these URE models with a special focus on the ones in STEM (science, technology, engineering, and mathematics) related fields. This study also indicates the factors that mediate a constructive relationship between students and specific URE models like the Course-based Undergraduate Research Experience (CURE) model in juxtaposing with other traditional and hybrid URE models. Most models have been implemented to biology-related fields and experienced in the United States (U.S.). This depicts a gap in research for the effective implementation of URE in other STEM fields and other countries. Moreover, the CURE model was found to be an effective practice providing large-scale research opportunities to students. However, it is majorly focused on the life sciences field and needs more extensive research in the other disciplines. Also, being comparatively a newer form of URE, there is room for more research in developing this model. While other traditional and hybrid models demonstrated positive characteristics, large reforms are needed for their efficient implementation. Finally, we summarize the strengths and limitations of the URE models from the last decade to highlight the practically successful models for future designers to be implemented in different disciplines.

1. Introduction

Undergraduate research experiences (UREs) encourage undergraduate students to pursue advanced degrees and research career pathways. Especially for the students contemplating a career in research, UREs provide a vital path for their academic and professional development. It helps bridge the gap between theoretical and practical knowledge and inspires students to learn by creating an environment where they feel centric in the educational process. Through UREs, students get exposed to hands-on training guided by experienced mentors under pragmatic research projects. This involves them in open-ended inspections and indulges their creativity

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and insight in analyzing the interpretations of their own work, igniting the passion and curiosity to fuel scientific discover (Karukstis, 2007).

Research work incorporating undergraduate learners has been referred as the “purest form of teaching” (NRC, 2003). Previous studies show that over 68% of students show increased interest in STEM (science, technology, engineering, and mathematics) careers after participating in a URE program (Graham et al., 2013; Russell et al., 2007). In the field of biology education, UREs are regarded as an “integral part of the curriculum for all students” (Woodin et al., 2010). In engineering and technology (Carter et al., 2016) specifically stressed the importance of undergraduate research for engineering students and claimed it would significantly increase their scientific and communications skill levels. Their study hinted that a possible reason for this could be the exposure of undergraduate students to deliver posters and presentations in the URE. Moreover, the report stated that the investigative engineering sub-disciplines (civil, chemical, and biotech) students gain lower communication and networking skills than the other engineering sub-disciplines (industrial, mechanical, electrical, and others). Another important impact of UREs that has been extensively discussed in previous reports is its effect on students determination to pursue graduate studies and careers in the STEM workforce (Zhan, 2014). This is because research experiences contribute to the wealth of information on career plans to the students, providing a concrete option for the participants who are unsure about their careers (Gonzalez-Espada & LaDue, 2006). Further, there is a considerable positive impact on students’ graduation and retention rate in STEM fields, which hints that URE increases their affinity and confidence towards STEM experiments (Hernandez et al., 2018; Ing et al., 2020; National Academies of Sciences & Medicine, 2017). However, within all the STEM majors, UREs in the engineering and technology field seem to motivate a significantly lower fraction of students towards graduate degrees and research careers (Zhan, 2014). Most of the students tend towards pursuing careers in the industry field.

As typically, the engineering students have a good hands-on capability but do not show a lot of motivation towards theoretical and scientific analyses, which however is immensely important. Nevertheless, the development of characteristic research skills and soft skills like networking, teamwork, and communication are still very crucial for the engineering students. Therefore, the design of UREs for the engineering and technology majors is critically important to increase the student participation and retention throughout the course (Hunter et al., 2007).

In addition to the immense benefits that UREs provide to students in STEM fields, such experiences have also been helpful to improve the curriculum of courses. Faculty members have used research experiences for their curriculum lectures and laboratory procedures as real-world examples (Zhan et al., 2010; Zhang & Porter, 2010). This helps demonstrate the theoretical applications of concepts and solve practical problems, thus making it easier for students to grasp contextual theories and increase their motivation towards the course. Also, studies show that research-based experiences influence certain aspects of undergraduate students’ interest, self-confidence, and preference for elements of authentic research compared to the experience of students in a traditional cookbook lab course (Brownell & Kloser, 2015b; Brownell et al., 2012). In addition, UREs help to increase students’ motivation to work productively with faculty members to yield valuable research goals. In particular, increased faculty-student publications have been observed as a result of a constructive faculty mentored URE (Morales et al., 2017). However, this motivation for students to work productively with faculty is usually the case in laboratory based UREs. In UREs which are classroom oriented or course-based no such significant effect is found on students’ motivation and teamwork (Carter et al., 2016). Also, students are inclined to spend substantially less time performing work in a course based undergraduate research experience (CURE) than they would in a research internship (Auchincloss et al., 2014). Students enrolled in CURE classes would be less engaged in inquiry, which could impair their personal and classmates’ motivation, as well as longer-term motivational effects. Interns on the other hand, are often more prone to have close professional ties with mentors and other researchers, which can help them build their professional network.

Students who generally participate in UREs usually assume that the URE replicates their high school laboratory experiences with step-by-step guidance and planned results. Many are unprepared for the challenges and failures faced in independent research. Therefore, they initially spend most of their effort setting up and adapting to the environment, limiting their efforts in investigating and interpreting the results (Linn et al., 2015). Though their gradual transition into the research ambiance is likely, the time and resources spent during this phase restrict the scalability of UREs. Moreover, when students develop new ideas in their experience, they require supportive guidance to consolidate them with their expectations. Therefore, to effectively cultivate and establish the "hands-on" and "minds-on" conception among the students, URE designers have carefully devised frameworks and learning models to be implemented at different institutions. In general, these programs can be customarily segregated into two types of settings, (a) course-based undergraduate research experience (CURE) or (b) co-curricular, informal, apprenticeship-styled, student-faculty grouped experience in a laboratory. Many other studies further tailor these two types of experiences to create more productive and exciting research experiences for undergraduate students. Taken together, the sub-categorical types of UREs are various, and their outcomes are diverse. The methodologies and indicators used to imply their efficacy in achieving those goals are similarly diverse. While there is a lack of data available on the trend of different learning models adopted by institutions for URE in the past, evidence suggests that there has been recent growth in the adoption of CURE models (National Academies of Sciences & Medicine, 2017). However, while various models for URE are present for students to participate at different institutions, there is very little analysis reported on which type of URE model might be most productive for students. Therefore, this review tries to answer this gap in literature, providing insights that will be helpful to other URE designers in seeking and understanding the pedagogical values of UREs. Hence the study is formulated with the following aims:

- To assess how effective URE models are being planned and integrated and how they functionally influence undergraduate students in various disciplines with a special focus on STEM-related fields.
- To compare the effectiveness of the different URE learning models and discuss the associated contrasting academic outcomes from such frameworks.

- To produce collective insights from the various studies of the last decade and provide supporting evidence into the body of literature of UREs.
- To generalize our review and suggest recommendations on the potent learning models that are apparent for the research development of undergraduate students.

2. Method

2.1. Literature Search

This review was performed systematically according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). Bibliographic documents establishing claims on methodological learning models for UREs and

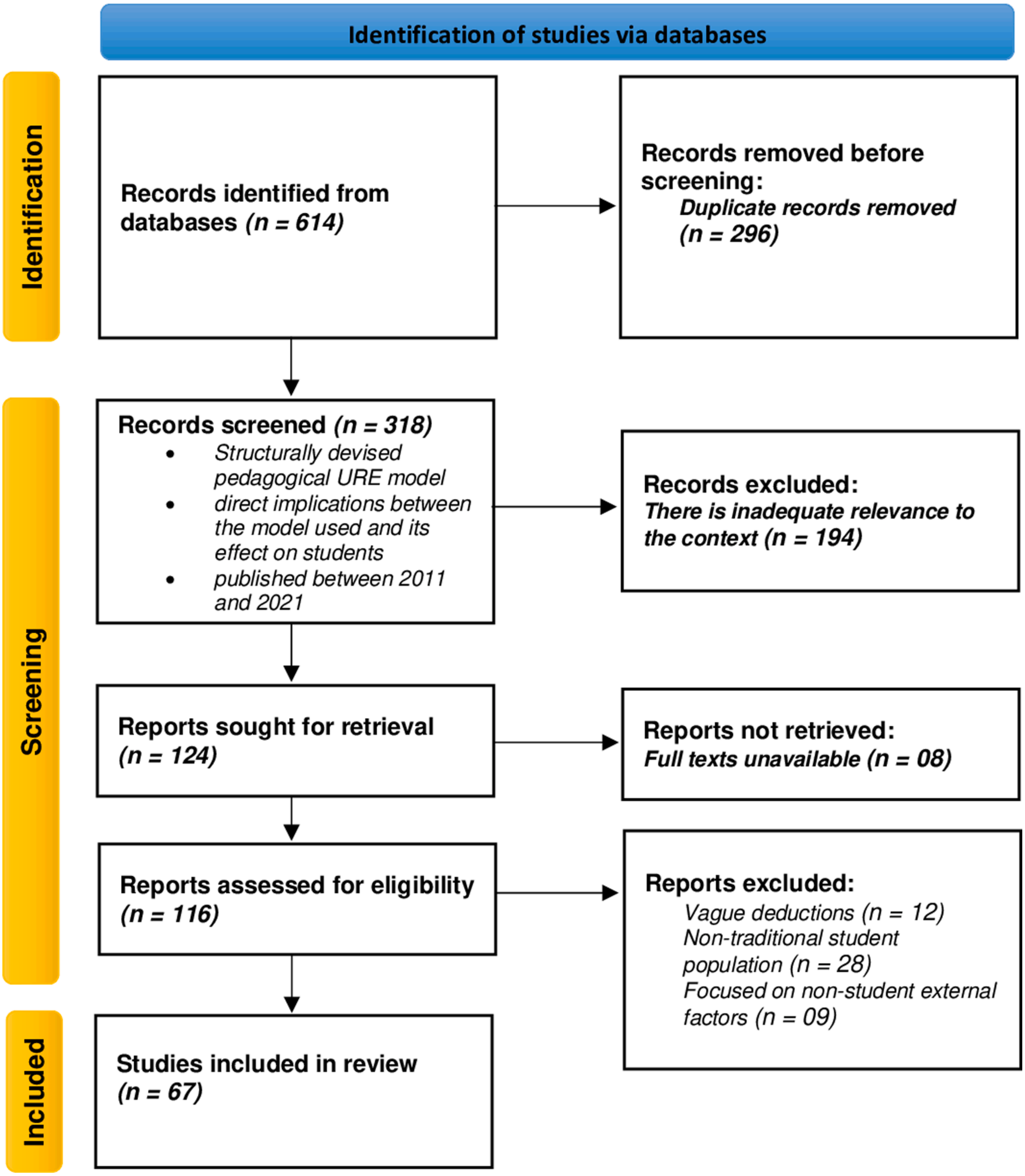

Fig. 1. PRISMA Flowchart of the Search and Inclusion Process of the Literature

Table 1
Empirical Studies of Various Learning Models for UREs Proposed in Research Literature Between 2011 to 2021.

Authors	Model Design	Disciplines	Model effectiveness indicators	Outcome	Country
1 (*Fasse & Benkeser, 2011*)	International URE	Biomedical Engineering	Global perspective on research challenges	Meaningful research contributions, mutual collaborative relationships	U.S.
1 (*Wang et al., 2012*)	URE	Biology	Introductory-level CURE	Professional scientific practices, Increased competence, and confidence	Australia
1 (*Rowland et al., 2012*)	Laboratory Experience for Acquiring Practical Skills	Biochemistry	Focus on core development of laboratory skills	Simple and controlled URE, increased technical skills	Australia
1 (*Rowland et al., 2012*)	Active Learning Laboratory Undergraduate Research Experience	Biochemistry	Authentic and challenging URE tailored for determined students	Higher understanding of the nature of science	Australia
1 (*Canaria et al., 2012*)	Lecture-Lab coupled with Summer Research Program	Chemistry and Biology	Exposure to lab techniques	Experience in scientific and lab methods	U.S.
1 (*Russell et al., 2015*)	CURE	Biology and Ecology	Integrated CURE	Ability in students to bride research in multiple courses and address common questions	Georgia
1 (*Danowitz et al., 2016*)	CURE combined with Lab based URE	Chemistry	Broad content with reduced time	Theoretical and practical understanding	U.S.
1 (*Whipple et al., 2015*)	Faculty mentored URE	Social Sciences	Students' knowledge, attitude, and anxiety levels on research	Evidence-based practice, analytical and practical skills	U.S.
1 (*Brownell et al., 2015*)	CURE	Biology	High enrollment introductory-level CURE	Improved conceptions of scientific thinking and data interpretability	U.S.
1 (*Woodzicka et al., 2015*)	Multi-faculty, multi-institution team	General	Multi-institutional and multi-cultural research practices	Sophisticated research understanding	U.S.
1 (*Mennella, 2015*)	One semester laboratory URE	Biology	Balanced hands-on experience	Scientific writing, sense of ownership	U.S.
1 (*Swanson et al., 2016*)	CURE	Biology	Inquiry-based CURE	Career clarification, enhanced science identity, ability to navigate uncertainty	U.S.
1 (*Shanle et al., 2016*)	CURE	Biology	Classroom-Lab integrated research	Increased confidence, scientific discovery	U.S.
1 (*Shubair et al., 2016*)	Independent Study for URE	Electrical and Computer Engineering	Individual and independent work	High quality research publications	U.A.E.
1 (*Bakshi et al., 2016*)	CURE	Biology	CURE based on ongoing, in-house research projects	Introduction to on-going research, increased motivation	U.S.
1 (*Sarmah et al., 2016*)	CURE	Biology	Introductory-level CURE	Course satisfaction, engagement, and enthusiasm	U.S.
1 (*Awong-Taylor et al., 2016*)	4YrURCE	STEM related	Research skills, scientific experience and literacy	Increase in Students' GPA, retention in STEM fields	U.S.
1 (*Kolber et al., 2016*)	Cross-disciplinary and community engaged biomedical summer URE	Medical Sciences	Basic science research, Clinical exposure	Increased interest towards the field, motivated to pursue postgraduation	U.S.
1 (*Thompson et al., 2016*)	CURE	Geoscience	Introductory level, non-science target group	Increased cognitive growth, interests, motivation, and communication skills	U.S.
1 (*Kappler et al., 2017*)	Authentic Large Scale URE	Biology	Systematic learning to solve problems	Increased confidence, analytical skills	Australia
1 (*Brown et al., 2016*)	Student-centric research	Biochemistry	Student participation and a structured URE	Improved critical thinking, communication, and participation	U.S.
1 (*Peteroy-Kelly et al., 2017*)	CURE	Biology	Year-long CURE	Gains in lower performing students, scientific enculturation	U.S.
	CURE	Biology	Field-based CURE		U.S.

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Table 1 (*continued*)

Authors	Model Design	Disciplines	Model effectiveness indicators	Outcome	Country
1 (*Flaherty et al., 2017*)				Understanding of scientific methods, increased confidence levels in males	
1 (*Hotaling et al., 2018*)	CURE	Biology	Introductory-level CURE	Increased knowledge, scientific process, and problem-solving skills	U.S.
1 (*Bhatt & Challa, 2018*)	CURE	Biology	Introductory-level CURE	Scientific process and identity, project-specific conceptual gains	U.S.
1 (*Sternquist et al., 2018*)	URE integrated with Kolbs experiential learning cycle	Social Sciences	Deep learning engagement and development of employable skills	Knowledge discovery, motivation in students	U.S.
1 (*May et al., 2018*)	CURE	Chemistry	Introductory-level CURE with environment focus	Confidence in research at early stage of UG career, positive attitude	U.S.
1 (*Casson et al., 2018*)	Network approached pilot URE program	Environmental Sciences	Enhance the honors thesis of students, learn techniques for collaborative sciences	Specialized instrumentation	Canada
1 (*Reeves et al., 2018*)	CURE	Biology	Introductory-level CURE	Content knowledge, self-reported research skills and scientific literacy	U.S.
1 (*Ayella & Beck, 2018*)	CURE	Biology	Iterative and collaborative CURE	Appreciation of science, increased students' attendance	U.S.
1 (*Rodrigo-Peiris et al., 2018*)	Hybrid of CURE and traditional apprenticeship	STEM	Academic performance in STEM	Increased retention, competency, and interests in STEM	U.S.
1 (*Mraz-Craig et al., 2018*)	CURE	Biotechnology	Authentic identity focused	Development of scientific identity	U.S.
1 (*Al-Ghadhban et al., 2018*)	CURE	Electrical Engineering	Exposure to research structure and methodology	Positive learning, interest towards postgraduation and technical skills	K.S.A.
1 (*Wooten et al., 2018*)	CURE	Astronomy	Science process skills and perception of science	Confidence in participation and collaborations	U.S.
1 (*Pagano et al., 2018*)	CURE	Chemistry	Informed experimentation, understanding of laboratory work and safety regulations in Lab	Subject and scientific research, genuine perception towards the course	U.S.
1 (*Stoeckman et al., 2019*)	CURE	Biology	Iterative and multi-semester CURE	Novel discoveries and publications, cost benefits and improved student attitudes	U.S.
1 (*Lee & Burnett, 2019*)	CURE	Food Science	Comprehensive CURE	Enhanced interests for future research, increased learning outcomes	U.S.
1 (*Periyannan, 2019*)	CURE	Biology and Biochemistry	Inquiry-driven CURE	Scientific reasoning, critical thinking skills and high confidence levels	U.S.
1 (*Kirkpatrick et al., 2019*)	CURE	Biology	Computer-based and bench-based CUREs	Higher interests, satisfaction, and sense of achievement	U.S.
1 (*Woodley et al., 2019*)	CURE	Physiology	4 year integrated CURE with service community engaged learning	Novel research, personal growth, and civic mindedness	U.S.
1 (*Dvorak & Hernandez-Ruiz, 2019*)	CURE	Psychology	Thinking and working like a scientist	Personal gains, research skills and scientific enculturation	U.S.
1 (*Ochoa et al., 2019*)	CURE	Biology	Modular CURE	Scientific communication, independent research, critical thinking	U.S.
1 (*Jones & Lerner, 2019*)	CURE	Animal Sciences	Increased participation of students without decreasing quality of education	Developed workforce and skills, ability for science-based decisions	U.S.
1 (*Hauwiller et al., 2019*)	Group based undergraduate research program (GURP)	Chemistry, Chemical Engineering and Materials Science	Open ended research, knowledge of research and scientific process	Exposure to research and self-identification as researchers	U.S.
1 (*Jelen et al., 2019*)	Affinity Research Group (ARG) Summer model	Computer Science	Team building and professional skill building	Exposure to advanced fields and problem-solving skills	U.S.

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Table 1 (*continued*)

Authors	Model Design	Disciplines	Model effectiveness indicators	Outcome	Country
1 ***(Lau et al., 2019)***	CURE	Analytical Chemistry and Environmental Toxicology	Multi-disciplinary CURE	Ability to connect ideas to research questions	U.S.
1 ***(Golding et al., 2019)***	Summer Undergraduate Research Experience	Psychology	Work-integrated learning	Skill development and networking	Australia
1 ***(Murren et al., 2019)***	CURE	Biology	Network integrated CURE	Quality results, low cost, increased self-efficacy in students	U.S.
1 ***(Procko et al., 2019)***	CURE	Biology	Inter-disciplinary CURE	Novelty driven research experience	U.S.
1 ***(Shelby, 2019)***	CURE	Biochemistry	CURE for students with limited lab experience	Enhanced interests and mentor-mentee relations	U.S.
1 ***(Irby et al., 2019)***	CURE	Biochemistry	Discovery and Problem solving	Knowledge, experience, confidence in research	U.S.
1 ***(McDonald et al., 2019)***	CURE	Biological Sciences	Increased faculty involvement	Redesigned academic laboratory courses	U.S.
1 ***(Hickey et al., 2019)***	Process-environment mentorship	Nursing Education	Mentor-mentee relationship	Developed research skills	Qatar
1 ***(Sun et al., 2020b)***	CURE	Microbiology	Journal driven CURE	Enculturation like scientists	Canada
1 ***(Furrow et al., 2020)***	CURE	Biology	Integrated CURE	Sense of ownership, iteration, and discovery	U.S.
1 ***(Lyles & Oli, 2020)***	CURE	Microbiology	CURE with Inquiry based approach	Enhanced knowledge, interests and attitude towards the field	U.S.
1 ***(Rennhack et al., 2020)***	CURE	Physiology	Understanding of research process, communication, and teamwork	Practice of skills, develop novel projects and findings	U.S.
1 ***(Mann et al., 2020)***	Interdisciplinary community based URE	Nutrition, Justice and Sociology	Interdisciplinary interaction and community engagement	Quality and valuable research, university-community collaboration	U.S.
1 ***(Pufall & Wilson, 2020)***	CURE	Biochemistry	Inter institute, cross-training, cross-disciplinary, collaborative scientific research.	Enhanced engagement, interest towards postgraduation, research publication	U.S.
1 ***(Guttilla Reed, 2021)***	CURE	Biology	Writing driven CURE	Literature, experimental and writing understanding	U.S.
1 ***(Petrie, 2020)***	CURE	Microbiology	Exposure to scientific knowledge	Contribution to scientific community	U.S.
1 ***(Zelaya et al., 2020)***	CURE	Microbiology	Discovery driven CURE	Authentic research experience as part of course curriculum	U.S.
1 ***(Sewall et al., 2020)***	CURE	Microbiology	Awareness driven CURE	Higher grades, increased interests, and awareness in science	U.S.
1 ***(Hernandez-Ruiz & Dvorak, 2020)***	CURE	Psychology	Scientific enculturation, attitude, and skills	Positive gains in scientific ability and behavior	U.S.
1 ***(Delventhal & Steinhauer, 2020)***	CURE	Biology	Discovery driven CURE	Gains in self-confidence, active learning, and writing	U.S.
1 ***(Hills et al., 2020)***	CURE	Biology	Backward designed CURE	Thinking, communicating and working like a scientist	Canada
1 ***(Marsiglia et al., 2020)***	CURE	Biochemistry	Discovery driven CURE	Learning of advanced techniques	U.S.

their effective relation to students' performance were identified by web searches in the databases of Scopus, ERIC (Education Resources Information Center), and Web of Science. These three databases were found to be optimum due to their scholarly recognition, central knowledge in educational research, and broad coverage of journals from the academic field. Following several trial searches, the concluding web searches were conducted in August 2021. The following search queries were performed: ((“undergraduate research experience” OR "undergraduate research opportunities") AND (“model” OR “program” OR “method” OR “design” OR “type” OR “framework”)). The Scopus and ERIC directory resulted in 454 and 181 hits, respectively, while Web of Science returned 153 hits.

2.2. *Inclusion and Evaluation of Studies*

To include only the concise and relevant studies in this review, further screening of the searched articles was required as shown in Fig. 1. To be selected for inclusion in our review, an article had to (a) comprehend a structurally devised pedagogical model for URE;

(b) contain direct implications between the model used and its effect on the undergraduate students; (c) be published between the years 2011 and 2021 in a peer-reviewed journal. Applying the above conditions during the initial screening, a provisional selection of 114 studies was obtained. Further, conditions for exclusion criteria were inspected in these studies. Studies without well-defined results which did not give concrete conclusions on the effects of their learning models on students were excluded to avoid any obscurity in the review. Also, few studies were performed on non-traditional and underrepresented student populations, these were also ignored as their conclusions could not be applied to the undergraduate masses in general. The studies focusing on other variables like teacher's or mentor's experience, student disabilities, environmental, and other social or cultural factors were eliminated to narrow down the purpose of this review to the aims of our study. Thus, only the studies which reported the influence of models on the elements within the bounds of the university/institute, students, and faculty were included.

The norms mentioned above were adopted in the initial selection process of the journals. The eligible articles' abstract was screened, and if the abstract was unavailable, the complete publication was retrieved and inspected. The first preliminary selection based on the inclusion criteria resulted in the provisional nomination of 114 publications. These studies were extracted from online libraries and then carefully examined. For the final screening, careful consideration was done by the authors, which finalized 67 publications for this review that met all the inclusion and exclusion criteria (see Fig. 1). The included publications were grouped in relation to five salient features: (a) author(s), (b) model design, (c) discipline for which the model was proposed, (d) model effectiveness indicator, (e) outcome affiliated to the model, and (f) country of publication (based on the university location of the corresponding author). Table 1 presents the list of studies included for review in the present work. Table 2 classifies the studies with respect to the discipline and country of publication, respectively.

3. Results

In this section, we present the results of our review to discuss the different learning models used for UREs. We classify the learning models into three subcategories, namely, (a) CURE models, (b) Traditional apprenticeship-styled models, and (c) Integrated and collaborative models. Lastly, we outline the preponderance of the effective learning models in the STEM disciplines to highlight the decisive features that can contribute to the general synergistic development between faculty and students involved in the UREs.

3.1. CURE Models

The first published description of the concept of a CURE model can be traced back to 1956, where (Fromm, 1956) depicted a transformation of an undergraduate course with elements of research embedded to engage students in publishable research. Subsequently, since then educators have been extensively developing the CURE model with a parallel growth in the debate considering what comprises an effective CURE. Here, we have compiled the studies of the last decade and reviewed 45 studies of CURE models, the majority of which are directed towards the STEM fields, particularly the biology field. Table 1 presents an overview of all the included studies for URE models. The CURE models can be further classified into the following categories based on their model effectiveness indicator reported in the studies. Most commonly, CUREs were implemented as an introductory-level experience. Further, multi-disciplinary CUREs and curriculum reformed CUREs have also gained the interest of educators.

Table 2
Distribution of the URE Studies Between 2011 and 2020 by Disciplinary Field and Country of Publication.

Category	Total Studies	Subject-wise studies		Country-wise studies	
STEM disciplines	62	Biology	34	U.S.	28
				Australia	02
				Canada	02
				Georgia	01
				Qatar	01
		Biochemistry	07	U.S.	05
				Australia	02
		Chemistry	06	U.S.	06
		Engineering	03	U.S.	01
				K.S.A	01
				U.A.E	01
		Physiology	02	U.S.	02
		STEM (General)	02	U.S.	02
		Food Science	02	U.S.	02
		Biotechnology	01	U.S.	01
		Geoscience	01	U.S.	01
		Computer Science	01	U.S.	01
		Environmental Science	01	Canada	01
		Astronomy	01	U.S.	01
		General	01	U.S.	01
Non-STEM disciplines	05	Psychology	03	U.S.	02
				Australia	01
		Social Sciences	05	U.S.	02

3.1.1. Introductory-level CURE Models

(Bangera & Brownell, 2014) argued that through CURE, the entry point in research should be restructured so that all students are privileged to an opportunity in research. They claimed introductory-level CUREs to be an effective way to expose students of different backgrounds into the research field, broadening the scientific community's diversity and opening a wide door for next-generation potential scientists. Applying this, (Kortz & Van Der Hoeven Kraft, 2016) designed an innovative CURE for introductory-level, non-science majors. Their study reports cognitive growth in students with enhanced interest, motivation, and communication skills. Similarly, (Shelby, 2019) proposed a CURE model in the biochemistry discipline, which provided opportunities for students with limited laboratory experience and varying levels of preparation to participate in the research. This incited an engaging experience for the students with increased levels of interest in performing research, in addition, to positive mentor-mentee relations. Further, (Thompson et al., 2016) proposed expanding the introductory-CURE model to provide meaningful field-based research experiences to more students. Their model suggested a five-week introductory-biology research-focused course incorporating the features of CURE in a field-based setting. Participating students were given the freedom to select their research questions and form self-selected teams. Consequently, a higher sense of ownership in students was noted with positive learning outcomes and increased confidence levels in addition to optimistic self-efficacy and enthusiasm for research. Similarly, (Brownell et al., 2015) presented an introductory-level CURE as a requirement for all introductory biology major students. Their course results revealed that students acquired gains in their ability to analyze and interpret data. Their study indicated that such a compulsory CURE for introductory-biology majors has a positive impact on the development of learners' conceptions and scientific thinking. A similar study by (May et al., 2018) in the field of chemistry represented a novel integration of environmental chemistry research into an introductory level chemistry course through the CURE format. This was done to give an environmental focus to the general chemistry curriculum, resulting in students developing connections to the environment and improving their engagement. This study indicated that the students self-confidently built their understanding of general research skills showing positive attitudes towards the subject, thereby signifying their retention. Similar studies incorporating introductory-level CUREs proved to be an effective gateway for undergraduates to research experiences which in turn provides a gateway to become members of the scientific community (Ayella & Beck, 2018; Bhatt & Challa, 2018; Flaherty et al., 2017; Hotaling et al., 2018; Peteroy-Kelly et al., 2017; Reeves et al., 2018; Sarmah et al., 2016; Sewall et al., 2020; Wang et al., 2012).

3.1.2. Multi-courses Integrated CURE Models:

A CURE model can also be an approach to blend systems thinking into the curriculum by building a methodological collaboration between courses. This proposition is applicable to facilitate the design of CURE models with research questions that cannot be entirely answered through a single disciplinary field alone. For example, (Lau et al., 2019) report a collaborative CURE between the Analytical Chemistry and Environmental Toxicology courses. Students from both courses participated in the experience and illustrated the ability to associate ideas and techniques gained to a broad-ranging research question. Similarly, (Russell et al., 2015) initiated an integrated CURE model to build connectedness between the sub-disciplines, Biology, and Ecology and engage students in a long-term analysis of biodiversity. Such horizontal integration between research experiences of distinct biology courses was used to address a common outcome. This was intended to benefit the undergraduate students' research experience by stressing the integrative nature of scientific processes and discovery. Also, it enables students to learn and build skills over two courses of biology. The study reported gains in students' comprehension and confidence levels. Supporting this model, (Furrow et al., 2020) worked to outline an integrative CURE model that combined contemporary Biology with quantitative Mathematics. Their study proposed to improve students' practical techniques in biology with additional focus on their quantitative skills using mathematical modeling. Thus, students generated their own data from experiments to quantitatively model the results, creating a sense of ownership, iteration, and scientific discovery. Moreover, studies by (Kirkpatrick et al., 2019; Murren et al., 2019; Procko et al., 2019) have proved computational-based CUREs to better students' exposure in practical research, preparing them for future research endeavors and expanding their definition of "real research". Also, it suits the online learning environment, which is popular to be an effective pedagogy.

3.1.3. Curriculum Reformed CURE Models

Studies by (Bakshi et al., 2016; Delventhal & Steinhauer, 2020; Irby et al., 2019; Lee & Burnett, 2019; Lyles & Oli, 2020; Mraz-Craig et al., 2018; Periyannan, 2019; Petrie, 2020; Shanle et al., 2016; Stoeckman et al., 2019; Swanson et al., 2016; Zelaya et al., 2020) report a CURE model in the field of biology that follows an inquiry-based approach where students apply scientific processes to examine an unknown question with no predetermined outcome. This experience was an easy implementation and adaptation among students enhancing their content knowledge and attitude towards the subject. Another effective reform was demonstrated by (McDonald et al., 2019) in their institute's Department of Biological Sciences, which redesigned 12 of its laboratory courses using the elementary principles of CURE. This led to the training and development of their faculty which helped the faculty to become compatible with the implementation of the CURE model. Such amendments in faculty and curriculums address the call for more authentic research, developing a shared vision with reflective pedagogical practices in instructors. The University of British Columbia reformed its URE in microbiology by developing a unique CURE model revolving around an undergraduate research journal (Sun et al., 2020b). Their CURE operated in a feed-forward manner where student teams worked to formulate their research questions, derive hypotheses, and perform experiments to publish their work in the journal, subsequently deriving new research questions in the course. This disciplined experience proved to be an applicable learning tool for the university to immerse the students in the process of science. A similar model was presented by (Guttilla Reed, 2021) where the participating undergrad students worked on writing a grant proposal in the wake of performing research to test their individual hypotheses. As a result, students reported having gained an enriched understanding of the primary literature, experimental research designs, and publications style scientific writing. (Jones & Lerner, 2019) implemented CURE in the animal sciences curriculum and reported a developed workforce with skills to make science-based decisions.

They argued that the CURE could increase the quality of student learning and at the same time offer these experiences to a larger undergraduate audience.

3.2. Traditional Apprenticeship-styled Models

In contrast to CUREs, the traditional UREs offer "hands-on" laboratory-based experience to students in the form of one-on-one mentoring. Generally organized during the summer, in this setting, students spend the bulk of their time in a research facility to devise, refine and carry out a research project with supervision from their mentor. In a research-driven laboratory setting, students get the potential to enhance their problem-solving and critical-thinking abilities, define and investigate their own research, and cultivate the characteristics of being a scientist.

The URE courses typically cater to a diverse learning cohort with students of mixed motivational and skill levels. Students with more capability need to be addressed with high creative activities and freedom for conceptual extension, whereas the students lacking interests require a simple start with a smooth transition to the more challenging portions. (Rowland et al., 2012) answered this with a dual-modeled URE in Biochemistry with two parallel but equivalent streams of courses offered according to the choice of students. One design called the Laboratory Experience for Acquiring Practical Skills (LEAPS) was intended to acquire a range of common laboratory skills. The other design, the Active Learning Laboratory Undergraduate Research Experience (ALLURE), was offered to students desiring authentic research. Their strategy revealed that though the dual model gave a different learning experience to each cohort, students from both reported similar gains in practical skills and interest in research. This structure of customized research experience offers students the freedom to choose their experience which best fits their academic background, future career intentions, and personality traits. Similarly, studies report authentic large-scale URE frameworks to be beneficial to a wider scale of students, thus yielding more productive results in scientific research (Brown et al., 2016; Kappler et al., 2017). One study by (Mennella, 2015) demonstrated a URE model through a laboratory course in molecular biology designed to replicate an authentic research project. This way URE was provided to a larger scale of students than other selective URE models. Moreover, the experience was confined to a typical lab course duration. Another such model was reported by (Awong-Taylor et al., 2016) that imparted all STEM-undergraduates the opportunity to experience research irrespective of their career goals. Their strategy claimed a four-year undergraduate research and creative experience (4yrURCE) model which embedded faculty-mentored research into the curriculum courses.

A study by (Whipple et al., 2015) implemented a faculty-mentored URE in the social sciences field, improving students' evidence-based learning. Their practical abilities to use software and analyze data increased along with significant improvements in attitude towards research. Further, (Woodzicka et al., 2015) proposed a multi-faculty model to allow students to engage in shared interests and benefit from the synergy emerging from collaboration among institutes and faculty. This provided students with a more extensive and sophisticated understanding of scientific research with a fuller sense of appreciation for scientific research. Similarly, (Mann et al., 2020) implemented an interdisciplinary URE program with collaboration from three different faculties, including nutrition, criminal justice, and sociology. Their design was a community-based participatory research, modeled to implement appropriate interventions in the social cause of the community. Also, (Kolber et al., 2016) and (Fasse & Benkeser, 2011) applied their summer undergraduate research experience model with community engagement to give a more complete and authentic experience to the medical students involved. The students reported enhanced affinity towards the STEM field and increased interests in clinical medicine as their future career option. Another study by (Kobulnicky & Dale, 2016) also supports the community mentoring model in UREs to achieve the best research-based practices in STEM UREs. Studies by (Casson et al., 2018; Golding et al., 2019; Ochoa et al., 2019; Pufall & Wilson, 2020; Shubair et al., 2016) further identified opportunities to enhance the URE by using a network approached pilot program to incorporate collaborative techniques and skills within a team. Similarly, (Jelen et al., 2019) proposed the Affinity Research Group (ARG) model in Computer Science, where faculty and student mentors guide undergraduate students to expertise their skills and become equal contributors to the research group. The critical take-away from all these studies suggest the importance of building a strong sense of community in undergraduate students through UREs.

3.3. Integrated and Collaborative Models

Both the traditional UREs and CUREs suffer from their respective limitations in accordance with the type of framework used and the environment they are implemented in. For instance, burdens on the faculty members assigned in CUREs, limited and compact duration of experiences, and an exclusive selection of students in traditional UREs (Ashraf et al., 2011; Carpenter & Pappenfus, 2009; Iimoto & Frederick, 2011). To overcome these and deploy the combined effects of both the common practices, educators have used different integrated forms of UREs. One such combinational approach is reported by (Danowitz et al., 2016) and (Hickey et al., 2019) using a course and lab-based teaching model to equip students with both technical and conceptual research characteristics. This team-taught course in Chemistry proved to nurture the fundamental skills of research in students to prepare them to present a research proposal. Another study by (Canaria et al., 2012) used a lecture-laboratory multi-disciplinary model in chemistry and biology to reinforce and cumulatively evolve students' practical and critical-thinking skills. Students were found to show increased commitment to research and develop the qualities of an independent researcher. Further, (Rodrigo-Peiris et al., 2018) designed a hybrid model for STEM undergraduates considering a supportive and authentic research environment for the students. Their program improved the STEM retention rates through the academic years contributing directly to the high graduation rates of students. Similarly, studies by (Hauwiller et al., 2019; Hills et al., 2020; Marsiglia et al., 2020) proposed a hybrid model as "Group-based URE" to expose students early into research and provide a sense of self-identification as researchers. This helped students to determine their interest in research and plan better for their future in STEM careers.

To compare lecture-based CUREs with integrated lecture-laboratory hybrid models, (Lloyd et al., 2019) conducted a comparison study between both these models for a Psychology course. The lecture-lab fused model proved to show increased performances on students in terms of its effectiveness, attitudes towards science, post-graduation plans, scientific information and literacy, and research process. It is evident from these studies that integrated models of traditional UREs and CUREs broaden the knowledge-based outcomes from the course and reduce the burden on faculty members. Moreover, students experience theoretical and practical understanding of the course simultaneously, creating a mutually informative and enhanced learning environment. Another study by (Sternquist et al., 2018) implemented Kolb's experiential learning cycle in URE to advocate a four-stage model incorporating a process of knowledge transformation through experience. Their strategy rests on the four foundational pillars of a holistic educational experience; concrete experience, reflective observation, abstract conceptualization, and active experimentation. These steps are carried out in a repetitive loop such that the learner actively engages in experiencing, reflecting, thinking, and performing, a cumulative experience for deep learning in research. This type of integrated model is unique and different from the common integrated models that offer typical apprenticeship elements in URE.

Similarly, (Woodley et al., 2019) proposed a CURE integrated with community-engaged learning to provide students with novel research equipped with civic-mindedness and personal growth. Their study hypothesized involving students in novel URE revolving around an essential community problem to improve their analytical and critical thinking abilities, social and communication skills, and affiliated academic knowledge. Moreover, the student-reported gains from this model were greater than a matched cohort of students participating in summer undergraduate research experience.

4. Discussion

CUREs offer an alternate and effective pedagogical strategy to engage students over traditional laboratory-based independent research internships. Instead of going through the hassle of application and selection processes, students can simply enroll in credited courses that provide the freedom to engage in authentic research. The substantial differences between CURE and other URE models are listed in Table 3. The main feasible advantage of CUREs is their potential to allow more students to participate in research. Though CUREs can adopt diverse structures and themes in different disciplinary fields, they are based on the following foundational principles that ensure the practice of authentic research: (a) Engagement of students in scientific practices; (b) Exposure to scientific discovery to address novel scientific questions by examining hypotheses; (c) Emphasis on broadly relevant works that has importance beyond the course context; (d) Incite collaboration; and (e) Incorporate iterative work practices (Auchincloss et al., 2014). However, these fundamentals are not unique to CUREs; but instead, their integrative effect seeks to create a harmonic learning experience for students in undergraduate research. In addition, CUREs provide participants to access a unique combination of activities (classroom and lab-based) that ensue their progressive development of diversified cognitive, psychosocial, and behavioral characteristics (Corwin et al., 2015). Also, CUREs are comparatively less bounded by principal investigators and research grants to produce publishable units (Brownell & Kloser, 2015a). This considerably reduces the stress on instructors as well as students and helps to focus their attention on the learning process. Unlike internships and lab based UREs, students do not have to volunteer for the experience and in turn earn course credits for their academic program. Moreover, such models when consolidated in introductory-level courses, have the capability to exert greater influence on the academic and research careers of undergraduate students as compared to research internships

Table 3
The Distinct Summarization of the URE Models Discussed in this Review.

URE Model	Disciplines	Strengths	Limitations
CURE	Astronomy Biology Chemistry Biochemistry Engineering Biotechnology Food Science Geoscience Psychology	• Opportunity to all students • Exposure to students of different backgrounds • Gateway to research experience • Covers large portions in limited time	• Limited research in non-life sciences disciplines • Comparatively a new form of URE • More extensive research needed for further development
Traditional apprenticeship-styled	Biology Biochemistry Engineering Computer Science Environmental Science Food Science Social Science Psychology	• Development of core practical abilities • Strong mentoring • Authentic research experience • Strong sense of community	• Detrimental competition among students for participation • Limited student participation • Lack of theoretical knowledge gains in students
Integrated and Collaborative	Chemistry Physiology Social Sciences	• Integrated benefits of both CURE and traditional UREs • Community engaged learning	• Very limited research • Complicated models • Comparatively impractical to be implemented

(Dolan, 2016; Hunter et al., 2007). Participation in CUREs generally increases the chances of successfully getting further research opportunities and competitive internships (Jordan et al., 2014; Rowland et al., 2012; Shaffer et al., 2010). Also, introductory CUREs' ability to increase the persistence of students in STEM-related fields is well established (Reason et al., 2006). Therefore, many institutions provide first-year undergraduates with introductory-level CUREs to engage them in "real science" practices from the onset of their careers. Also, a high enrollment from these experiences provides a strong reason for their integration and reformation within the curriculum, promoting a large-scale collaboration. This practicality of CUREs is another important reason for their edge over other types of UREs. By providing more students these experiences, CUREs eliminate some of the common barriers faced by students in other independent UREs. Also, as mentioned above, traditional management and structure of science laboratories do not generally cultivate these dispositions. CUREs thus provide a refreshing alternative to "recipe-based" traditional UREs considering they practice more authentic experiences with promising benefits for both learners and mentors.

Moreover, introductory-level CUREs are highly recommended for biology majors to engage students in research and shift their "thinking like a scientist" from novice to expert (Brownell et al., 2015). This is because at the introductory-level, CUREs have the potency to create an increased impact on students' academic and career paths than traditional UREs, which typically take place later in the undergraduate degree and represent mainly to certify prior academic or career options (Auchincloss et al., 2014; Hunter et al., 2007). Furthermore, at the introductory level of biology courses, inquiry-based and discovery-driven approaches result in higher student engagement along with better mentor enthusiasm for teaching freshman biology (Harrison et al., 2011).

In general, the logic model behind the assessment of CUREs can be sketched within three different sections, as shown in Fig. 2. The different contexts in which CURE can take place are either individually, with the faculty or within self-formed student groups. The subsequent activities that are performed highlight the principles of CURE i.e., use of science practice, collaboration, broader relevance, scientific discovery, and iterative work. These are affiliated to the resulting outcomes, which can be short-term and strengthened over time to concentrate on long-term results. Moreover, based on our assessment of all the CURE models in this review, this logic model paves the way for CURE designers to plan specific paths of experience incorporating the appropriate elements of context and activities to achieve the resulting outcomes. Attributing very closely to the principles of CUREs, these factors are the crucial components that

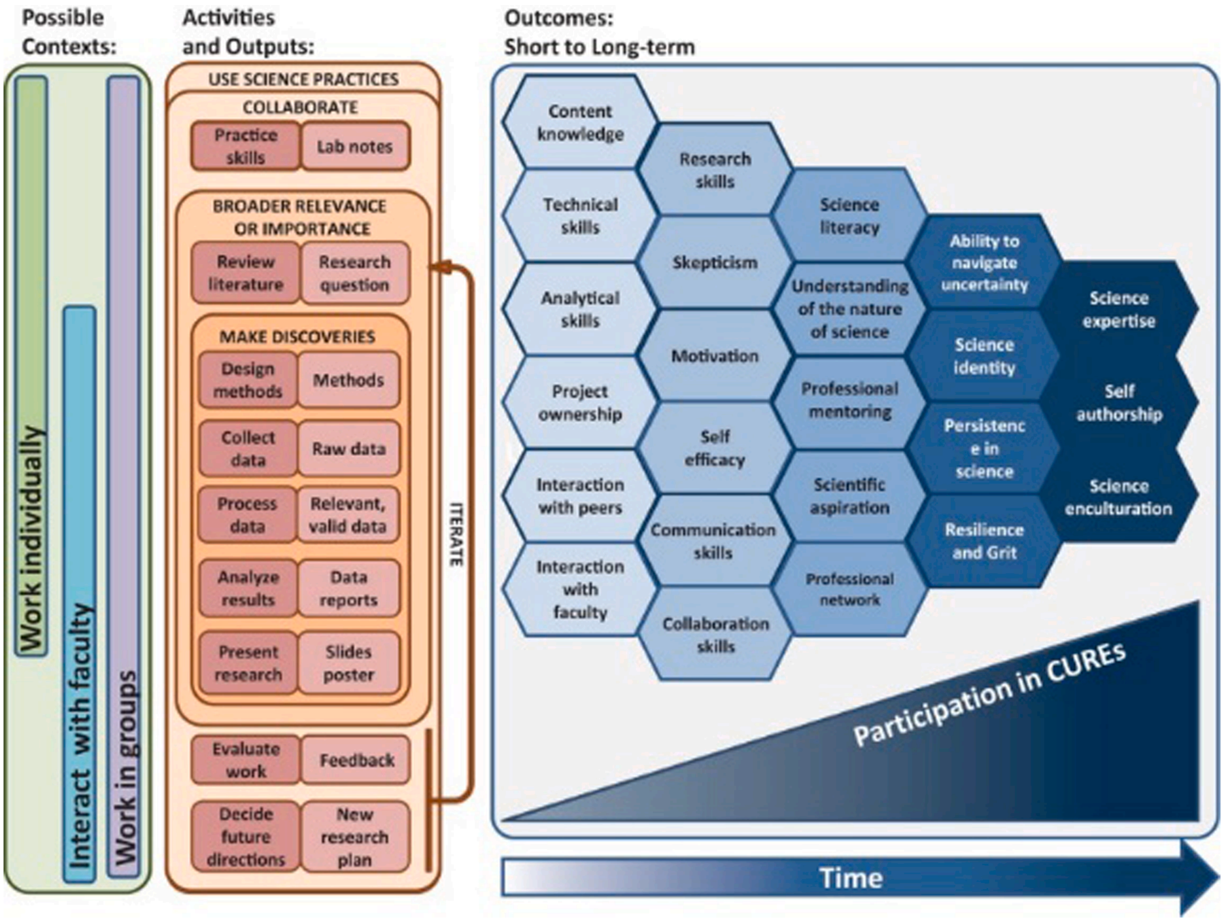


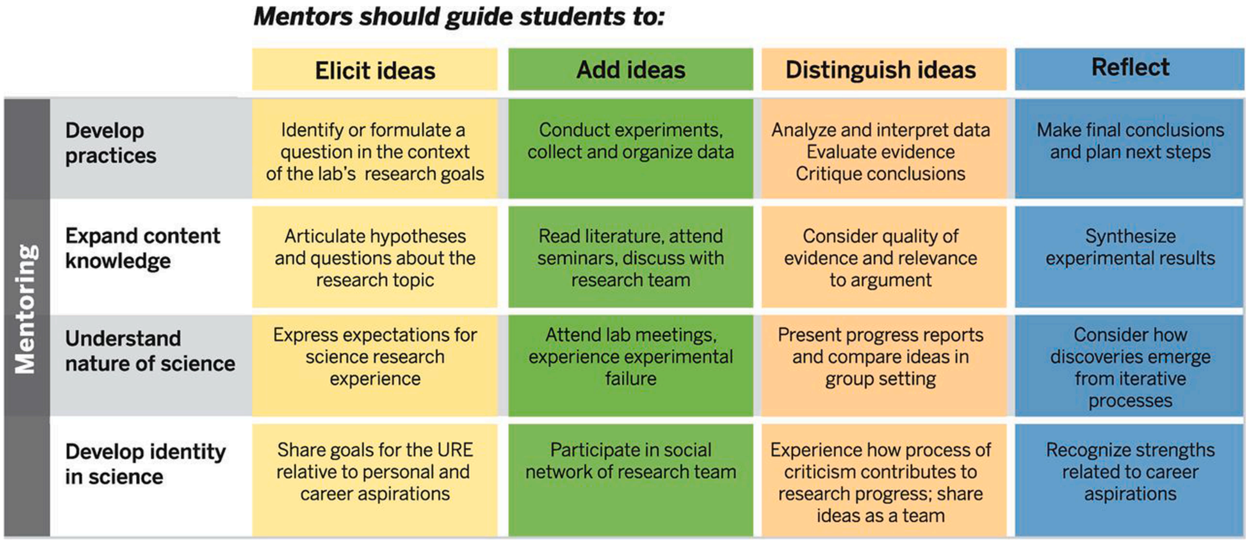
Fig. 2. Logic Model of CURE which Represents the Hypothetical Relation Between Time and Involvement in CUREs
Note. Adapted from "Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report" by Auchincloss et al., 2014, CBE—Life Sciences Education, 13(1), p. 29. Copyright 2014 by the American Society for Cell Biology.

contribute to a constructive relationship between the students and the research experience.

In contrast, for the traditional apprenticeship styled UREs the main factor which builds a similar constructive relationship is mentoring. This is because of the one-on-one mentor-mentee relationship in traditional UREs compared to the one-to-many configuration in CUREs. Therefore, mentoring deems to be an essential aspect for contemporary UREs. Moreover, though CURE participants indulge in scientific research and their efforts makeup to achieve the research goals, they generally do not partake in most of the crucial tasks that ascertain the deciding direction and scope of the research. For instance, in many CUREs, mentors perform the detrimental tasks of posing overarching research questions, which guides the participants towards high-yielding directions. Students then undertake much of the peripheral work of collecting and analyzing data to answer these research questions. Therefore, there seems to be a gap in students' scientific enculturation, which can be bridged by strengthening the mentor-mentee relationship. Students' success in UREs, especially in the STEM-related fields, depends prominently on the support structures (mentors) in place (National Academies of Sciences, 2017). Designers can use the characteristic features of the knowledge integration framework developed by (Linn et al., 2015) to evaluate the performance of UREs and subsequently improve them by stressing the mentoring provided to students (see Fig. 3). The main idea here is to promote a sense of scientific enculturation in students with the guidance of the mentors who orient them according to the research experience. The key enabling features of mentoring include developing practices, expanding the content knowledge, which leads to a greater understanding of science, and eventually developing a scientific identity. Each of these features needs to be implemented along with the motivation in students to evoke ideas, implement them, critically analyze them, and finally conclusively reflect on them. However, to successfully incorporate these elements in students, proportionally greater contact between mentor and mentee needs to be maintained. Incorporating such ideologies in students becomes practically difficult when there is inadequate exposure to successful mentors; a possible drawback of the CURE models which promote the one-mentor-to-many-mentee experience. This is another reason why designers propose the traditional apprenticeship-styled models, especially in the STEM-related disciplines. Traditional URE designers also claim their experiences to offer authentic research experiences, which are of utmost requirement in the practical applications of the STEM fields.

Moreover, various hybrid models offered in UREs are designed to impart the combined effects of the traditional and CURE models. Also, few other community-based and other informal URE models are administered to meet specific requirements of the undergraduate course and satisfy the determined interests of the students and faculty.

Table 3 summarizes the categories of the URE models studied in this review with the disciplines they have been implemented in, along with their concise strengths and limitations. The CURE model provides the opportunity to a larger population of students from a wide range of backgrounds. It is majorly focused on the life sciences field and needs more extensive research in the other disciplines. This is because undergraduate biology courses related to life sciences have a vast syllabus and portions to cover in limited periods of time. This often restrains the complete knowledge transfer between the classroom lectures and laboratory experiences, therefore disconnecting the link between theoretical and practical learning for the students. Hence, there is a high dependency on CUREs to bridge this gap. Implementing CUREs in such cases gives students a more encompassing and holistic approach to attribute their classroom concepts into hands-on research techniques. Thus, particularly in biology-related fields, CUREs can be highly effective in exposing undergraduate students to research, allowing students to engage intimately with the scientific discovery and process (Smith et al., 2021). However, other disciplinary areas in STEM have also employed CURE, but in limited numbers. For instance, (Al-Ghadhban et al., 2018) studied its effectiveness in the Engineering field (Wooten et al., 2018) in Astronomy (Pagano et al., 2018) in



Mentors should guide students to:

		Elicit ideas	Add ideas	Distinguish ideas	Reflect
Mentoring	**Develop practices**	Identify or formulate a question in the context of the lab's research goals	Conduct experiments, collect and organize data	Analyze and interpret data Evaluate evidence Critique conclusions	Make final conclusions and plan next steps
	Expand content knowledge	Articulate hypotheses and questions about the research topic	Read literature, attend seminars, discuss with research team	Consider quality of evidence and relevance to argument	Synthesize experimental results
	Understand nature of science	Express expectations for science research experience	Attend lab meetings, experience experimental failure	Present progress reports and compare ideas in group setting	Consider how discoveries emerge from iterative processes
	Develop identity in science	Share goals for the URE relative to personal and career aspirations	Participate in social network of research team	Experience how process of criticism contributes to research progress; share ideas as a team	Recognize strengths related to career aspirations

Fig. 3. Features of Mentorship for Knowledge Integration in UREs
Note. Adapted from "Undergraduate research experiences: Impacts and opportunities" by Linn et al., 2015, Science, 347, 627. Copyright 2015 by the American Association for the Advancement of Science.

chemistry, and (Rennhack et al., 2020) in the field of Physiology. All of them claimed positive implications of CURE and raised their call for researchers in respective disciplines to employ the CURE model due to its effectiveness.

Also, being comparatively a newer form of URE, there is room for more research in developing this model. On the contrary, the traditional UREs are directed towards the practical development of students and thus are claimed to be a more authentic research experience with better mentoring. But the limited student participation and lack of theoretical gains require extensive reformation. Lastly, the integrated and collaborative models of URE have limited research but have proved to impart the benefits of both CURE and traditional UREs. However, designers still must develop these models into more practical and easy forms so they can be implemented more often.

Discussing the costs involved in implementing UREs, few studies have reported CUREs to be less expensive than summer research programs, which adds to their appeal as a way to broaden access to research opportunities (Rodenbusch et al., 2016; Smith et al., 2021). The entire expenses of the CUREs indicated in literature is anticipated to be around $400 USD per student (Smith et al., 2021). These costs are relatively low compared to summer research internships where students are provided with lodging, facilities, and stipends. Therefore, given the low cost of CUREs and the absence of variation in self-reported outcomes, CUREs may be able to provide more undergraduate research opportunities. On the other hand, studies have reported CUREs to be more expensive than regular lab classes, though the reasons for this are unknown (Shortlidge et al., 2016; Spell et al., 2014). Nevertheless, CUREs have been described as having the potential to keep costs per student low by picking research projects that employ materials often used in standard lab courses, as well as using processes and materials that are less expensive (Dolan, 2016). To sum up, there is no documented cost comparison between CUREs, inquiry courses, and standard lab courses, which can be relied upon to conclude the cost effectiveness of CUREs with confidence.

5. Limitations

Although the studies offered deep insights into the effectiveness indicators of the model used on the students, research gaps remain. Most of the studies reviewed in this paper are based on the CURE learning models which are predominantly used in UREs of the last decade. Very few studies used hybrid and other integrated learning models. Secondly, most of the studies were published by universities and educators in the U.S., leaving the minimal emphasis on the different educational institutions worldwide. Thus, geographical limitations are apparent in this review. Many studies emphasize the importance of mentors and promote multiple mentee networks involving graduate students, postdocs, and teaching assistants. However, very little is reported and assessed on the guidance of these mentors to identify and professionally develop their mentoring practices. Strategies should be allocated for the support and encouragement of mentors for a harmonic mentor-mentee relationship and an effective URE program. Another limitation of the studies reviewed is the need for a better understanding of the expenses and budgets of the URE programs for capacity building, improving workforce diversity, and enhancement of human capital. Adequate focus and observation of the funds can be reported to aid other URE designers in implementing economic-friendly research experience programs.

6. Summary and Outlook

In this review of 67 different studies of URE learning models, we have compiled a detailed and comprehensive comparison and analysis of models implemented in various disciplinary fields of undergraduate education. However, most of the studies were published in the field of Biology, and most of the studies claimed the CURE model to be effective for UREs. Though a considerable number of studies favored the traditional URE models, and a few studies devised hybrid models to address specific challenges in contemporary undergraduate education. Greater studies conducted in CURE models are because of their emerging nature in well-developed countries. While the traditional UREs are well established in these regions, CUREs are deemed newer-generation models increasingly researched and sought to be implemented in disciplines related to the life sciences (Sun et al., 2020a). In biology-related fields, where lab courses had been a staple of the curriculum since inception, the UREs took the form of a “cookbook” procedure where students were obliged to a recipe to procure a known result (Brownell et al., 2013). In response to the call for reforms, a shift towards research-based curricula progressed to deploy CUREs which have succeeded and reformed biology UREs measurably better. Therefore, with the advent of many CUREs used in biology-related STEM fields, extensive educational research is also being practiced. However, CURE, the "new" URE model, is yet to be developed entirely in the other STEM fields. CURE combats traditional and lab-based research experiences to accommodate and provide expertise to a larger scale of the student population. It also fulfills the prerequisite for many graduate and internship programs, which require considerable research experience as a prerequisite. This inequity creates a ripple effect of competition among students, which further builds up their careers.

CUREs can be highly effective in exposing undergraduate students to research, allowing students to engage intimately with scientific discovery and process. However, other disciplinary areas in STEM have also employed CURE, but in limited numbers. All of them claimed positive implications of CURE and raised their call for researchers in respective disciplines to employ the CURE model due to its effectiveness.

Launching developed and well-funded research experience programs is crucial for culminating undergraduate students’ research culture and developing extensive and effective learning models in the STEM field. Faculty members should be aware of curriculum-friendly CUREs that can be easily implemented for undergraduate students. Also, universities and educational bodies need to implement the awareness of established local and national URE programs. Transformation of traditional UREs and internships into CUREs can create engagement for a broader range of participation from different undergraduate years, thus providing access to all undergraduate students. In particular, incorporating CUREs in students’ first- and second-year courses can provide intellectual benefits to our undergraduate communities and thus increase the persistence to pursue research experiences ahead in their careers. However, solely transforming the curriculum and pedagogy is not enough to assure widespread changes. Consequential resources need to be devoted to developing reliable and accessible research models. To progressively understand the influence of CUREs, STEM fields should adopt more common evaluation approaches in line with the components of the logic model defined in Fig. 2.

The specific assets, resources, interests, and limits of educational bodies, as well as those of individual mentors, influence the aims and structures of UREs. Overall, though institutions are demonstrating tremendous innovation in utilizing unique resources, repurposing existing facilities, and capitalizing on student excitement to expand research possibilities for their students, there is much room for development. In biology related disciplines, though CUREs provide the right logistical principles in place, time and money restrictions remain major roadblocks to their implementation (Shortlidge et al., 2016; Shortlidge & Brownell, 2016). To address these difficulties, cost-effective inquiry-based learning laboratory sessions need to be developed, and any subsequent student learning improvements can be utilized as leverage to expand the learning process into CUREs. Collaborations through large-scale CUREs that already have established resources and finance methods pose a potential research question for new educators. Further, in fields related to engineering, colleges need to investigate how to include and encourage more UREs in their campus programming to support the development of a diverse set of practical skills that will benefit students in the profession and in their personal life. Lastly, in the social sciences field, future research approaches include investigating instructors' experiences with planning and implementing UREs, using pre/post-test designs to analyze real (instead of perceived) student achievement results, examining the graduate experiences of students, and investigating how engagement in UREs influences student-mentor relationships.

The various pedagogical models discussed in this review are published from the U.S. and a minor portion from Australia and Canada. We found a very insignificant number of studies reported from the Middle Eastern region and none from the rest of the world, which points at a concerning research gap in the value of UREs. A significant factor for this deficiency could be the scarcity of research experience programs and awareness of their importance for undergraduate students. For instance, in the U.S., the reputation of URE is well established and widely recognized within universities, colleges and student groups due to the formulation of a particular program, "Research Experiences for Undergraduates (REU)" by the National Science Foundation (NSF) in 1987 (Zhan, 2014). Since then, tremendous efforts from the NSF-funded REU programs have led to more and more attention from educators extending its discussion in the literature. Therefore, the majority portion of URE studies reviewed in this article are from the U.S.

Comparison studies and reviews from the other parts of the world need to be made so that there is greater evidence to identify measures of research developments and construct a better research experience in their institution. Good measures should be tested across the universities in these regions to reciprocate the effective value of UREs. Finally, educators and institutions need to address the calls for more authentic research experiences for undergraduates with coordinated curriculum reforms.

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