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Review

Pedagogical Models to Implement Effective STEM Research Experience Programs in High School Students

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Abstract: High school research experience programs (HSREPs) provide opportunities for true science education and expose students to scientific investigations in laboratory settings. Various HSREPs models have been practiced to shape students' research understandings; however, a systematic comparison of the success, challenges, and opportunities of these HSREPs has not been gauged. This article compares the effectiveness of such science, technology, engineering, and mathematics (STEM) based HSREP models reported in the last two decades. We shortlisted seventeen studies on the most effective HSREPs and identified the characteristics of these reports. Results show that student research experiences vary depending on the structure of the model used and the nature of the laboratory setting to which students are exposed. However, there is a dire need to integrate more collaborative and customized research practices to accommodate more students in HSREPs. Additionally, intensive support, mentoring, and coaching are essential to provide students a comprehensive understanding to excel in their research career pathway. Finally, there is a desperate need for further studies to develop the frameworks that can help the smooth transition of high school students into research-oriented university programs.

Keywords: high school; research experience; STEM; scientific inquiry; educational reform

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1. Introduction

Research experience programs (REPs) are leading practices to expose students to scientific research [1]. In principle, REPs provide the students an understanding of the research phenomenon and improve their science knowledge [2]. It builds their research skills and develops critical thinking to analyze, disseminate, and efficiently solve problems. Typically, REPs are being accomplished at the university level; however, there has been a shift in the focus of REPs to the secondary and elementary schools since the last couple of decades [3,4]. High school provides the right time to invite students to join REPs, develop their more profound understanding of subject matters, and integrate their personal and social skills through collaborative and independent research. HSREPs contribute to their intellectual and professional growth and conceptual knowledge and instigate a scientific-thinking mindset. This way, students experience the exploration process of their interests and can be exposed to potential career opportunities in research-oriented fields [5]. Additionally, pre-college research experiences deem to improve the research self-efficacy of students, enhancing their interests' and confidence in conducting research during college [6,7].

When students are introduced to research experience, they understand the inquiry process, problem-solving skills, data collection procedures, and observation processes to draw research findings. The inquiry process reflects the activities, conceptual demands, and values of "authentic science" [8]. The students are indulged in formulating research questions, developing scientific inquiry, and practical understanding of science concepts. However, the REPs are not globally standardized, and studies depict differences across international practices [9,10]. For instance, inquiry-based education incorporates more "hands-on" practices elements and is not frequently "minds-on." The meagerness of established goals in inquiry processes limits the authenticity of a research experience (RE). At the same time, the stress on educating high-stakes standardized tests has diverted the attention away from lab-based investigations. Hence, states have tried to incorporate authentic research practices in secondary education to engage students in effective knowledge-based education [11,12]. In Australia, educators have worked to substitute purposeful contexts in chemistry to create an independent and extended experimentation environment in students. In Germany, pre-experimental activities created opportunities for students to formulate relevant research questions and designs. In the UK, the national curriculum has prioritized the research investigation in school sciences.

Scholars have also recognized that a collaborative environment is necessary to make up an authentic RE to cultivate learning and endurance in science, technology, engineering, and mathematics (STEM) research [13,14]. They have incorporated science epistemology in their program through students, mentors, and researchers' collaboration. Providing students with self-learning mechanisms allows them to focus on collaborative practices in processes of interactions, social support, and task performances [15]. Educators stress the importance of social contexts as a predictor of student learning as well. In particular, the extent to which the research experience is integrated into the school's culture and curriculum may be important. Such an integrated STEM-based program has a notable effect on the quality of the mentor-mentee relationships, an important variable for the learning outcomes associated with authentic research experiences [16]. This mutual engagement encourages recognition in participants involving them in sustained collaborative relationships where ideas, perceptions, and responsibility propagates the research group's functionality.

This study aims to assess the impact of various STEM-based HSREP models on students using a systematic review of the literature. The study covers the chief characteristics, methodologies, and strategies used to implement HSREPs and provide an outlook on the potential benefits as well as the challenges faced to impact the scientific development of secondary education students. We believe that this study will assist other designers and educationists in understanding, planning, and deploying the pedagogical values of STEM-based REs in high school education.

2. Method

2.1. Literature Search

The present study was performed as a systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [17]. We identified bibliographic documents with proposed learning models for HSREPs claiming their effective relation to students' performance through web searches from the online databases of Scopus, ERIC (Education Resources Information Center), and Web of Science. These databases were chosen because of their international recognition, central knowledge in the educational field, and specific content in terms of educational research. In this sense, the resources fulfill the broad coverage criterion and show an optimum database combination. After running trial searchers, the final concluding search was performed in September 2021. Our search query was set up in the following way: (("research experience" OR "research opportunities") AND ("high school" OR "secondary education") AND ("learning model" OR "model" OR "design" OR "type" OR "method" OR "framework")). The search collected all studies where the search query was met in the title, abstract, or keywords of the articles. The search period was not restricted to any time frame. The Scopus and ERIC directory resulted in 184 and 382 hits, respectively, while Web of Science returned 58 hits. In addition, we also used the snowballing method and other external resources like Google Scholar and ResearchGate to identify relevant studies. In total, 634 articles were found.

2.2. Inclusion and Evaluation of Studies

Subsequent screening of studies was required to include only relevant and concise reports. Figure 1 shows the stepwise filtering of the search procedure. The articles qualifying the search strategy were retrieved from the data sources and their abstract and conclusion were carefully examined. To comply with our inclusion criteria, studies had to meet the following: (a) be published in a peer-reviewed journal in the English language; (b) report a structurally devised pedagogical "research oriented" model for high school students; (c) clearly describe the distinguished features of the model; and (d) indicate the effectual aspects of the model features on the students' development. The above-stated conditions were considered for the initial screening of the studies. A provisional candidature of 97 publications was obtained during the initial preliminary screening based on the inclusion criteria. Concerning the exclusion criteria, we scrutinized for the following: (a) absence of a research-oriented methodology of the learning model; (b) review articles and reports with non-quasi experimental procedures; (c) studies with non-traditional and underrepresented student populations; (d) articles focused on other variables like teacher's experience, student disabilities, non-relevant environmental, and other social or cultural factors. Such bibliographies were eliminated.

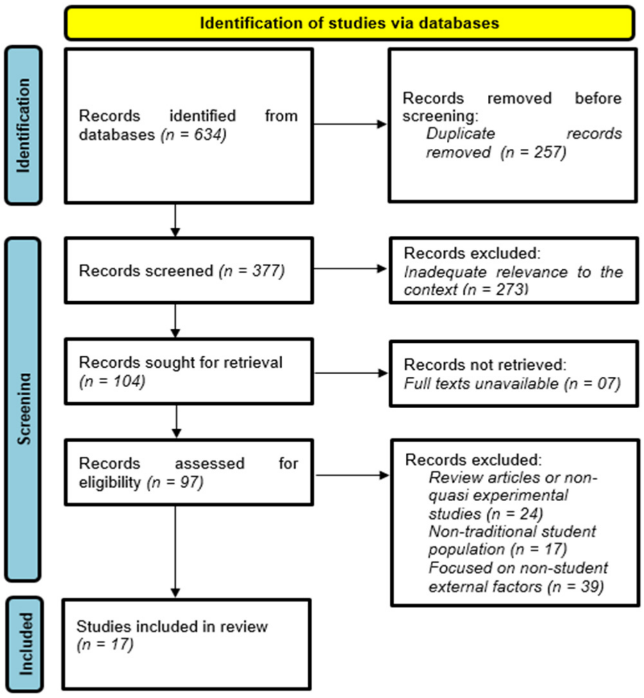

Figure 1. PRISMA flowchart of the search and inclusion process of the literature.

Further, these articles were retrieved from online libraries and precisely studied by extracting their descriptive findings (aim, method, population, results). Finally, the authors performed a concluding selection with careful consideration, which finalized 17 studies for this review. These selected publications met all the inclusion and exclusion criteria (see Figure 1). Table 1 provides the highlights of the eligible studies based on seven notable features: (a) author(s), (b) model design, (c) type of study, (d) population, (e) model effectiveness indicator, (f) outcomes of the study, and (g) country of publication (see Table 1). These articles were analyzed based on the quality of their findings and effectiveness by highlighting the thematic aspects like the specialty of the learning model in their approach, and its correlating outcomes on the efficacy of the student learning process. Thus, this methodological review gives a comprehensive understanding of the various strategies used for high school students to effectively expose them to scientific STEM research.

Table 1. Studies of various learning models for HSREPs, proposed in the research literature.

Authors	Model Design	Type of Study	Population	Model Specialty	Outcomes	Country
1. Lewis et al. [18]	Summer Apprenticeship	Likert-scale assessments	$N = 7$	Career exploration and mentoring	Exposure to a true research environment	USA
2. Sikes and Schwartz-Bloom [19]	Inquiry-based Summer Course	Pre and post-assessments	$N = 47$	5E Model: Engage, Explore, Explain, Elaborate and Evaluate	Gains in knowledge and interest in science	USA
3. Otterstetter et al. [20]	Collaborative laboratory experience	Survey	$N = 26$	An experiential introduction to science	Cooperative learning and career exposure	USA
4. Brooks et al. [21]	Collaborative authentic research	-	-	The partnership between high school students, teachers, and scientists	Understand the nature and process of science	USA
5. Duggan et al. [22]	Summer Research Program	Survey	$N = 414$	Authentic summer research experience increased awareness of STEM careers	Self-efficacy in STEM enhances national STEM capacity	USA
6. Flowers et al. [23]	Introductory field-skills training	Pre and post-assessments	$N = 121$	Scientific exploration and assisting scientists in fieldwork	Scientific enculturation, realistic view of science, and increased confidence	USA
7. Flowers et al. [23]	Advanced field-research internship	Pre and post-assessments	$N = 51$	Extended work experience and scientific communication training	A strong connection between experience and understanding	USA
8. Shoemaker et al. [24]	Mentorship-based research	Pre and post-assessments	$N = 80$	Develop professionalism, career orientation towards STEM	Real-world environment, experience with professionals	USA
9. Gong and Mohlhenrich [25]	Integrated STEM Research	Survey	$N = 44$	Integrate research program into school culture	Understanding the nature of science, part of the scientific community, affinity towards STEM	USA
10. Wang et al. [26]	Research Camp	Survey and interview	$N = 9$	Project-based learning and constructivism theory	Understanding of STEM topics, real-world applications	USA
11. Leuenberger et al. [27]	Field-based experiential learning	Questionnaire	-	Investigate science and experience authentic research	Developed scientific reasoning and experimental technique	USA
12. Oakes et al. [28]	Summer Program	Pre and post-assessments	$N = 10$	Integrate research and education with technological innovation	Knowledge of research and industry, ability to read and use scientific literature	USA
13. Petersen and Chan [29]	Collaborative and Inquiry-based authentic research	Pre and post-assessments	$N = 54$	Collaboration between high school students and community college	Confidence in scientific ability, student engagement, interest in STEM	USA
14. Gong and Mohlhenrich [30]	STEM Research Program	Survey	$N = 330$	Thinking and working like a scientist, gains, and behavior as a researcher	Significant gains in research skills and understanding	China and USA
15. Corson et al. [31]	Virtual Summer Research Experience	Pre and post-assessments	-	Exposure to research, inspiration towards further studies, and networking	Greater appreciation for research, in-depth study, and ethical gains in research conduct	USA
16. Kahn et al. [32]	Summer Enhancement Program	Survey questionnaire	$N = 25$	Strengthen research capabilities and introduce them to future careers	Engagement in research and enhanced knowledge	USA
17. Deemer et al. [15]	Summer Science Program	Survey	$N = 200$	STEM enrichment as authentic research	Increased motivation, retention in STEM, and socialization	USA

3. Results

STEM education is becoming vital to the modern economy and attained much attention from educators and policymakers, in recent years. Increased consideration is being given to impart the pedagogical values of STEM education through research experience programs in secondary education. This is being incorporated through research apprenticeships, summer camps, exposing high school students to university students, and other school-based programs. Such research studies can be classified into two categories: (a) summer research experience models and (b) collaborative and other informal models. This section presents a comprehensive review of these studies and reports on STEM based HSREPs and their key features proposed in the literature. It also discusses the distinct characteristics of both types of models and their correlational effects on student performances.

3.1. Summer Research Experience Models

The summer research experience models are further classified into the following four categories.

3.1.1. Extended Duration SREPs

Gong and Mohlhenrich [30] performed survey on school-based summer research experiences from two countries, the USA and China. Their study reported significant gains on variables that report the positive students' experience and their development through Summer Research Experience Programs (SREPs). These performance indicators included gains in thinking and working like a scientist, personal development, skill development, attitude as a researcher, and aspiration for future career education. Their study also discussed that when high school students indulge in research practices, they should be expected to self-direct their research and perform the stages of inquiry and research individually. Such individual nature of SREPs positively affects their sense of ownership and autonomous nature of carrying out the research process. Another important factor is the duration of the SREPs. Studies have confirmed that the length of the programs considerably affects the learning outcomes in students [25,33,34]. With a long duration of experiences, students can experience authentic research offering multiple iterations of the scientific method, thereby building a diversity of skills in students. However, engaging students in long durations also challenges maintaining their interests and concentration throughout the research program.

3.1.2. Mentorship Focused SREPs

All REs have a common aim to engage the students in hands-on experiences and scientifically develop their skills. Oakes et al. [28] developed a summer research program where graduate fellows mentored high school students. The students and their mentors created a literature review, followed by a research abstract, and finally shared their posters at respective institutions. Such a graduate mentored program helped the secondary students to learn about research resources available on campus, thereby becoming familiar with the campus and the industry. Their pre and post-survey results indicated significant gains in participant confidence in communicating about science and education, understanding the use of scientific literature, and designing experiments.

Similarly, Duggan et al. [22] conducted a summer research program to ensure that high school students with proficiency in STEM get the opportunity to partake in a comprehensive RE. The participating students were aided with mentorship from collaborative teams of faculty, graduate, and undergraduate students. This vertical mentoring process gives adequate guidance and knowledge to the secondary students even after completing the program. Thus, participants gain trust and confidence in STEM fields in addition to their research and scientific abilities. Moreover, such mentorship builds an environment of social engagement in students, which sustains long-term relationships between them and the mentors. This program increased self-efficacy, research interest, and STEM interest in high school students, expanding the established STEM community to enhance the national STEM capacity. Another similar six-week summer model was proposed by Wang et al. [26] to provide high school students a better knowledge of the research process and improve their scientific skills, STEM interests, and equip them to meet the 21st-century skill requirements. Their study reported significant gains in student interests in research and highlighted their motivation to apply the acquired research skills for future learning. Further, [15] established a rigorous STEM enrichment through a SREP among high school students. Results indicated that the program significantly increased the participants' research motivation, competence, retention, and identification with the STEM community.

3.1.3. Inquiry-Driven Real-World SREPs

Sikes and Schwartz-Bloom [19] conducted an inquiry-based science enrichment program to increase the competence of high school students in biology and chemistry, fostering their interests in science careers. Their summer research model followed a 5E (Engage, Explore, Explain, Elaborate, and Evaluate) learning paradigm to provide students with a framework that encourages them to explore controversial topics in detail. This incites a sense of curiosity in students and therefore boosts their interest in learning about the subject. Further, students are guided to extend their knowledge to plan and research an original research question. This enrichment program showed significant gains in high school students' knowledge in biology and chemistry and motivated them to pursue careers in science. Some of the students were even successful in earning honors for their research in regional state fairs. This approach for original research coupled with college-level coursework in high school students enhanced their enthusiasm and success rate in science.

Similarly, Lewis et al. [18] conducted small-group apprenticeships for secondary-level students in biotechnology to provoke student participation in active research projects. Students worked in skilled teams within interdisciplinary fields to present a real-world RE. Their course design provided an opportunity for career exploration and scientific enculturation of the students. The students were able to produce helpful research information equipped with modern techniques by the end of the summer program.

Flowers et al. [23] presented a study examining two consecutive dual-staged career exploration apprenticeship models designed to convey real-world practices and connections to a research career. The initial model offered introductory field-skills training to the 10th and 11th-grade students to engage in scientific exploration at a nature reserve. This way, students were encouraged to step into the environmental research career and clarify their thinking about the scientific research pathway. The students that partook in this program gained a more realistic understanding of the research fieldwork, and, thus, awareness was created amongst the participants about the certain monotonous aspects of the research process. Additionally, students were exposed to professional scientists in mentoring them to apply the basic field skills to actual research leading to a high level of interest in the fieldwork. The graduates of this model were provided with a second consecutive model offering a more advanced field research internship program, competitively selected during their 11th and 12th grades. This time participants were immersed in a research study with university-based research teams and were mentored to perform real research experiments to develop scientific posters. Students were found to have increased confidence levels over time, a deeper understanding of subject matters, and career benefits indicative of a stronger dedication to pursue a research career. This two-stage model reportedly features the characteristic qualities of scientific communities with practices that reproduce themselves successfully. In both models, the students are trained with opportunities to assist professional researchers with one-on-one hands-on experiences. A similar field-based experiential learning model (Leuenberger et al., 2019) was implemented to engross students in a practical inquiry-based scientific process. Simple experiments were developed to demonstrate ecological practices among high school students, providing opportunities to investigate the nature of science and drive integrative scientific approaches like scientific method and inquiry. The students involved gained the ability to develop a hypothesis, scientific reasoning, practical skills, and experiential techniques.

3.1.4. Virtual SREPs

Since the novel coronavirus (COVID-19) outbreak in 2019, the subsequent pandemic posed a distinct challenge for summer research programs. In particular, due to the social distancing and other COVID-19 protocols, research programs directed towards hands-on experiences were not feasible to be held physically. This led many educationists and authorities to devise virtual RE models to continue the smooth functioning of practical apprenticeships and summer internships. One such study was modeled by Corson et al. [31], incorporating research practices in students through digital and online means. Their self-reported student and mentor results suggested a high degree of satisfaction with the virtual program. One unique advantage of such a model was that it offered a chance for meaningful engagement of students who were previously hindered from participating in research due to limited mobility. Similarly, Kahn et al. [32] formulated a supportive environment for online instruction and developed adaptions to the research program with collaborative and holistic approaches, implicating a meaningful RE to students in a remote manner. The physical connections were overcome by building social engagement between students, instructors, and mentors with frequent meetings and decision-making strategies. Such virtual format SREPs can turn out to be effective means of engagement for high school students and seed the development of their scientific identity. Mainly, virtual SREPs hold the potential to lay out new avenues for high schoolers that might have not experienced a full SREP, including students with household and work responsibilities, students in remote and distant places, and students possessing disabilities.

3.2. Collaborative and Other Informal Models

It is well known from the literature, as discussed previously, that authentic REs for high school students have been deemed effective to achieve STEM learning goals, including knowledge of the subject matter, research capabilities, intellectual development, and influence on future career aspirations [8,35]. These developmental effects can be cultivated in high school students through school-based STEM programs, which come in different forms having organizational factors which affect the pedagogical quality of the experience. In other words, the extent to which the research program is integrated into the school curriculum and design is highly crucial for its productivity. This can be executed through collaborations with scientists, universities, and mentors. This partnership provokes a more authentic research environment and helps students to understand the nature of scientific processes. Additionally, simple teacher-led demonstrations of research activities in classrooms and labs have predictable outcomes, thus falling short of the discovery process through iteration practices. Therefore, HSREP models require a structure for students to participate in a complete research process that can achieve unknown outcomes with inquiry-based learning. One such model was formulated by Brooks et al. [21], which involved a collaborative model with scientists to engage students in a large-scale research project. Their study allowed teachers and students to move away from traditional "cookbook" practices and provided the means to expose students to novel practices in research. In the process, students are guided to formulate testable hypotheses individually and make logical connections with their research project. One of the high school students discovered a novel finding that contributed to a research publication. Therefore, students, teachers, and the scientific community can benefit from collaborations like these by opening opportunities for each other and covering up the gaps in their positions.

Another collaborative model was implemented by Otterstetter et al. [20], fostering collaboration between various entities, including faculty members, graduate, undergraduate, and high school students and professionals. They reported that such a diverse network of cooperation increases the effectiveness of mentorship, leadership, and knowledge-based opportunities for all the students. However, successful implementations of such models require careful strategic planning with sound protocols to ensure the smooth administration between the different entities. Similarly, Petersen and Chan [29] suggested a partnership model between a community college professor and high school students along with the school faculty implement authentic practices in students' application of knowledge and experimental designs. The results showed a positive indication with many students motivated to pursue science-based careers and most expressed confidence in their ability to perform scientific practices. Such collaborative models are a cure for various issues educators face in HSREPs, including inadequate funding and lack of laboratory training and resources. Forming collaborative ties with academic institutes, professional scientists and college students can help alleviate some of these barriers. Additionally, institute entities and specialists can work well with school faculty members to adequately design learning approaches that are age-appropriate to the high school students.

For building the STEM careers of students, careful mentorship contributes majorly to develop skills and essential professional practices leading to their bright careers. Shoemaker et al. [24] stressed these criteria and developed a mentorship program that pushes students to take leading roles in performing research with scholars and professionals from collaborating universities or corporations. Their proposed ideology is that students should seek mentors with similar interests from partner institutions to collaborate in their REs. This emphasis on experiential learning opens the opportunity for high school students to develop soft skills like resourcefulness, teamwork, and communication and invokes responsibility to fulfill their desired goals. As a result, a synergistic learning process was formed between mentors and students, with each entity having its shared benefits. At the national level, demonstrations of student talent in various academic and professional corporations highlighted the value of schools' education.

The majority of the learning models reviewed in this study are a few weeks or a couple of months long. One study by Gong and Mohlhenrich [25] reported a two-year, on-campus research project for high school students in the field of their selection. The program's increased duration offered students a vital aspect of the scientific method by performing multiple iterations and in-depth understanding of the process. Moreover, the program demonstrated that STEM integration of an effective research experience also requires other requisitions such as the length of the program, whether participation is required or not, and the number of disciplinary fields in which students can pursue the research. However, one disadvantage that lengthy durations carry is keeping the consistent level of student engagement throughout the program. Moreover, the overall results of such a model were reported to be compatible with the learning goals of STEM REs. Self-report gains of the participants included practical research skills, ability to work like a scientist, incitement to pursue a STEM career, and feeling of being part of the scientific community. The critical takeaway from all these integrated and collaborative models is that establishing and assessing how different HSREPs' design affects student performance and participation needs urgent attention. The diverse range of HSREPs makes it difficult to categorize all the models methodologically. However, the critical dimension remains to understand the degree of integration of the program with the school's module.

4. Discussion

The involvement of high school students in inquiry-driven hands-on experiences provides the critical aspects of their understanding of science. The learning process, particularly when subjected to student ownership, engages students in effective knowledge retention, motivating them towards research [36,37]. SREPs tend to effectively expose these features in their experiences in the models mentioned above, making it one of the most common models implemented in high schools. When students are made to follow authentic research practices, it incites a true feeling of a scientist in them. When the scientific process follows step-by-step, the students begin asking questions to reach fruitful conclusions.

Moreover, by the end of the research activity, their desire for considering future research is well established. As experiments are filled with curiosity, they raise new questions and assist students in thinking about what they can do differently to improve their research. This leads to the development of hypothetical continuation in young students where they hypothesize new questions and combat with ways to test their theories. Hence, a complete research process is implemented, and students gain a thorough understanding of real-world research practices. Another main advantage of SREP is its non-classroom nature which adheres to the importance of extracurricular activities in students. The working instructional model developed by Sikes and Schwartz-Bloom [19] embraces this fact by following a standard 5E (Engage, Explore, Explain, Elaborate, and Evaluate) learning cycle (see Figure 2). Through this paradigm, students extend their learning process beyond the classroom boundaries, gaining more independence in the research and inquiry process. Different studies also verify this aspect and specifically demonstrate this effect on STEM students [38,39]. The majority of the students who showcase strong talent and dedication towards STEM indicate that the reason behind their increased affinity towards STEM is due to non-classroom experiences with extracurricular activities, science fairs, hands-on experiments, nature, astronomy, and so on. Thus, a constructivist learning model like the mentioned above acts as an influential science enrichment program by integrating student exposure to scientific careers in a professional research ambience. Additionally, such a direct involvement by the scientific community in secondary education could help to attract a larger population of students choosing a science career for their higher studies [40,41].

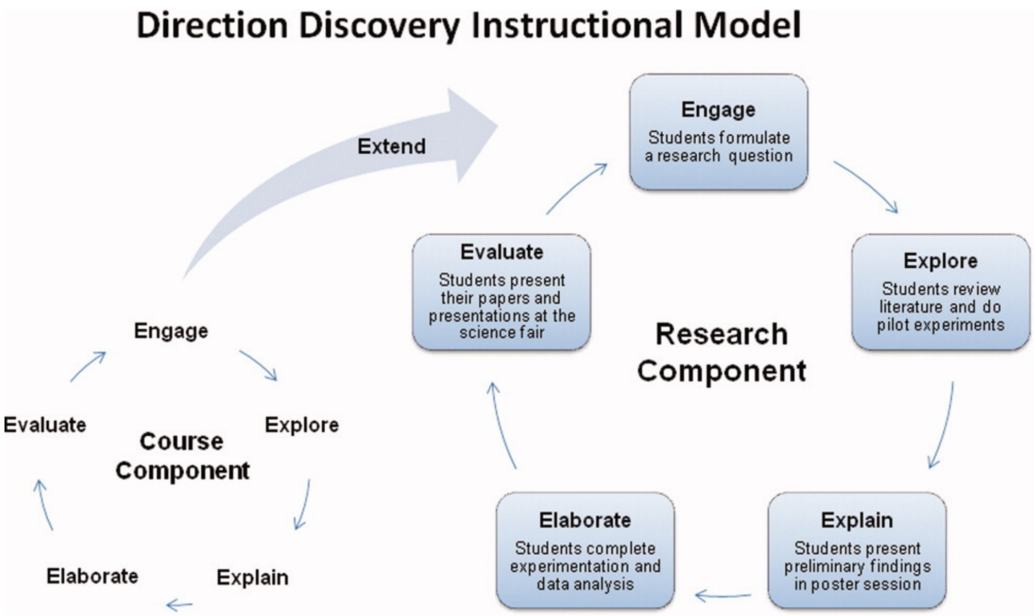

Figure 2. The 5E learning cycle including a course and a research component. The former is performed as an intensive summer course, and the latter takes the form of mentored research project in the following academic year. Reproduced with permission from [19]. Copyright Elsevier, 2009.

In one study by Tai et al. [41], students who pursued research apprenticeships during their high school period were found to have a strong positive correlation to their careers in MD/PhD programs. In fact, the study reported that respondents reporting research exposure in both high school and college time periods were more than four times more likely to pursue MD/PhD program than their peers who never participated in an REP. Figure 3 represents the graphical representation of the estimated probabilities for four sets of categories differing in their REs: (a) Respondents with both high school (HS) and college laboratory research apprenticeship (LRA), (b) Respondents with only HS-LRA, (c) Respondents with only college LRA, and (d) Respondents with no LRA experience. It is clearly noticed that having a LRA significantly affects the persuasion of a doctorate degree. Moreover, in the graph, the area between the curve for both HS and college LRA and only college LRA indicates the important "added value" of HS-LRAs. However, it should be noted here that the level of academic achievement shown in the graph is measured concerning the first attempt score of the respondent in the Medical College Admission Test (MCAT), which provides a measure of their academic performance. This study provides crucial importance of HSREPs, proving that the combined benefits of HS-LRA and college LRA experiences are more effective than only college LRA experiences. Thus, students performing research perceive to show more sophisticated learning processes in STEM fields and are more creative and scientific in their approach towards research. Moreover, the significance of such programs exemplifies the enhancement in high school students' interest in the scientific research process. Their participation in authentic hands-on research experiences could help them develop a cognitive scheme for a research career. In particular, such programs become highly crucial for the students who do not have regular exposure to individuals possessing a STEM background. This is because secondary students get the opportunity to hear success stories directly from those who have experienced research practices before. Therefore, by offering students precollege research experiences, young students can be given enough time, resources, and exposure to gain their research identity and prepare the necessary academic background required for success.

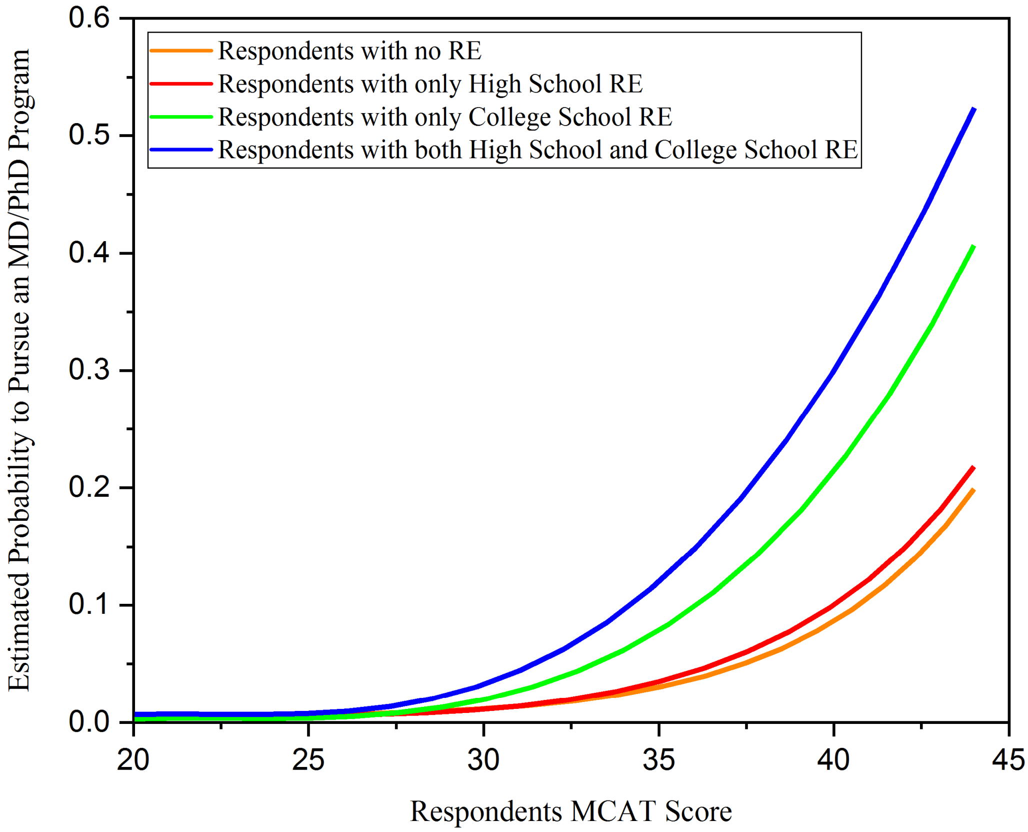

Figure 3. The fitted probabilities of respondents pursuing an MD/PhD program with respect to their Medical College Admission Test (MCAT) scores. Reproduced with permission from [41]. Copyright The American Society for Cell Biology, 2017.

Science pedagogy which is dependent on monotonous learning activities and traditional "cookbook" procedures can contribute to science identity development; still, there is a dire need for authentic REs in today's competitive world which provide a unique self-concept in the student's mind. Research identity thus should be focused more on the authentic practices in HSREPs because these experiences create an understanding of science's novelty and meaningful aspects. The studies discussed in this view, which stick to authentic practices, hint that the participating students perceive a robust increase in their potential to grasp research literacy. This gives the students more personal control over their research individually and allows them to use proper techniques to interpret and understand the research process. Additionally, in authentic research practices in STEM fields, it is recommended to provide students with prior STEM knowledge before entering the program. This way students can be smoothly transitioned towards challenging and complex research practices, eventually refining their skills.

While contemporary SREPs highlight the importance of incorporating authentic REs, educationists have also pioneered collaborative models to strengthen few potent aspects of research. For instance, the necessity of solid mentorship in REs is vital for an enhanced and rightly guided experience for students. The right mentorship allows students to explore their true interests and passion in the subject field. It focuses on their professional skill development during the experience, and in particular: (a) curiosity towards research, (b) ownership and responsibility, (c) ability to accept failure, (d) scientific literacy, (e) professional ethics, (f) collaboration, and (g) real-world consciousness [24]. Thus, mentors can help to create the perfect ground for the evolution of the students into being part of the scientific community. Collaborative models which reinforce the concept of strong mentorship layout frameworks act as a gateway for students to discover their true position and interests in the research field. A guided framework presented by Shoemaker et al. [24] outlines the crucial aspects that students should carefully consider when taking up research practices that best suit their needs and interests. Students should comprehensively understand these essential factors for deciding their research pathway, which include: (a) identifying the discipline of interest, (b) the right timing to start the research, (c) the entry choice of research program (competitive or non-competitive), (d) the goals to accomplish by the research experience, (e) extent of efforts and commitments, and (f) the extent of time they would dedicate to the research. If students structure their entry into research with this mindset, it nurtures their seriousness about research. In addition, it matures them for future academic or corporate sites by exposing them to professionalism and increases their efficacy in STEM learning. Additionally, students who engage in high school opportunities show a robust positive correlation towards pursuing a future STEM degree [42–45]. However, there are limitations faced by collaborative models to implement a highly self-sustainable and effective HSREP meeting all the demands and requirements of a RE. Availability of research-oriented faculty and staff at high schools, along with the costs associated with their training, transportation, resources, and essential logistics, can be a barrier to their efficacy. Establishing an ample human resource of potential mentors to provide research mentorship to students can work best to offer multiple schools and universities within a small-scale location.

The integrated STEM-based HSREPs provide a distinct possibility to influence the socio-cultural values of the school community directly. For instance, the study by Gong and Mohlhenrich [25] found out that their integrated model enabled a unique culture to arise in the high school practices where the investigation and discovery process was highly valued. They observed that this newly emerged culture of research initiated a constructive feedback cycle among the students, enhancing the RE's learning efficacy. Research at the school became more acknowledged and valued. Students showed high levels of motivation to engage themselves in research practices, thus creating a more authentic and meaningful research environment. Therefore, it can be correlated that the culture of research very likely shapes the attitudes and beliefs of self-efficacy among students up to some degree. Moreover, HSREPs need to create a sense of tradition through their programs and stress imparting the significant unique values of research practices in the scientific processes. This is crucial also because when facilitating early access to STEM careers, students should be fostered with persistence and exposed to making strong connections with fellow researchers and mentors [46]. This view connects well with our previous stance on the importance of mentorship in research practices. Therefore, collaborative and integrated models act as a solid backbone to build the professional research community within young scientists exposing them to the STEM career pathway. Lastly, though the benefits of all the models discussed in this review are positive, there is much room for more models to be developed and implemented for high school research.

5. Limitations and Outlook

The discussion presented in this review is limited to a theoretical description (neither precise nor scientific) of the HSREPs reported in the literature. This is because many of the reported studies were performed on relatively small student populations and thus cannot be relied on to make concrete conclusions. This exhibits a pressing need for further studies to experiment on larger student audiences. Additionally, the learning models should be devised in a manner to encourage more students towards research practices, providing more incredible benefits to the educational society. Highly integrated and supportive models for high schoolers need to be reformed to help students decide their research career pathways, inciting their passion for the subject matter.

Moreover, in many countries, STEM-based HSREPs are integrated into classroom experiences through school projects, competitions, workshops of educational administrations, and even curricular subjects. Consequently, many such experiences are unreported, and not much emphasis has been placed on standardizing such REs into systematic research programs at a regional or international level. However, most of the standard HSREPs reported in the literature are from the USA, and thus this review focuses only on such authentic experiences. Therefore, the discussions and conclusions do not certainly apply to the rest of the scientific community.

Some of the studies show an over-reliance on self-reported data. This poses a challenge to synthesize their collective evidence and make concise conclusions on their impact and efficacy. Hence, more work is needed to improve the quality of evidence and establish clear potential benefits of HSREPs in school curriculums. Most importantly, studies should strengthen their claims by using experimental or quasi-experimental designs in their analyses. Data reliability can be increased by deploying control and intervention groups in the study designs. More diligence can be introduced in studies by enabling broader student populations and multiple data sources for reporting student performance. Considerable efforts should be made to use the existing and validated instruments to collect data, thereby building a more coherent evidence base.

6. Conclusions

This review provides insight into the various pedagogical frameworks used for the STEM research experience programs in high schools. It discusses their implications and critical features that impact the student's scientific development. The aim of this review is to gauge the success, challenges, and opportunities of these HSREPs focusing on their effective planning, integration, and influence on high school students. For this, shortlisting criteria were followed to extract relevant from online databases. After their careful examination, the studies were grouped based on their key features and comprehensively studied.

The majority of the studies assessed in this article adhere to the summer version of Research Experience Programs (REPs) which provides a more feasible model for high school students. However, there is diversity in the conceptualization and execution within all the reported programs. While Summer Research Experience Programs (SREPs) offer authentic research practices in students and focus on the overall development of students, collaborative models have been successful in achieving STEM literacy by stressing specific features of research like mentorship, integration, collaboration, and experiential learning. Additionally, integrating school-based STEM research programs into the school culture presents a viable methodology to involve high school students in authentic research experiences.

To sum up, more distinct studies should be performed with customized learning models that can serve students' scientific development apart from the summer models. There seems to exist a lack of reinforcement for schools in offering REPs to students. Authorities and educationists are required to encourage the schools to launch more REPs, and this can reveal unique indications for more effective and sustainable pedagogies that mature students in different aspects of scientific learning.

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