Effective STEM Research Experience Programs for High Schools

Subjects: Education & Educational Research | Education, Scientific Disciplines

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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 entry compares the effectiveness of such science, technology, engineering, and mathematics (STEM) based HSREP models reported in the last two decades.

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

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. High school research experience programs (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.

2. Current Insights

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 [17][18]. Summer research experience programs (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 1**). 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 [20][21]. 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 [22][23].

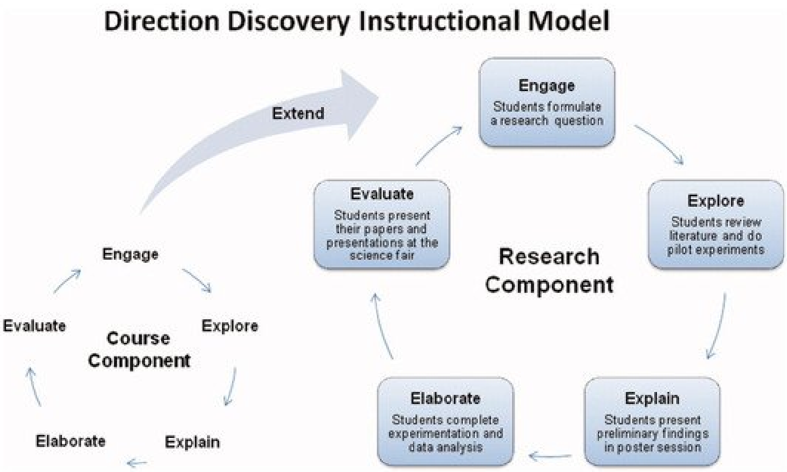

Figure 1. The 5E learning cycle including a course and a research component. The former is performed as an intensive summer course, and the latter takes the form of mentored research project in the following academic year. Reproduced with permission from [19]. Copyright Elsevier, 2009.

In one study by Tai et al. [23], 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 2** 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.

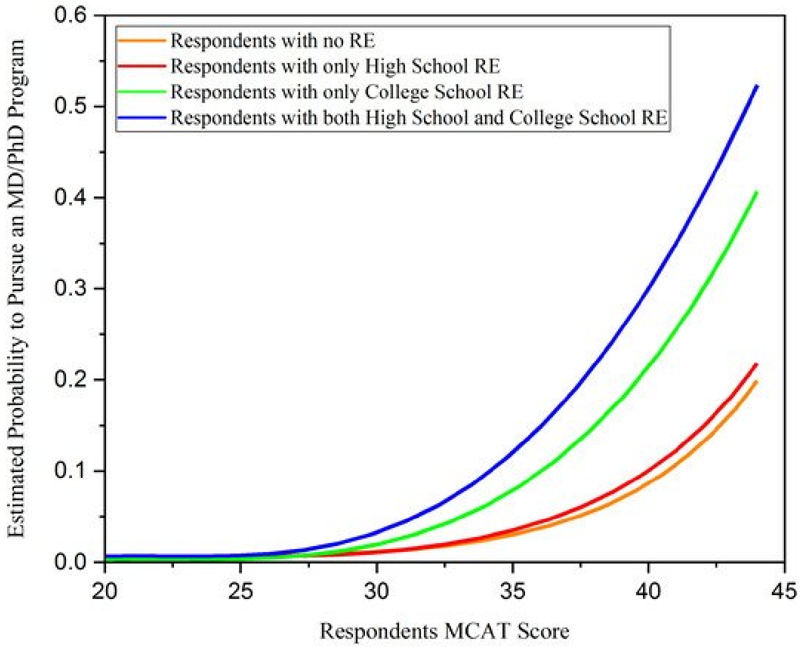

Figure 2. The fitted probabilities of respondents pursuing an MD/PhD program with respect to their Medical College Admission Test (MCAT) scores. Reproduced with permission from [23]. Copyright The American Society for Cell Biology, 2017.

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 [25][26][27][28]. 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 [29] 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 [30]. 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 entry are positive, there is much room for more models to be developed and implemented for high school research.

References

1. Feldman, A.; Divoll, K.; Rogan-Klyve, A. Research education of new scientists: Implications for science teacher education. J. Res. Sci. Teach. 2009, 46, 442–459.
2. Leedy, P.D.; Ormrod, J.E. Practical Research; Pearson Custom: Saddle River, NJ, USA, 2005; Volume 108.
3. Danch, J.M. The Impact of a High School Research Course on Participants at the Undergraduate, Graduate and Post-Graduate Levels. In Proceedings of the AGU Fall Meeting Abstracts, San Francisco, LA, USA, 9–13 December 2019; p. ED23C-01.
4. Abdelrahman, M.; Yilmaz, M. Best Practices in Creating and Running Research Experience Programs. In Proceedings of the 2012 ASEE Annual Conference & Exposition, San Antonio, TX, USA, 10–13 June 2012; pp. 25.259.1–25.259.16.
5. Guillen, T.D.; Yilmaz, M.; Garcia, C.A.; Ramirez, D. A K-12 Advanced Research Camp for Engineering and Science Disciplines. In Proceedings of the 2011 ASEE Annual Conference & Exposition, Vancouver, BC, Canada, 26–29 June 2011; pp. 22.49.1–22.49.11.
6. Swan, A.K.; Inkelas, K.K.; Jones, J.N.; Pretlow, J.; Keller, T.F. The Role of High School Research Experiences in Shaping Students' Research Self-Efficacy and Preparation for Undergraduate Research Participation. J. First-Year Exp. Stud. Transit. 2018, 30, 103–120.
7. Tai, R.H.; Qi Liu, C.; Maltese, A.V.; Fan, X. Planning early for careers in science. Science 2006, 312, 1143–1144.
8. Sadler, T.D.; Burgin, S.; McKinney, L.; Ponjuan, L. Learning science through research apprenticeships: A critical review of the literature. J. Res. Sci. Teach. 2010, 47, 235–256.
9. Abd-El-Khalick, F.; Boujaoude, S.; Duschl, R.; Lederman, N.G.; Mamlok-Naaman, R.; Hofstein, A.; Niaz, M.; Treagust, D.; Tuan, H.L. Inquiry in science education: International perspectives. Sci. Educ. 2004, 88, 397–419.
10. Hofstein, A.; Navon, O.; Kipnis, M.; Mamlok-Naaman, R. Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. J. Res. Sci. Teach. 2005, 42, 791–806.
11. Neber, H.; Anton, M. Promoting Pre-experimental Activities in High-school Chemistry: Focusing on the role of students' epistemic questions. Int. J. Sci. Educ. 2008, 30, 1801–1821.
12. King, D.; Bellocchi, A.; Ritchie, S.M. Making connections: Learning and teaching chemistry in context. Res. Sci. Educ. 2008, 38, 365–384.
13. Brownell, S.E.; Kloser, M.J.; Fukami, T.; Shavelson, R. Undergraduate Biology Lab Courses: Comparing the Impact of Traditionally Based "Cookbook" and Authentic Research-Based Courses on Student Lab Experiences. J. Coll. Sci. Teach. 2012, 41.

14. Spell, R.M.; Guinan, J.A.; Miller, K.R.; Beck, C.W. Redefining authentic research experiences in introductory biology laboratories and barriers to their implementation. CBE—Life Sci. Educ. 2014, 13, 102–110.
15. Deemer, E.D.; Ogas, J.P.; Barr, A.C.; Bowdon, R.D.; Hall, M.C.; Paula, S.; Capobianco, B.M.; Lim, S. Scientific Research Identity Development Need Not Wait Until College: Examining the Motivational Impact of a Pre-college Authentic Research Experience. Res. Sci. Educ. 2021, 1–16.
16. Pfund, C.; Byars-Winston, A.; Branchaw, J.; Hurtado, S.; Eagan, K. Defining attributes and metrics of effective research mentoring relationships. AIDS Behav. 2016, 20, 238–248.
17. Minner, D.D.; Levy, A.J.; Century, J. Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. J. Res. Sci. Teach. 2010, 47, 474–496.
18. Mutlu, A. Evaluation of students’ scientific process skills through reflective worksheets in the inquiry-based learning environments. Reflective Pract. 2020, 21, 271–286.
19. Sikes, S.S.; Schwartz-Bloom, R.D. Direction discovery: A science enrichment program for high school students. Biochem. Mol. Biol. Educ. 2009, 37, 77–83.
20. VanMeter-Adams, A.; Frankenfeld, C.L.; Bases, J.; Espina, V.; Liotta, L.A. Students who demonstrate strong talent and interest in STEM are initially attracted to STEM through extracurricular experiences. CBE—Life Sci. Educ. 2014, 13, 687–697.
21. Pender, M.; Marcotte, D.E.; Domingo, M.R.S.; Maton, K.I. The STEM pipeline: The role of summer research experience in minority students’ Ph. D. aspirations. Educ. Policy Anal. Arch. 2010, 18, 1.
22. Roberts, L.F.; Wassersug, R.J. Does doing scientific research in high school correlate with students staying in science? A half-century retrospective study. Res. Sci. Educ. 2009, 39, 251–256.
23. Tai, R.H.; Kong, X.; Mitchell, C.E.; Dabney, K.P.; Read, D.M.; Jeffe, D.B.; Andriole, D.A.; Wathington, H.D. Examining summer laboratory research apprenticeships for high school students as a factor in entry to MD/PhD programs at matriculation. CBE—Life Sci. Educ. 2017, 16, ar37.
24. Shoemaker, S.E.; Thomas, C.; Roberts, T.; Boltz, R. Building a mentorship-based research program focused on individual interests, curiosity, and professional skills at the North Carolina school of science and mathematics. Gift. Child Today 2016, 39, 191–204.
25. Maltese, A.V.; Tai, R.H. Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. Sci. Educ. 2011, 95, 877–907.
26. Pueyo, N.C.; Raub, A.G.; Jackson, S.; Metz, M.M.; Mount, A.C.; Naughton, K.L.; Eaton, A.L.; Thomas, N.M.; Hastings, P.; Greaves, J. Oxidation of ethidium using TAML activators: A model for high school research performed in partnership with university scientists. J. Chem. Educ. 2013, 90, 326–331.
27. Markowitz, D.G. Evaluation of the long-term impact of a university high school summer science program on students’ interest and perceived abilities in science. J. Sci. Educ. Technol. 2004, 13, 395–407.
28. Gibson, H.L.; Chase, C. Longitudinal impact of an inquiry-based science program on middle school students’ attitudes toward science. Sci. Educ. 2002, 86, 693–705.
29. Gong, X.; Mohlhenrich, E.R. An Integrated Secondary School STEM Research Program: Results, Challenges, and Opportunities. In Proceedings of the 2019 IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, USA, 16 March 2019; pp. 76–82.
30. Eeds, A.; Vanags, C.; Creamer, J.; Loveless, M.; Dixon, A.; Sperling, H.; McCombs, G.; Robinson, D.; Shepherd, V.L. The school for science and math at Vanderbilt: An innovative research-based program for high school students. CBE—Life Sci. Educ. 2014, 13, 297–310.
