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THE IMPACT OF INSTRUCTIONAL STRATEGIES ON PROMOTING SCIENCE, TECHNOLOGY, ENGINEERING, AND MATH EDUCATION AMONG K-12 IN THE UNITED STATES

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ABSTRACT

This review discussed the impact of instructional strategies on advancing (STEM) education among K-12 students. This study encompasses students ranging from 5 to 18 years of age. The promotion of STEM education among K–12 students in America necessitates a diverse array of instructional strategies and interventions. Effective pedagogical strategies are essential for fostering students' engagement with and comprehension of STEM subjects, which are increasingly critical to equipping them to address societal challenges and future occupational demands. This study examined the background of STEM education in America, with a focus on K-12 students. The review also discussed the challenges associated with STEM education in this student demographic and analyzed the instructional and other strategies implemented to address these challenges. Implementing these instructional strategies has yielded some positive impacts in math; for instance, the United States continues to underperform compared to its global peers. This finding points to the need for more strategic and coordinated efforts to improve STEM education in K-12. Furthermore, this paper explored future strategies to promote STEM education among K-12 students.

KEYWORDS: *STEM education, K-12, Gamification, socioeconomic factors*

1. INTRODUCTION

The educational concept known as STEM education emphasizes proficiency in science, technology, engineering, and mathematics. It encourages critical thinking and problem-solving skills in learners and gives them the tools they need for today's world. In addition to preparing students for a society that is fast-changing and increasingly dependent on technology, it fosters creativity and teamwork (National Science and Technology Council, 2018).

America's efforts to respond to national and international issues as they arise are reflected in STEM education. The issue of STEM education rose to the forefront of the national agenda in the middle of the twentieth century as a result of the US desire to dominate the world in technological and scientific fields during the Cold War (Bybee, 2013). Significant investments in science and math education were made by the Soviet Union after the launch of Sputnik in 1957 (National Academies of Sciences, Engineering, and Medicine, 2014). STEM education has changed in recent years to meet the demands of a more technologically advanced society (Honey et al, 2014). STEM goals were included in policies such as the Every Student Succeeds Act (ESSA) of 2015, which encouraged states to implement creative and integrated approaches to STEM instruction (U.S. Department of Education, 2015). Organizations such as the National Science Foundation (NSF) and Next Generation Science Standards (NGSS) are promoting interdisciplinary, experiential learning in STEM fields to better prepare students for the challenges of the future (National Academies of Sciences, Engineering, and Medicine, 2014).

STEM is being prioritized by educational institutions to equip students with the skills they will need to compete in a competitive economy and handle advanced technology in the workplace (Kayan-Fadlelmula et al., 2022). According to US business, government, and academic leaders, STEM education is essential for maintaining the country's capacity for innovation as well as serving as a basis for successful career opportunities, including but not restricted to STEM-related jobs (Honey, Pearson, & Schweingruber, 2014). By advocating for science, math,

engineering, and technology research, the National Science Foundation (NSF) has been instrumental in the STEM education movement in the United States (National Science Foundation, 2020).

The allure of STEM careers is that they foster creativity, address global concerns, and maintain a country's competitiveness (National Science Board, 2020). Among the most promising fields in K–12 education across the US is STEM, or math, science, technology, and engineering. (National Academy of Engineering, Medicine, and Sciences, 2014). The interdisciplinary nature of 21st-century issues like health, the environment, and climate change can be better addressed by students through integrated STEM education (Moore et al., 2020; National Academy of Engineering [NAE] and NRC, 2014).

At the age of five or six, students in the US start formal schooling. After completing the kindergarten to grade 12 (K–12), students can decide whether to enroll in college or university (U.S. Department of Education, 2021). According to the US Department of Homeland Security, elementary to secondary educational institutions in America are classified into public and private institutions.

STEM education encompasses a variety of events that entail some degree of connectivity, rather than being a single, clearly defined experience. The encounters can take place during one or more class periods, across a curriculum, in a single course or the entire school, or as part of an after-school program. Different planning strategies, resource requirements, implementation difficulties, and results are suggested by each integrated STEM education variation (Honey, Pearson, & Schweingruber, 2014).

There has long been an effort to enhance the teaching of science and math in grades K–12. Curriculum development initiatives, career advancement networks, and the production of national standards papers (e.g., AAAS 1993; NCTM 1989; NRC 1996) have all been part of these endeavors since the 1960s. Teaching and learning of these subjects have received more national attention since the release of the Common Core State Standards for Mathematics (NGACPB 2010) and the Next Generation Science Standards (NGSS; Achieve 2013), the latter of which was based on A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC 2012) (Honey, Pearson, & Schweingruber, 2014).

2. CHALLENGES OF STEM EDUCATION AMONG K-12 IN THE US

Every student in grades K–12 needs to benefit from the foundation of high-achieving science, technology engineering and mathematics education if the America is to maintain its technical and economic competitiveness in the future (National Science and Technology Council, 2018). The different STEM fields must come together in STEM teaching and learning processes to facilitate meaning-making and the cultivation of relevant 21st-century skills. (Guzey el al, 2020)

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However, the U.S. has yet to achieve the goal of providing consistently high-quality STEM education across the K-12 system (Studley et al., 2014). Despite the conclusive scientific data supporting the advantages of active learning and integrated STEM pedagogies, their implementation approaches remain a significant challenge (Chiangpradit, 2024).

2.1 Teacher Training Shortfalls

According to Holmund et al., (2018), the teachers themselves state that they are not prepared to conduct STEM lessons due to a lack of preparation. A 2018 report argues that STEM education is challenging for teachers to implement and advocates for a definition of STEM in K–12 learning contexts (National Science and Technology Council, 2018). Existing professional development gaps demand continuous education. For STEM education to be effective, ongoing professional development is essential (Bybee, 2013). The implementation of a Google CS4HS (Computer Science for High Schools) grant program to improve computer science teaching in impoverished rural communities is discussed in 2024 research, highlighting the significance of ongoing teacher training (Harms 2024). Margot and Kettler (2019) examined 25 pieces of research to find out how K–12 educators felt about STEM instruction and inclusion. According to their findings, instructors valued STEM education, but they also mentioned obstacles like lack of teacher support, pedagogical difficulties, curricular difficulties, institutional difficulties, and worries about students and assessments. Negative perceptions also affect K-12 STEM education in America (Bybee, 2013).

The lack of curriculum resources is another significant barrier for STEM educators. The first and most important requirement is to identify educational materials that cover all four STEM fields and that have been specially developed for smooth and easy integration. (ALI Research Staff, 2023).

2.2 Negative Perception

The majority of Americans think STEM education in the US is either mediocre or worse than in other affluent countries, per a recent Pew Research Center survey (Kennedy, 2024).

2.3 Diversity and Socio-economic Factors

According to research, students have better experiences and are positively impacted and motivated by teachers with whom they share similar ethnic and racial traits (Redding, 2019). However, the range of backgrounds of the student body in American classrooms is not reflected in contemporary teaching recruitment and employment (SSEC, 2024).

There are still persistent differences in math and science test performance between racial, ethnic, and socioeconomic groups (NSB, 2022). On important standardized tests, children from racial and ethnic minorities performed far worse than their white counterparts, except for Asian students. For pupils with lower socioeconomic status (SES), as shown by their need for free or reduced-price school lunches, performance declined even further. Interestingly, low-SES pupils routinely score much worse on these standardized examinations when compared to higher-SES peers in the same demographic category, across all racial/ethnic groups ((NSB, 2022).

3. Strategies to Address These Challenges

Over time, some strategies have been developed to deal with STEM's difficulties in K–12 education (Suhirman et al, 2023). Although STEM education has been shown to benefit students, comprehension of instructional design is still lacking for STEM education, even though this knowledge is essential for research and classroom activities. Insufficient understanding of pertinent instructional design could disrupt the introduction of STEM education in the classroom (Halawa et al., 2024).

When information, varying approaches, and skills are contextualized within the learning process, integrated STEM education takes place, according to the National Science Teaching Association (NSTA, 2020). Programs that help translate STEM research into fair, evidence-based teaching materials, real-world learning opportunities, and teacher preparation and growth opportunities that meet the needs of students in pre–K–12 must continue to be funded by federal agencies. (Committee on Science, Technology, Engineering, and Mathematics [STEM] of the National Science & Technology Council, 2024).

3.1 Governmental Effort

Through conferences, workshops, research, and grant funding, federal agencies can assist post-secondary institutions in better aligning their programs with STEM and Career and Technical Education (CTE) curricula in secondary schools. Programs should be better matched, for instance, to allow students to avoid retaking similar courses at post-secondary institutions and to obtain more dual or concurrent course credits through secondary and CTE curricula. Leaders in education policy should remove obstacles that prevent teachers from collaborating across subject areas and from alternating between official and unofficial settings. Federal funding for STEM educator "upskilling" and professional growth, including CTE and college preparatory instructors and educators working in both formal and informal settings, must be prioritized to accomplish this (Committee on STEM Education of the National Science & Technology Council, 2018).

The White House's 2022 report aimed at promoting equity and excellence in STEM education identified issues of inequality, socio-economic constraints, and shortage of STEM teachers for underrepresented student demographics. The White House report's objectives were to: close the funding gap and support researchers and communities that have historically been denied access to essential resources; Address the STEM teacher shortage, which disproportionately affects underrepresented students; provide sufficient support for students, teachers, workers, communities, and others to engage in and contribute to science and technology throughout their lives; and scale solutions that eradicate prejudice, discrimination, and harassment in the classroom, laboratory, and workplace. (White House Office of Science and Technology Policy [OSTP], 2022).

3.2 Instructional Strategies

Over the years, strategies like project-based learning (PBL), inquiry-based learning, collaborative learning, inclusive curriculum design, and the integration of technology and gamification have been incorporated into K-12 STEM education to promote an engaging learning environment (Deak et al., 2021).

3.3 Project-based learning (PBL)

In the K–12 STEM educational system in America, project-based learning (PBL), is a strategy of delivering instruction in which students spend a lot of time working on an open-ended topic or challenge. As a teaching

strategy, PBL emphasizes student-centered inquiry, teamwork, and context that incorporates STEM fields. It fosters critical thinking, creativity, and communication skills, preparing students for higher education and careers in STEM fields (Barron & Darling-Hammond, 2015). In a PBL setting, students work on assignments that more often require them to solve complicated problems or respond to real-world, cross-disciplinary inquiries. Students might, for example, develop models of new technology, tackle environmental issues in their area, or use information to address issues in the community (Capraro et al., 2016). In addition to using STEM knowledge in real-world projects, PBL helps students improve collaboration skills (Caparo et al., 2016). PBL has been applied in STEM-related schools, after-school programs, and initiatives aimed at closing the STEM gap and preparing students for the current job market in the United States. Through this approach, students not only acquire knowledge but also develop other abilities including persistence, teamwork, and project management (Krajcik & Blumenfeld, 2020).

3.4 Inquiry-based learning (IBL)

With the theory of inquiry-based learning (IBL), students actively participate in their education by posing queries, exploring solutions, and creating meanings through investigation and problem-solving. This pedagogical technique is often applied in STEM (science, technology, engineering, and math) education in K–12 classrooms in the United States because it inspires curiosity, critical thinking, and problem-solving (Krajcik & Blumenfeld, 2020). Additionally, inquiry-based learning is thought to enhance students' creativity (Smyrnaiou et al., 2020), knowledge, curiosity, and engagement (Sinatra et al., 2017). Additionally, scholars have noted that inquiry-based learning is crucial for enhancing students' perceptions of professions in science (Kim, 2016). Inquiry-based learning has been found to have goals and traits in common with mathematics, technology, and engineering, despite its primary concentration on scientific knowledge in order to engage students in authentic learning (Halawa et al., 2024).

3.5 Collaborative Learning

With collaborative learning, students are divided into small groups to work together on a project, solve a problem, or meet learning goals as part of the group work method of learning facilitation. To solve STEM problems, this instructional method and practice in K–12 STEM education in the US integrates collaborative communication and teamwork. Because students are compelled to apply their knowledge and abilities to explain material to other students, collaborative learning has been shown to enhance critical thinking and the ability of students to solve problems. The main reason this approach is so beneficial in STEM classes is that it replicates the way researchers collaborate in teams. In science, technology, engineering, and math learning environments, cooperative learning settings incorporate elements like group activities, peer evaluations, and shared tasks. Students' social and interpersonal skills are developed through STEM teaching approaches in preparation for future collaboration and teamwork as well as for professional interactions in different fields (Barron & Darling-Hammond, 2015; Johnson & Johnson, 2017).

3.6 Inclusive Curriculum Design

The focus of an inclusive curriculum design is on creating curricula that answer to and broadly represent students' social and cultural learning peculiarities. All members of society must have access to STEM opportunities and educational success standards must be equalized before the full potential of a STEM-engaged society can be actualized. Motivating, training, and maintaining STEM workers and students nationwide is essential to the country's competitiveness. Because of historical and current prejudice, latent biases, and unequal resource distribution and access nationwide, not all Americans today have access to high-quality STEM opportunities. (Committee on Science, Technology, Engineering, and Mathematics [STEM] of the National Science & Technology Council, 2024). These barriers can be based on differences in geography, socioeconomic status, race, ethnicity, and gender/gender identity (White House Office of Science and Technology Policy [OSTP], 2022).

3.7 Diversity in Teacher Recruitment and Training

According to the Smithsonian Science Education Center, current efforts to diversify the STEM teaching field focus on hiring new employees, ignoring other workable options like retention and leadership development. There will be more teachers from minority groups overall if recruitment, retention, and leadership development efforts are improved for teachers of color. Additionally, more teachers will be able to acquire the experiences necessary to advance to senior leadership roles in the sector. More mentors and role models for students from marginalized communities will result from an increase in STEM master instructors from underrepresented groups, which will encourage more students to pursue careers in STEM. (Smithsonian Science Education Center, 2024)

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3.8 Technology and Gamification

By making learning more dynamic and interesting, technology in STEM education promotes creativity and critical thinking, two traits that employers highly respect (University of Iowa, 2024.) Working with technology also helps students develop critical skills for potential STEM vocations, preparing them to meet the needs of a technologically advanced world (World Economic Forum, 2023). Students are actively involved in the learning process and project-based learning is supported by tools like coding platforms and simulation software. This in turn encourages problem-solving and critical thinking (University of Iowa, 2024)

The use of game-design concepts and components outside of games is known as gamification. In education, gamification refers to the integration of elements like challenges, leaderboards, badges, and points into instructional activities. The objective is to use the inherent incentive and engagement that games provide to improve the educational process and support the market for educational technology. Since kids will be working in a future where technological proficiency will be essential, gamification has emerged as the next big thing in K–12 education (Grand View Research, 2024).

4. IMPACT OF INSTRUCTIONAL STRATEGIES

4.0 Struggles in Mathematics Education

U.S. student performance on standardized examinations in math and science has not improved in more than ten years, according to the National Science Board's Elementary and Secondary STEM Education report, putting the country in the middle of a lengthy list of international competitors (NAEP, 2022). The United States ranks at the center of a long list of nations when it comes to K–12 student performance in math and science. The United States ranks last among our biggest rivals in research and engineering, which include China, Korea, and the G-7 (National Science Board, 2022).

According to a recent Pew Research Center survey, the majority of Americans think that, as compared to other wealthy countries, STEM education in the US is either average or below average. According to recent results from international standardized tests, American kids are falling behind their counterparts in other affluent countries in math. However, when compared to children in these other nations, American students are performing above average in science (Pew Research Center, 2024).

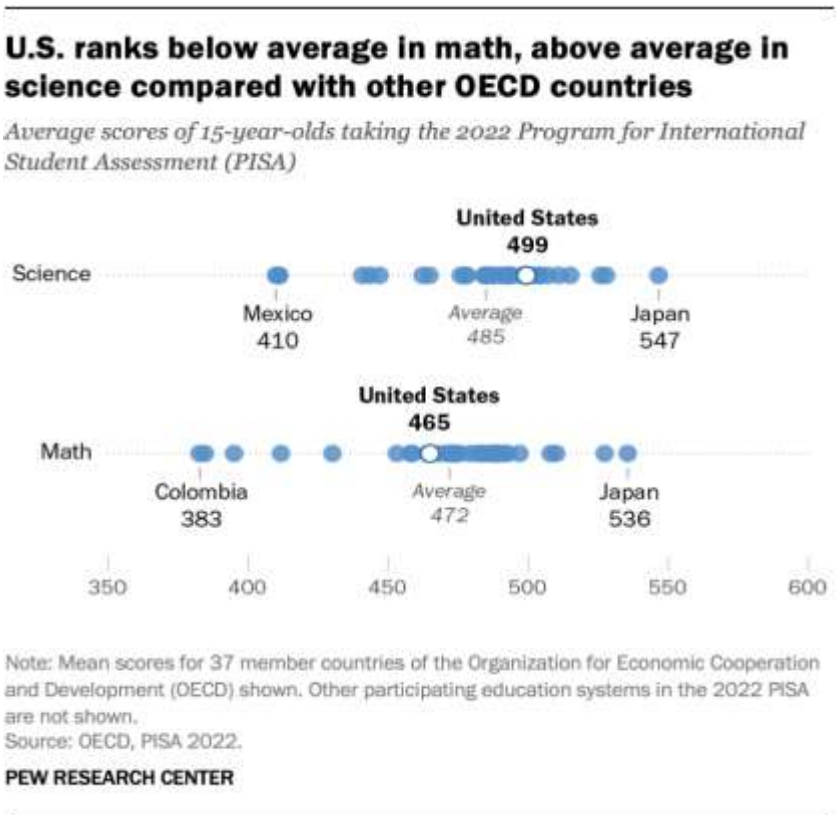


Figure 1: ***Average scores of 15-year-olds from 37 OECD countries taking the 2022 PISA student assessment***

Note: This figure shows the performance of 15-year-old students in math and science across 37 OECD countries and shows U.S. students' underperformance in math (OECD, PISSA, 2022).

Despite a 13-point decline in math scores following the pandemic, U.S. students placed 28th out of 37 nations that are members of the Organization for Economic Cooperation and Development, a ranking comparable to the last time the test was given in 2018. However, after a 3-point decline in scores, the United States came in at number 12 out of 37 OECD nations in science. In both subjects, the average U.S. score was within 15 points of the global average (Pew Research Center, 2024).

4.1 The Positives

The instructional strategies to promote STEM education among K-12 in the United States have shown positive results regardless of the unfavorable perception of the performance of segments of the U.S. populace about STEM education.

4.2 The Success of Teaching and Learning Strategies

Prior study indicates that to accomplish specific educational objectives, researchers have implemented STEM teaching designs (Halawa et al.). For example, Sullivan and Bers (2019) employed design-based learning to enhance kids' interest in engineering and their performance in primary school, with a focus on engagement and career choice. To encourage students' interest in science, Kang et al. (2021) integrated career education into inquiry-based learning for high school. To enhance students' STEM literacy and attitude, Vallera and Bodzin (2020) implemented project-based learning in northeastern US primary schools. Preininger (2017) employed problem-based learning to affect students' perceptions of mathematics and math-related occupations. To allow students to apply STEM ideas to the model of building an optical instrument, King and English (2016) implemented design-based learning in the context of STEM literacy. STEM project-based learning was used by Han et al. (2015) to raise the math proficiency of underachievers. English et al. (2017) implemented design-based learning to enhance students' capacity to manage task complexity with twenty-first-century competencies (English et al., 2017).

Inquiry-based and project-based instruction are two instructional strategies that have piqued students' curiosity in STEM. In Iowa, for instance, when funding was increased for STEM education, it led to an increase in interest from students in STEM careers and they got better results in standardized math and science examinations (Studley et al., 2014). According to Caparo et al. (2016), students' abilities to apply STEM concepts are enhanced by project-based learning, they learn how to work in teams, making the learning experience more intensive and engaging. Also, research has demonstrated that project-based learning nurtures students into achievers, motivates them, and enhances their ability to retain what they learn in STEM (Barron & Darling-Hammond, 2015). Research conducted by Krajcik and Blumenfeld (2020) discovered that inquiry-based learning nurtures curiosity and critical thinking, These skills help students to understand and explore complex concepts in STEM. Inquiry-based learning has been merged with technology and this improves students' investigative and data analysis skills (Nguyen et al., 2021).

Learning and instruction strategies that promote collaboration and problem-solving are important for preparing students for the work force. Employers place a premium on critical thinking and teamwork abilities. Therefore, programs integrating STEM education with real-world challenges are important (National Science Board, 2022). Johnson et al. (2017) emphasize that collaborative learning enhances students' problem-solving abilities and work in different teams, which is essential in modern STEM fields.

Concerning equity, inclusion, and access, specific interventions aimed at marginalized and underserved groups have shown the potential to expand participation improving performance in STEM fields (National Science Foundation, 2022).

The impact of K-12 STEM education goes beyond the academic achievements recorded at the K-12 level. Students are influenced in their post-secondary education and career choices by the superiority of the STEM education they receive at the secondary school level (National Academy of Sciences, 2023). This relationship between the performance outcomes of elementary and secondary STEM education and future academic and career choices highlights the importance of effective instructional strategies at the K-12 level.

4.3 Impact of Instructional Strategies on Students

Through creative exploration, interpretation, and representation, students who are lucky enough to get high-quality STEM education cultivate their creativity (Robinson, 2011). Technology literacy is strengthened by the resources

they employ. The highly collaborative nature of the discovery process sharpens cooperation and communication abilities. In the wake of failure, tenacity and resilience are forged. Curiosity is fostered by posing and responding to questions. Truth and facts are evidence-based but always uncertain, and defending and disproving ideas fosters critical thinking. Different viewpoints foster empathy. Additionally, doing STEM gives you the confidence to pursue STEM as a career (Weld, 2024).

The United States has made efforts to integrate and promote technology integration into STEM education. This has been shown to have a positive effect on student performance. Research shows that using digital tools for teaching STEM increases student engagement thereby allowing them to develop skills that make them technologically literate (Xie & Stevenson, 2020).

Instructional strategies in K-12 STEM play a significant role in student engagement, academic performance, development of critical skills, equity, and long-term career outcomes. As the field of education continues to evolve, policies, activities, and initiatives must be centered on proven and effective strategies that lead to active learning and promote inclusion. These will prepare students for a world driven by technology.

5.0 FUTURE OF K-12 STEM EDUCATION

Acting on behalf of the future STEM workforce is primarily the responsibility of K–12 formal and informal education at the everyday practical level. Teachers should take advantage of this historic moment to support American economic vitality and national security, one student at a time, insofar as state policies empower, government and non-government funded programs support, and preparatory training equips. They can do this by implementing equitable behavior that ensures every student belongs in STEM, coordinating learning activities across in-school and out-of-school experiences, connecting learning environments to careers, empowering students to cross disciplinary boundaries while exploring complex local and global challenges, and deciding which curriculum items to include based on evidence of their impact. Since state governments establish the regulations that dictate practices, states are in the best position to assist local workforce and education organizations in addressing the material and human resource issues preventing the full supply of future talent for high-demand vocations. (Weld, 2024).

The United States requires "all hands on deck" to improve K–12 STEM education and subject itself to strict evaluation with accurate, current data in order to promote individual and national prosperity and competitiveness. (National Science Board, 2022).

Countries are overtaking the United States, regardless of population size, since their students consistently exceed ours (OECD, 2023). This poor performance needs to be rectified because it jeopardizes our ability to lead in innovation and be economically viable in the future. As educators and policymakers, we must make it plain that being "bad at math" is no longer acceptable, just as being illiterate is (National Science Board, 2022).

Particularly at the K–12 level, many kids, families, and educators lack the comprehensive assistance they require to maintain continued education. Thus, long-standing differences in student science and math achievement across different socioeconomic demographics continue, and American student achievement in these subjects has not improved in more than ten years, with current studies indicating that it is declining. Thus, the committee pledged to provide sufficient assistance for students, educators, workers, communities, and others to engage in and contribute to science and technology throughout their lives (Committee on Education, 2024).

Recommendations for improvement in the STEM education in K-12 made by NGSS Lead States include; ensuring that existing gaps in access to standards-aligned science instruction start to close and that new ones don't arise, states, school districts, and schools should make sure that teachers have access to excellent instructional resources and assistance to meet the needs of their students rather than asking them to make their own or find resources online. Additionally, science teachers should have more opportunities for continuous professional development. Instead of punishing schools and districts that require assistance, these systems ought to emphasize finding and assisting them (NGSS Lead States, 2023).

6. Conclusion

Elementary and secondary STEM education provides the foundation for the nation's future technological and scientific (S&E) workforce, and thus the US economy and security (National Science Board, 2022). All over the ecosystem of scientific and technological advancement,individuals, groups, institutions, and communities can use their distinct assets, viewpoints, and abilities to confront these issues and promote chances for revolutionary change. (Committee on Education, 2024).

This paper has highlighted the fact that STEM education is of prime importance to the United States. However, there are many issues still to be addressed by the country's education stakeholders. The first is to change public perception about STEM education, provide requisite training to STEM instructors, develop curricula that addresses teaching and learning challenges and embrace the diversity of the U.S. The next is to improve teaching and learning outcomes, extend STEM education to reach a broader and more diverse population, and make it a preferred career choice for students in a world where technology is at the center of global dominance and innovation. These will ultimately maintain the United States' rank as a global powerhouse in scientific and technological advancement.

From the conceptualization of STEM in K-12, the responsibilities of teachers in delivering excellent STEM instruction, and the proper harmonization of initiatives and policies across America, it is evident that there needs to be a clearer path and a more uniform approach to formulating and implementing strategies that will improve STEM teaching and learning, especially in elementary and secondary education in America. A more concerted effort will enable the United States to achieve its objective of maintaining its status as the global powerhouse in science and technology.

REFERENCES

1. *ALI Research Staff (2023, January 10). The Challenges of STEM Education – Barriers to Participation. https://blog.acceleratelearning.com/the-challenges-of-stem-education-barriers-to-participation*
2. *Barron, B., & Darling-Hammond, L. (2015).* Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning. *Jossey-Bass.*
3. *Barron, B., & Darling-Hammond, L. (2015). Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning.* Jossey-Bass.
4. *Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. National Science Teachers Association.*
5. *Capraro, M. M., Capraro, R. M., & Morgan, J. R. (2016).* STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach. *Springer. https://doi.org/10.1007/978-3-319-02565-6*
6. *Capraro, M. M., Capraro, R. M., & Morgan, J. R. (2016). STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach.* Springer.
7. *Chiangpradit, L. (2024, July 10). 8 challenges of teaching STEM. STEM Sports. Reviewed by S. Barton & H. MacLean. Retrieved from https://stemsports.com/8-challenges-of-teaching-stem*
8. *Committee on Science, Technology, Engineering, and Mathematics (STEM) of the National Science & Technology Council. (2024).* Federal strategic plan for advancing STEM education and cultivating STEM talent. *National Science & Technology Council.*
9. *Committee on STEM Education of the National Science & Technology Council. (2018).* Charting a course for success: America's strategy for STEM education. *Retrieved from https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf*
10. *Committee on STEM Education. (2024). Federal strategic plan for advancing STEM education and cultivating STEM talent: A vision to transform the U.S. STEM ecosystem. National Science and Technology Council. Retrieved from https://www.whitehouse.gov/ostp/news-updates/2022/12/12/equity-and-excellence-a-vision-to-transform-and-enhance-the-u-s-stemm-ecosystem/*
11. *Deák, C.; Kumar, B.; Szabó, I.; Nagy, G.; Szentesi, S. Evolution of New Approaches in Pedagogy and STEM with Inquiry-Based Learning and Post-Pandemic Scenarios. Educ.*
12. *English, L. D. (2016). STEM education K-12: Perspectives on integration. International Journal of STEM Education, 3(1), 3. https://doi.org/10.1186/s40594-016-0036-1*
13. *English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. Journal of Educational Research, 110(3), 255–271. https://doi.org/10.1080/00220671.2016.1264053*
14. *Grand View Research. (2024, December 20). Gamification in education: Trends and growth opportunities. Grand View Research. Retrieved December 26, 2024, from https://www.grandviewresearch.com/blog/gamification-education*
15. *Guzey, S. S., Moore, T. J., & Harwell, M. (2020). Development of an instrument to assess attitudes toward science, technology, engineering, and mathematics (STEM).* Journal of Science Education and Technology, 29*(2), 229–241. https://doi.org/10.1007/s10956-020*
16. *Halawa, S., Lin, TC. & Hsu, YS. Exploring instructional design in K-12 STEM education: a systematic literature review. IJ STEM Ed* ***11****, 43 (2024). https://doi.org/10.1186/s40594-024-00503-5*
17. *Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (stem) project-based learning (pbl) affects high, middle, and low achievers differently: The impact of student factors on achievement. International Journal of Science and Mathematics Education, 13(5), 1089–*

1113. https://doi.org/10.1007/s10763-014-9526-0

18. *Harms, S. K. (2024). Tackling CS education in K-12: Implementing a Google CS4HS grant program in a rural underserved area.* arXiv. *https://doi.org/10.48550/arXiv.2407.17483*
19. *Holmlund, T.D., Lesseig, K. & Slavit, D. Making sense of "STEM education" in K-12 contexts. IJ STEM Ed* ***5****, 32 (2018). https://doi.org/10.1186/s40594-018-0127-2*
20. *Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. National Academies Press.*
21. Honey, M., Pearson, G., & Schweingruber, H. A. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research* (Vol. 500). Washington, DC: National Academies Press.
22. Honey, M., Pearson, G., & Schweingruber, H. A. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research* (Vol. 500). Washington, DC: National Academies Press.
23. Johnson, D. W., Johnson, R. T., & Holubec, E. J. (2017). *Cooperation in the classroom: The integration of theory and practice*. Interaction Book Company.
24. *Kang, J., Salonen, A., Tolppanen, S., Scheersoi, A., Hense, J., Rannikmae, M., & Keinonen, T. (2021). Effect of embedded careers education in science lessons on students' interest, awareness, and aspirations. International Journal of Science and Mathematics Education. https://doi.org/10.1007/s10763-021-10238-2*
25. *Kayan-Fadlelmula, F., Sellami, A., Abdelkader, N., & Umer, S. (2022). A systematic review of STEM education research in the GCC countries: Trends, gaps, and barriers. International Journal of STEM Education, 9, 1-24.*
26. *Kennedy, B. (2024, April 24). Most Americans think U.S. K-12 STEM education isn't above average, but test results paint a mixed picture. https://www.pewresearch.org/short-reads/2024/04/24/most-americans-think-us-k-12-stem-education-isnt-above-average-but-test-results-paint-a-mixed-picture/*
27. *Kim, H. (2016). Inquiry-based science and technology enrichment program for middle school-aged female students. Journal of Science Education and Technology, 25(2), 174–186. https://doi.org/10.1007/s10956-015-9584-2*
28. *Krajcik, J., & Blumenfeld, P. (2020). Project-based learning. In R. K. Sawyer (Ed.), The Cambridge Handbook of the Learning Sciences (2nd ed., pp. 317–334). Cambridge University Press. https://doi.org/10.1017/9781108894332.021*
29. *Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. International Journal of STEM Education, 6(1), 1-16. https://doi.org/10.1186/s40594-019-0192-1*
30. *Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2020). STEM integration in K-12 education: Contexts, challenges, and research. Routledge. https://doi.org/10.4324/9780429457428*
31. *National Academies of Sciences, Engineering, and Medicine. (2014). Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics. The National Academies Press.*
32. *National Academies of Sciences, Engineering, and Medicine. (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. National Academies Press. https://doi.org/10.17226/18612*
33. *National Academy of Engineering [NAE], & National Research Council [NRC]. (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. National Academies Press. https://doi.org/10.17226/18612*
34. *National Academy of Sciences. (2023). K–12 science education: A landscape study. Retrieved from https://media.carnegie.org/filer_public/81/31/81315c4d-4fb3-4fd0-a20e-865531aac9e4/science_landscape_report_013123.pdf*
35. *National Assessment of Educational Progress (NAEP). (2022). "The Nation's Report Card"*
36. *National Science and Technology Council. (2018). Charting a course for success: America's strategy for STEM education. Executive Office of the President. https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf*
37. *National Science and Technology Council. (2018). Charting a course for success: America's strategy for STEM education. U.S. Government Printing Office. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/stem_strategy_2018.pdf*
38. *National Science Board. (2020). The State of U.S. Science and Engineering 2020. National Science Foundation. Retrieved from https://ncses.nsf.gov. 01/27/2025*
39. *National Science Board. (2022). Science & Engineering Indicators 2022. National Science Foundation. Retrieved from https://www.nsf.gov/nsb/sei/one-pagers/K-12-Indicator-2022.pdf*
40. *National Science Foundation. (2020). NSF and the Birth of STEM Education. Retrieved from:https://www.nsf.gov/ on 01/27/2025.*
41. *Nguyen, H., Le, S., & Tan, S. (2021). Technology integration in inquiry-based learning for K-12 STEM education: A review. Journal of Educational Technology & Society, 24(2), 98-110*
42. *OECD. (2023). PISA 2022 Results (Volume I): The State of Learning and Equity in Education. OECD Publishing.*
43. *Pew Research Center. (2024, April 24). Most Americans think U.S. K-12 STEM education isn't above average, but test results paint a mixed picture. Pew Research Center. https://www.pewresearch.org/short-reads/2024/04/24/most-americans-think-us-k-12-stem-education-isnt-above-average-but-test-results-paint-a-mixed-picture/*

44. *Preininger, A. M. (2017). Embedded mathematics in chemistry: A case study of students' attitudes and mastery. Journal of Science Education and Technology, 26(1), 58–69. https://doi.org/10.1007/s10956-016-9651-3*
45. *Redding, C. (2019). A Teacher Like Me: A Review of the Effect of Student-teacher Racial/ethnic matching on Teacher Perceptions of Students and Student Academic and behavioral outcomes. Review of Educational Research, 89(4), 499–535. https://doi.org/10.3102/0034654319853545*
46. *Sci. 2021, 11, 319. https://doi.org/10.3390/educsci11070319*
47. *Sinatra, G. M., Mukhopadhyay, A., Allbright, T. N., Marsh, J. A., & Polikoff, M. S. (2017). Speedometry: A vehicle for promoting interest and engagement through integrated STEM instruction. Journal of Educational Research, 110(3), 308–316. https://doi.org/10.1080/00220671.2016.1273178*
48. *Smithsonian Science Education Center (SSEC). (n.d.). Inclusion, diversity, equity, and accessibility (IDEA). Retrieved December 26, 2024, from https://ssec.si.edu/inclusion*
49. *Smyrnaiou, Z., Georgakopoulou, E., & Sotiriou, S. (2020). Promoting a mixed-design model of scientific creativity through digital storytelling – the CCQ model for creativity. International Journal of STEM Education, 7(1), 25. https://doi.org/10.1186/s40594-020-00223-6*
50. *Studley, T., & others. (2014). Consistently high-quality STEM education across the K-12 system. In Proceedings of the 2014 American Society for Engineering Education Annual Conference & Exposition. Indianapolis, IN: ASEE. https://doi.org/10.18260/1-2--20444*
51. *Studley, T., & others. (2014). K-12 STEM education for the future workforce. Federation of American Scientists. Retrieved from https://fas.org/publication/k-12-stem-for-the-future-workforce/*
52. *Suhirman, S., & Prayogi, S. . (2023). Overcoming Challenges in STEM Education: A Literature Review That Leads to Effective Pedagogy in STEM Learning . Jurnal Penelitian Pendidikan IPA, 9(8), 432–443. https://doi.org/10.29303/jppipa.v9i8.4715*
53. *Sullivan, A., & Bers, M. U. (2019). Investigating the use of robotics to increase girls' interest in engineering during early elementary school. International Journal of Technology and Design Education, 29(5), 1033–1051 https://doi.org/10.1007/s10798-018-9483-y*
54. *U.S. Department of Education. (2021). The condition of education 2021. National Center for Education Statistics. https://nces.ed.gov/pubs2021/2021144.pdf*
55. *U.S. Department of Education. (2021). The condition of education 2021. National Center for Education Statistics. https://nces.ed.gov/pubs2021/2021144.pdf*
56. *U.S. Department of Homeland Security. (n.d.). K-12 students. Study in the States. Retrieved December 29, 2024, from https://studyinthestates.dhs.gov/students/get-started/kindergarten-to-grade-12*
57. *University of Iowa. (n.d.). Technology integration in STEM education: Tools and techniques. Retrieved December 26, 2024, from https://onlineprograms.education.uiowa.edu/blog/technology-integration-in-stem-education-tools-and-techniques*
58. *Vallera, F. L., & Bodzin, A. M. (2020). Integrating STEM with AgLIT (Agricultural literacy through innovative technology): The efficacy of a project-based curriculum for upper-primary students. International Journal of Science and Mathematics Education, 18(3), 419–439. https://doi.org/10.1007/s10763-019-09979-y*
59. *Weld, J. (2024, April 9). K-12 STEM for the future workforce. Federation of American Scientists. https://fas.org/publication/k-12-stem-for-the-future-workforce/*
60. *White House Office of Science and Technology Policy (OSTP). (2022, December 12). Equity and excellence: A vision to transform and enhance the U.S. STEMM ecosystem. Retrieved from https://www.whitehouse.gov/ostp/news-updates/2022/12/12/equity-and-excellence-a-vision-to-transform-and-enhance-the-u-s-stemm-ecosystem/#_edn1*
61. *White House Office of Science and Technology Policy (OSTP). (2022, December 12). Equity and excellence: A vision to transform and enhance the U.S. STEMM ecosystem. The White House. https://www.whitehouse.gov/ostp/news-updates/2022/12/12/equity-and-excellence-a-vision-to-transform-and-enhance-the-u-s-stemm-ecosystem/*
62. *World Economic Forum. (2023). The future of jobs report 2023. Retrieved December 26, 2024, from https://weforum.org/docs/WEF_Future_of_Jobs_2023.pdf*
63. *Xie, K., & Stevenson, C. (2020). The role of digital technology in STEM education: Impact and challenges. Educational Technology Research & Development, 68(3), 1417-1434.*

List of Abbreviations

1. *AAAS (1993): American Association for the Advancement of Science*
2. *NCTM (1989): National Council of Teachers of Mathematics*
3. *NRC (1996): National Research Council*
4. *NGACPB (2010): National Governors Association Center for Best Practices*
5. *NGSS; Achieve 2013: Next Generation Science Standards*
6. *CS4HS – Computer Science for High Schools*
7. *CTE – Career and Technical Education*