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Strategies for making STEM accessible to everyone: A paper concept

Nur Choiro Siregar [1*], Warsito [2], Aris Gumilar [3], Ahmad Amarullah [4]
[1]Department of Informatics Engineering, Tangerang Muhammadiyah University, Indonesia
[2]Department of Mathematic Education, Tangerang Muhammadiyah University, Indonesia
[3]Management, Tangerang Muhammadiyah University, Indonesia

* Corresponding Author: **Nur Choiro Siregar**

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Abstract
In recent years, there has been a growing emphasis on the importance of Science, Technology, Engineering, and Math (STEM) education in preparing individuals for the challenges of the 21st century. However, equitable access to quality STEM education remains a significant challenge. This paper highlights the strategies to make STEM education accessible to all, regardless of background or ability. Educators and policymakers have recognized the need to adopt innovative approaches in STEM education. It includes promoting hands-on, experiential learning opportunities that engage students in practical problem-solving and critical thinking. Moreover, fostering a supportive, inclusive learning environment that embraces diversity is crucial. Addressing unconscious biases and providing equal opportunities can dismantle barriers to STEM participation. Furthermore, technology is pivotal in making STEM education accessible to everyone. Digital platforms, online courses, and educational apps provide flexible learning options that cater to diverse learning styles and schedules. Virtual reality (VR) and augmented reality (AR) tools offer immersive experiences that enhance understanding and engagement. Collaboration between educational institutions, government agencies, non-profit organizations, and the private sector is another essential aspect of promoting inclusive STEM education. Partnerships can facilitate sharing of expertise and best practices, ensuring a comprehensive and sustainable approach to equitable education. In conclusion, achieving STEM education for all requires a multi-faceted approach. By implementing strategies such as experiential learning, fostering inclusivity, leveraging technology, and promoting collaboration, barriers to STEM education can be overcome. Empowering individuals from diverse backgrounds with the knowledge and skills needed for STEM fields will enhance their opportunities and contribute to a more prosperous and innovative society.

Keywords: Accessibility, Inclusivity, STEM education, Strategies

Introduction

Background and significance of STEM education for all learners

STEM education has gained considerable attention worldwide due to its significance in preparing learners for the challenges of the 21st-century workforce (Kelly & Erb, 2018) [64]. Rapid technological advancements and the increasing demand for STEM-related careers necessitate a comprehensive approach to education that fosters critical thinking, problem-solving, and analytical skills. Including STEM education for all learners, regardless of gender, socioeconomic status, or cultural background, is crucial to ensure equal access to opportunities and promote diversity and inclusion in STEM fields (Miller, 2019; Siregar *et al*., 2023) [83, 105]. By providing learners with a strong foundation in STEM disciplines, educational institutions can empower them to become active contributors to society, develop a scientifically literate population, and drive innovation and economic growth (Gupta, 2017) [41].

Overview of the barriers and challenges faced by underrepresented groups in accessing STEM education

Underrepresented groups face various barriers and challenges in accessing STEM education. These groups include women, racial and ethnic minorities, individuals with disabilities, and those from low-income backgrounds. The past five years have seen a growing awareness of the need to address these disparities and promote diversity in STEM fields (Smith *et al*., 2021) [111]. One significant barrier is more representation and diversity in STEM disciplines. Women and racial/ethnic minorities are notably underrepresented in these fields. Role models and mentors with similar backgrounds and experiences can discourage individuals from pursuing STEM education and careers (Jones & Lee, 2022) [59]. This lack of representation perpetuates stereotypes and biases that hinder the progress of underrepresented groups in STEM.

STEM education is the persistence of implicit biases and stereotypes. Negative perceptions regarding the abilities and aptitudes of individuals from underrepresented groups can discourage their participation in STEM disciplines (Johnson *et al*., 2020) [18]. These biases can be found in educational settings, such as unreasonable teacher expectations or limited access to advanced STEM courses, further exacerbating STEM education disparities.

The lack of representation, implicit biases, and stereotypes hinder the progress of these groups in STEM fields. Addressing these barriers and promoting diversity is imperative to create a more inclusive and equitable STEM education environment (Williams & Davis, 2023) [122]. By recognizing and overcoming these challenges, we can work towards a future where all individuals have equal access and opportunities in STEM education and careers regardless of their background.

Objectives of the paper

(a) To explore strategies that can make STEM education accessible to individuals from diverse backgrounds, including underrepresented groups, individuals with disabilities, and those from low-income communities.
(b) To present effective strategies implemented or proposed to address the accessibility challenges in STEM education.

Literature Review

Understanding Inclusivity in STEM Education

Definition and conceptual framework of inclusivity in STEM education

Inclusivity in STEM education is a multi-faceted concept encompassing intentional efforts to provide equitable access, opportunities, and support for individuals from diverse backgrounds to engage in STEM disciplines. Recent research highlights the importance of inclusivity in addressing disparities and promoting diversity within STEM education (Johnson *et al*., 2020) [18]. It recognizes that individuals with different socio-cultural, gender, and ethnic backgrounds bring unique perspectives, experiences, and talents that can enhance the quality and innovation of STEM education. Inclusivity goes beyond equal access, emphasizing creating inclusive learning environments that foster a sense of belonging, support diverse learning styles, and promote the success and retention of all learners (Bullock *et al*., 2021) [11].

The conceptual framework of inclusivity in STEM education is grounded in equity, diversity, and inclusion principles. Recent literature emphasizes the need to address systemic barriers and promote equitable practices to ensure that all learners, regardless of their background or identity, have equal opportunities to engage and succeed in STEM education (Ramirez-Andreotta *et al*., 2018) [92]. Diversity recognizes the value of diverse perspectives and experiences in enriching STEM fields and aims to broaden the representation and participation of individuals from underrepresented groups. Inclusion complements equity and diversity by creating supportive learning environments that foster a sense of belonging, respect, and empowerment for all learners (Archer *et al*., 2020) [3].

In recent years, a growing body of research and initiatives has focused on promoting inclusivity in STEM education. Researchers have explored strategies and approaches to enhance inclusivity, such as culturally responsive pedagogy, learner-centred instructional practices, and inclusive curriculum design (Lei *et al*., 2020) [74]. Policy developments and educational initiatives have aimed to reduce barriers and improve access to quality STEM education for individuals from underrepresented groups (National Academies of Sciences, Engineering, and Medicine, 2020) [86]. Additionally, professional development programs and training opportunities have been implemented to enhance educators' knowledge and skills in creating inclusive learning environments (Wang, 2021) [119, 120]. The goal is to foster a more inclusive and equitable STEM education ecosystem that reflects the diversity of the broader society and ensures that all individuals have the opportunity to contribute to and benefit from STEM disciplines.

Importance of inclusive practices and their impact on student engagement and achievement

The importance of inclusive practices in education has gained significant attention in recent years due to its positive impact on student engagement and achievement. Inclusive practices involve creating learning environments that value and respect all students' diverse identities, experiences, and needs. Research within the last five years highlights the correlation between inclusive practices and increased student engagement (Meyer & Rose, 2019) [82]. When students feel included and valued, they are more likely to participate in classroom activities actively, contribute their unique perspectives, and take ownership of their learning. Inclusive practices allow students to connect their background knowledge and experiences to the content being taught, enhancing their motivation and interest in the subject matter. Additionally, inclusive courses foster a sense of belonging and create supportive classroom communities, leading to improved academic performance and achievement (Ladson-Billings, 2020) [68]. When students feel accepted and supported, they are more likely to develop a growth mindset, persist through challenges, and achieve their full potential.

The impact of inclusive practices on student engagement and achievement extends beyond the classroom. Inclusive education prepares students for the diverse and interconnected world they will encounter beyond their educational journey. Students develop empathy, respect, and critical thinking skills essential for navigating complex social and professional environments by engaging with diverse perspectives. Inclusive practices also create a more equitable and just society by breaking down barriers and promoting equal opportunities for all learners. Inclusive practices positively influence students' self-perception, self-efficacy, and overall well-being (Bottiani *et al*., 2019; Nieto *et al*.,

2019) [9, 88]. Students who experience inclusivity in their educational settings are more likely to have positive academic and social outcomes, including improved mental health, increased self-confidence, and higher aspirations for their future. Thus, embracing inclusive practices benefits individual students and contributes to a more inclusive and thriving society.

Examination of the benefits of diverse representation in STEM fields

The growing body of research highlights the significant benefits of diverse representation in STEM fields. The diverse term encompasses the inclusion and participation of individuals from various backgrounds, including genders, ethnicities, races, and socioeconomic statuses. Research has consistently shown that diverse representation in STEM fields leads to increased innovation, creativity, and problem-solving capabilities (Kalejaiye, 2019) [62]. When individuals from diverse backgrounds come together to tackle complex scientific challenges, they bring unique perspectives, experiences, and insights that enrich the field. This diversity of thought fosters a collaborative and inclusive environment where a broader range of ideas can be generated, leading to breakthroughs and advancements in STEM disciplines. Additionally, diverse representation in STEM fields inspires and motivates underrepresented groups, encouraging their pursuit of STEM education and careers (Cheryan *et al*., 2016) [20]. Providing role models and showcasing diverse success stories challenges stereotypes and promotes the belief that anyone, regardless of background, can excel and contribute to STEM fields.

The benefits of diverse representation in STEM fields extend beyond innovation and inspiration. Within the last five years, research has demonstrated that various teams and workplaces are more effective in addressing complex problems and making informed decisions (Hunt *et al*., 2015) [51]. Diverse perspectives and experiences lead to a more comprehensive understanding of issues and enable the identification of novel solutions. Diverse representation in STEM fields also contributes to developing products, technologies, and services that are more inclusive and responsive to the needs of diverse populations (Maltese & Tai, 2020) [79]. By considering different viewpoints and various end-users, STEM professionals can design and implement solutions that are culturally sensitive, accessible, and equitable. Furthermore, diverse representation in STEM fields has the potential to address longstanding disparities and promote social and economic equity (Freeman & Huang, 2015) [34]. Creating pathways for individuals from underrepresented groups to enter and thrive in STEM careers diversifies the STEM workforce, reduces systemic barriers, and provides opportunities for economic advancement and social mobility.

Barriers to Accessing STEM Education

Identification and analysis of barriers faced by underrepresented groups in STEM education

Underrepresented groups refer to individuals who have been historically marginalized or have limited representation in STEM fields, including women, racial and ethnic minorities, individuals from low-income backgrounds, and individuals with disabilities. Research has highlighted various systemic barriers that hinder these groups' full participation and success in STEM education (Hernandez *et al*., 2018) [47]. These barriers include early access to quality STEM education, lack of exposure to STEM role models and mentors, bias and stereotypes, inadequate support networks, and exclusionary practices within educational institutions. Identifying and analyzing these barriers is crucial for understanding the root causes of underrepresentation and developing targeted strategies and interventions to promote equity and inclusion in STEM education.

Analyzing the barriers underrepresented groups face in STEM education provides valuable insights into the complex factors contributing to their underrepresentation. The biases and stereotypes, both explicit and implicit, play a significant role in shaping the experiences and opportunities of underrepresented groups in STEM (Walton & Spencer, 2019) [118]. Negative stereotypes can create a hostile and unwelcoming climate, decreasing self-confidence and reducing motivation to pursue STEM disciplines. The intersectionality of identities, where individuals may experience multiple forms of marginalization, also compounds the barriers underrepresented groups face in STEM education (Crenshaw, 1991) [25]. By examining and understanding these barriers, researchers and educators can develop targeted interventions and policies that address the unique needs and challenges underrepresented groups face, ultimately promoting greater inclusivity and diversity in STEM education.

Discussion of factors such as gender, race, socioeconomic status, disability, and cultural biases

Research conducted within the last five years has shed light on the complex ways these factors intersect and contribute to disparities in STEM education (Archer *et al*., 2019; National Academies of Sciences, Engineering, and Medicine, 2020) [1, 86]. Gender has been shown to influence students' self-perception, interest, and participation in STEM subjects, with females often facing stereotypes and biases that discourage their engagement in these fields (Eddy *et al*., 2014; Siregar & Rosli, 2021) [30, 106]. Individuals with disabilities often encounter physical, attitudinal, and systemic barriers restricting their full participation and access to STEM education (Jackson & Parry, 2017) [53].

Understanding the influence of these factors, including gender, race, socioeconomic status, disability, and cultural biases, is essential for developing effective strategies to promote inclusivity and equity in STEM education. Recognizing and challenging cultural biases is crucial to creating a more inclusive and welcoming learning environment for all students (Leslie *et al*., 2015) [75]. Addressing underrepresented groups' specific needs and experiences requires targeted interventions, such as implementing culturally responsive pedagogy and curriculum design incorporating diverse perspectives and experiences (Bryan *et al*., 2018; Gay, 2018) [10, 37]. Providing mentorship programs, role models, and support networks representing diverse backgrounds can also help overcome the barriers underrepresented students face (Malcom *et al*., 2018) [76]. The efforts to improve accessibility and accommodations for students with disabilities, including assistive technologies and inclusive instructional practices, are critical for ensuring their full participation in STEM education (Williams *et al*., 2019) [123].

Exploration of the intersectionality of barriers and their cumulative effects on access

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Strategies for Promoting Inclusivity in STEM Education

Inclusive curriculum design and development

Inclusive curriculum design and development have received significant attention in the past five years as essential to promoting equity and education access. Inclusive curriculum design aims to create learning materials and experiences that reflect and value the diversity of students' backgrounds, experiences, and identities (Moore & Pinder-Grover, 2021) [84]. It involves intentionally selecting and presenting content, instructional strategies, and assessment methods that are inclusive and accessible to all learners. Recent research has emphasized incorporating diverse perspectives, culturally relevant content, and real-world applications into the curriculum to engage students and enhance their learning experiences (Ladson-Billings, 2020) [68]. Inclusive curriculum design also considers students' varied learning styles, abilities, and interests, providing multiple entry points and differentiated instruction to meet their diverse needs. By adopting an inclusive approach to curriculum design, educational institutions can create more meaningful and relevant learning experiences, promote student engagement and achievement, and foster a sense of belonging for all learners.

Inclusive curriculum development involves a collaborative and iterative process considering input from diverse stakeholders, including students, educators, families, and community members. Over the last five years, there has been an increased emphasis on engaging students as active participants in the design and development of the curriculum (Boschman, 2020) [8]. Student voice and agency are integral to creating a curriculum that resonates with their interests, experiences, and aspirations. Involving educators in professional development and training opportunities focused on inclusive curriculum design has been recognized as crucial for successful implementation (Mertens, 2021) [80]. Building educators' capacity to design inclusive curricula allows them to address the diverse needs of their students and create more inclusive learning environments. Furthermore, leveraging technology and digital resources has provided new possibilities for inclusive curriculum design, enabling the customization and personalization of learning experiences to accommodate individual learners' needs and preferences (Hung & Hsu, 2019) [50]. By embracing inclusive curriculum design and development, educational institutions can create more equitable and empowering educational experiences that support the success of all learners.

Incorporating diverse perspectives and contexts in the STEM curriculum

The importance of integrating diverse cultural, social, and historical perspectives into the curriculum to make STEM education more meaningful and engaging for all students (Bybee, 2018) [14]. By including diverse perspectives, such as those of underrepresented groups, indigenous knowledge systems, and global perspectives, educators can provide students with a broader understanding of STEM disciplines' social, ethical, and cultural dimensions (Siregar & Anggrayni, 2023) [104, 105]. Incorporating diverse contexts and real-world applications of STEM knowledge also helps students see the relevance and practical applications of their learning, enhancing their motivation and interest in STEM subjects (Buxton *et al*., 2019; Siregar, 2020) [12, 103]. Furthermore, incorporating diverse perspectives and contexts in the STEM curriculum supports the development of critical thinking skills, problem-solving abilities, and cultural competence, preparing students for the complex challenges and opportunities of a diverse and interconnected world.

Incorporating diverse perspectives and contexts in STEM curricula requires intentional and thoughtful planning by educators and curriculum developers. Within the last five years, there has been a growing emphasis on the need for curriculum materials that reflect the diversity of students' backgrounds and experiences (Rothwell & Brooks, 2021) [100]. It includes selecting and designing learning resources, instructional activities, and assessments that incorporate a range of perspectives, examples, and case studies from diverse communities and cultures. In addition to representation, it is important to foster inclusivity by challenging stereotypes, biases, and systemic inequities within the curriculum (Irving, 2020; Siregar *et al*., 2022) [52, 107]. Integrating diverse perspectives and contexts also necessitates ongoing collaboration and dialogue with students, families, community members, and experts from various fields to ensure that the curriculum accurately represents and respects diverse knowledge systems and lived experiences (Gonsalves, 2020) [38].

Promoting culturally responsive teaching in STEM disciplines

Promoting culturally responsive teaching in STEM disciplines has gained significant attention in recent years to foster inclusivity and enhance student engagement and learning outcomes. Culturally responsive teaching recognizes the importance of valuing and integrating students' cultural

backgrounds, experiences, and perspectives into the STEM curriculum and instructional practices (Ladson-Billings, 2019) [67]. Research has shown that culturally responsive teaching in STEM disciplines can improve student motivation, interest, and achievement, particularly among underrepresented and marginalized students (Bartley, 2020; Estrada *et al*., 2019; Siregar *et al*., 2019) [4, 32, 109]. By incorporating culturally relevant examples, real-world contexts, and diverse perspectives into the STEM curriculum, educators can make the content more meaningful and relatable for students from diverse backgrounds. Culturally responsive teaching in STEM disciplines aims to challenge and dismantle systemic barriers and biases that have historically excluded certain groups from STEM fields (Keating & Stroubakis, 2021) [68]. Through the intentional integration of culturally responsive teaching practices, educators can create an inclusive learning environment that supports the success and well-being of all students and promotes equity in STEM education.

Efforts have been made to provide educators with the knowledge, skills, and resources necessary to promote culturally responsive teaching in STEM disciplines. Professional development programs and workshops have been designed to support educators in integrating culturally responsive pedagogy into their teaching practices (Jayeoba & Jimenez-Silva, 2020) [55]. These programs often focus on helping educators develop a deeper understanding of students' cultural backgrounds, examine their biases, and learn instructional strategies responsive to diverse learners' needs and interests. Furthermore, there has been a push to develop culturally relevant curriculum materials, textbooks, and resources for STEM education (Chiu *et al*., 2021) [21]. These materials incorporate diverse perspectives, culturally significant examples, and authentic applications of STEM knowledge, allowing students to see the connections between their lives and STEM disciplines. Technology has also promoted culturally responsive teaching in STEM by developing digital tools and online platforms that offer customizable and culturally relevant learning experiences (Heredia, 2020) [46].

Teacher training and professional development

Equipping educators with inclusive pedagogical strategies

Educators need to develop a range of inclusive teaching practices that meet the diverse needs of students and foster their engagement and achievement (Ben-Peretz & Dolev, 2021) [7]. Inclusive pedagogical strategies encompass various approaches, such as differentiated instruction, universal design for learning, culturally responsive teaching, and trauma-informed practices. These strategies empower educators to tailor their instruction, materials, and assessments to address students' diverse abilities, learning styles, cultural backgrounds, and prior knowledge (Howard & Hussain, 2020) [49]. Providing educators with training and professional development opportunities focused on inclusive pedagogy is crucial for enhancing their knowledge, skills, and confidence in implementing these strategies effectively (Robinson & Carrington, 2020; Zeichner & Conklin, 2020). By equipping educators with inclusive pedagogical approaches, educational institutions can support the success and well-being of all students, reduce achievement gaps, and create more equitable and inclusive learning environments.

Teacher education programs have recognized the importance of preparing pre-service teachers to effectively engage with diverse student populations and create inclusive classrooms (Sleeter & Hyry-White, 2021) [110]. These programs have incorporated coursework, field experiences, and reflective practices that help future educators develop the knowledge and skills to implement inclusive pedagogical strategies (Larke, 2020) [73]. Professional development initiatives for in-service teachers have focused on enhancing their understanding of inclusive pedagogy and providing ongoing support for its implementation (Riley, 2019) [94]. Collaborative professional learning communities, mentorship programs, and coaching have been employed to facilitate the adoption and sustained use of inclusive pedagogical strategies in the classroom (DeMonte *et al*., 2020) [28].

Fostering awareness of unconscious biases and stereotypes

Individuals, including educators, often hold unconscious biases and stereotypes that can unintentionally influence their perceptions, attitudes, and behaviours towards others (Greenwald & Krieger, 2020) [39]. Unconscious biases and stereotypes can contribute to disparities and inequities in educational settings, impacting student experiences, achievement, and opportunities. Therefore, efforts have been made to raise awareness among educators about these biases and stereotypes to create more inclusive and equitable learning environments. Professional development programs and workshops have been designed to provide educators with opportunities to reflect on their own biases, understand the impact of these biases on their instructional practices, and develop strategies to mitigate their influence (Sue *et al*., 2020).

Addressing unconscious biases and stereotypes in education requires ongoing commitment and a multi-faceted approach. Several strategies have been explored to foster awareness and mitigate the impact of these biases. One process involves providing educators with training and resources that focus on understanding the nature and consequences of unconscious biases and stereotypes (Lai *et al*., 2019) [70]. This training often includes discussions about the social and cognitive processes underlying preferences, case studies that illustrate the impact of biases in educational contexts, and strategies to reduce the influence of biases on decision-making and interactions with students (Lai *et al*., 2021) [71]. Fostering awareness of unconscious biases and stereotypes can involve creating inclusive learning environments that encourage open dialogue, respect for diversity, and critical reflection (Steele *et al*., 2018) [112]. It may include integrating culturally responsive teaching practices, diverse perspectives, and inclusive curriculum materials that challenge stereotypes and allow students to engage with different identities, experiences, and worldviews (Villegas & Irvine, 2018) [117].

Mentoring and support networks

Establishing mentorship programs for underrepresented students in STEM

Mentorship can be crucial in fostering underrepresented students' academic and professional success in STEM disciplines (Eby *et al*., 2020) [29]. Mentorship programs provide a supportive and nurturing environment where underrepresented students can receive guidance, encouragement, and career advice from experienced professionals or peers (Campbell & Campbell, 2021) [17]. These programs address the unique challenges and barriers

underrepresented students face, including limited access to resources, lack of role models, and feelings of isolation (Malone & Barabino, 2019) [78]. Through regular interactions with mentors, underrepresented students can gain insights into the STEM career pathway, develop essential skills, build confidence, and expand their professional networks.

Efforts to establish mentorship programs for underrepresented students in STEM have gained momentum in the last five years, leading to various program models and initiatives. One approach involves creating formal mentorship programs within educational institutions, such as universities and colleges (Byars-Winston *et al*., 2021) [13]. These programs often match underrepresented students with mentors who share similar backgrounds and experiences or possess expertise in the student's chosen field of study (Rodriguez *et al*., 2021) [98]. Mentorship programs have been established through collaborations between educational institutions, industry partners, and community organizations (Campbell & Campbell, 2021) [17]. These programs offer underrepresented students the opportunity to connect with mentors from diverse professional backgrounds, providing a broader range of perspectives and opportunities for career exploration. Furthermore, online platforms and virtual mentorship programs have emerged as viable options, offering flexibility and accessibility to underrepresented students regardless of geographical location (Campbell & Johnson, 2020) [18].

Creating supportive communities to encourage engagement and persistence

Creating supportive communities has emerged as a key strategy in the past five years to encourage student engagement and persistence in various educational settings, including STEM disciplines. When students feel a sense of belonging and connection within their learning environment, they are more likely to engage actively in their studies and persist in facing challenges (Hausmann *et al*., 2019) [45]. In STEM education, establishing supportive communities can help students develop a network of peers, mentors, and role models who provide emotional support, academic assistance, and encouragement (Estrada, 2016) [31]. These communities can be created through various means, such as formal mentoring programs, student organizations, affinity groups, and collaborative learning environments (Wright, 2020) [125]. Moreover, supportive communities can help address the unique challenges and barriers faced by underrepresented students in STEM, such as stereotype threat and feelings of isolation, by providing a space where students can share experiences, seek guidance, and celebrate achievements (Moran & Contreras, 2018) [85].

Efforts to create supportive communities in educational settings have been complemented by technological advances, enabling the establishment of virtual communities that transcend physical boundaries and offer support to students in diverse locations (Gurin *et al*., 2013) [42]. Within the last five years, online platforms, social media, and virtual collaboration tools have been leveraged to connect students with similar interests, goals, and experiences in STEM education (Shen & Tsai, 2021) [102]. These digital communities provide spaces for students to share resources, exchange ideas, and engage in collaborative projects, fostering a sense of belonging and creating opportunities for peer-to-peer support (Perez *et al*., 2019) [90]. These virtual communities offer platforms for connecting students with mentors, professionals, and alums who can provide guidance and serve as role models (Fabelo *et al*., 2020) [33]. By leveraging technology to create supportive virtual communities, educational institutions and organizations can extend support to a wider range of students, including those facing geographical barriers or having limited access to in-person support networks. These virtual communities contribute to cultivating a supportive and inclusive ecosystem that encourages engagement, persistence, and success in STEM education.

Collaboration and partnerships

Collaborating with industry, community organizations, and universities to provide resources and opportunities

They were increasing emphasis on collaboration between educational institutions, industry partners, community organizations, and universities to provide valuable resources and opportunities for students in various fields, including STEM. Such partnerships aim to bridge the gap between academic learning and real-world applications, preparing students for future careers and fostering their engagement and success in STEM disciplines (Rogers *et al*., 2021) [99]. By partnering with industry, educational institutions can gain insights into the skills and knowledge required in the job market, aligning their curricula and programs accordingly (Griffin *et al*., 2020) [40]. Industry partners can offer internships, co-op programs, and work-study opportunities that provide students with hands-on experiences, industry mentorship, and real-world challenges and practices (Roach *et al*., 2021) [95]. Collaboration with community organizations, such as non-profit groups and professional associations, can provide additional resources, networking opportunities, and enrichment programs that enhance students' understanding of STEM fields and career pathways (Lampley, 2020) [72]. Furthermore, universities can collaborate with industry and community partners to establish research centres, innovation hubs, and entrepreneurship programs that encourage multidisciplinary collaboration and support students in translating their knowledge into tangible outcomes (Gaviria *et al*., 2022) [36]. These collaborative efforts between educational institutions, industry partners, community organizations, and universities help bridge theory and practice, expose students to diverse perspectives, and provide them with the resources and opportunities needed to succeed in STEM education and further on.

One notable example is the establishment of industry-sponsored scholarship programs and grants supporting students from underrepresented backgrounds in STEM education (Davis *et al*., 2021) [27]. These programs provide financial support and offer mentorship, career guidance, and networking opportunities through industry professionals. Community organizations have played a crucial role in facilitating STEM outreach programs, after-school initiatives, and mentorship schemes that expose students to STEM fields and spark their interest (Trauth *et al*., 2020) [115]. These collaborations allow students to engage in hands-on activities, interact with role models, and participate in STEM-related projects that enhance their understanding and enthusiasm for STEM disciplines (Siregar & Anggrayni, 2023) [104, 105]. Moreover, universities have partnered with industry and community organizations to establish cooperative education programs, where students alternate between academic study and practical work experience, gaining valuable skills, industry connections, and a

competitive edge in the job market (Robbins-Roth, 2022) [96]. Through these collaborative efforts, students can access various resources, mentoring relationships, and experiential learning opportunities that broaden their horizons, foster their professional development, and empower them to succeed in STEM fields.

Forging partnerships to develop inclusive STEM programs and initiatives

These partnerships aim to create collaborative networks that leverage the expertise, resources, and perspectives of multiple stakeholders to enhance the accessibility and effectiveness of STEM education (Chen *et al*., 2021) [19]. By working together, these partnerships can address the unique needs and challenges faced by underrepresented groups, such as women, racial and ethnic minorities, and individuals from low socioeconomic backgrounds, in STEM education and careers (Jorgenson *et al*., 2021) [60]. Educational institutions bring pedagogical expertise, curriculum development knowledge, and access to students, while community organizations contribute community connections, outreach capabilities, and an understanding of local contexts (Kahn, 2022) [61]. Industry stakeholders can provide industry-specific knowledge, mentorship, and support, helping to bridge the gap between classroom learning and real-world applications (Galindo *et al*., 2021) [35]. Together, these partnerships foster the development of inclusive STEM programs and initiatives that promote diversity, equity, and accessibility, creating pathways for underrepresented groups to enter and succeed in STEM fields.

The forging of partnerships to develop inclusive STEM programs and initiatives has resulted in various collaborative efforts within the last five years. For example, collaborations between educational institutions and community organizations have established STEM enrichment programs and after-school initiatives targeted at underrepresented students (Reuben *et al*., 2020) [93]. These programs provide hands-on experiences, mentoring, and resources to engage students in STEM disciplines and spark their interest in STEM-related careers. Partnerships between educational institutions and industry stakeholders have facilitated the development of work-integrated learning programs, internships, and apprenticeships that bridge the gap between classroom learning and the professional world (Radford *et al*., 2021) [91]. These programs allow students to apply their knowledge in real-world settings, gain industry-specific skills, and establish professional networks. Collaborations between multiple stakeholders have created inclusive curriculum materials, online resources, and professional development opportunities for educators (Bybee *et al*., 2022; Bell *et al*., 2020) [15, 6]. These resources support educators in implementing inclusive teaching practices, addressing implicit biases, and creating learning environments that are accessible and welcoming to all students. Through these partnerships, inclusive STEM programs and initiatives are developed, enhancing opportunities for underrepresented groups and promoting diversity and equity in STEM education and careers.

Policy Recommendations

Policy Implications for promoting inclusive STEM education

Policymakers, educators, and researchers have engaged in extensive discussions and analyses to identify key policy levers supporting and advancing inclusivity in STEM (Correll & Kurland, 2020) [23]. These discussions have identified several critical areas for policy intervention, such as the allocation of funding resources, the development of inclusive curriculum standards, and the implementation of equity-focused strategies (Knezek *et al*., 2021; Miller *et al*., 2022) [66]. Policy implications have emerged for various educational levels, from early childhood education to postsecondary institutions, with a particular emphasis on addressing disparities and inequities faced by underrepresented groups (Wang *et al*., 2021) [119, 120]. Furthermore, policy discussions have highlighted the importance of collaboration among policymakers, educators, industry representatives, and community stakeholders to ensure the effective implementation and sustainability of inclusive STEM education initiatives (Kim, 2022) [65]. By addressing these policy implications, policymakers can create a more equitable and accessible STEM education system that fosters diversity, supports underrepresented groups, and prepares all students for success in the STEM workforce.

Recent policy discussions and analyses have emphasized the importance of comprehensive policy frameworks that promote inclusive STEM education. These frameworks consider a range of policy domains, including funding and resource allocation, curriculum development, teacher professional development, and assessment practices (Dare *et al*., 2020; Metz, 2021) [66, 81]. Policy implications have focused on the need for targeted investments in underserved communities, providing equal access to quality STEM education opportunities for all students, regardless of their socioeconomic status or demographic background (Cohen & Piquero, 2021; Wilson *et al*., 2022) [22, 124]. Additionally, policies have emphasized the importance of developing inclusive curriculum standards that incorporate diverse perspectives, culturally relevant content, and interdisciplinary approaches (Craig *et al*., 2020) [24]. Policy implications also call for the implementation of professional development programs that equip educators with the knowledge and skills to create inclusive learning environments, address implicit biases, and support the diverse needs of students (Hewlett *et al*., 2022; Johnson *et al*., 2021) [48, 56].

Advocacy for policy changes and support at institutional, regional, and national levels

Advocates, including educators, researchers, and organizations, have actively raised awareness about the importance of inclusivity in STEM and advocated for policy reforms to address systemic barriers (Adams, 2021; Byrd *et al*., 2023) [1, 16]. At the institutional level, advocacy efforts have focused on promoting diversity and inclusion in hiring practices, fostering inclusive campus climates, and establishing support systems for underrepresented students in STEM disciplines (Parker & Roy, 2021) [89]. Regionally, advocates have collaborated with educational institutions, community organizations, and policymakers to develop regional STEM education networks, share best practices, and advocate for resources and funding to support inclusive STEM initiatives (Sanders *et al*., 2022; Thompson & Johnson, 2023) [101, 16]. Nationally, advocacy organizations have played a crucial role in lobbying for policy changes that prioritize inclusivity, equity, and access in STEM education, urging policymakers to allocate resources, develop

legislation, and establish national initiatives that support diverse students in pursuing STEM pathways (Hatch, 2020; Williams & Lewis, 2022) [44, 122]. Advocacy for policy changes and supporting inclusive STEM education has gained momentum in the last five years. Advocates have worked tirelessly to highlight the urgent need for policies addressing disparities and ensuring equal STEM education access for historically underrepresented groups (Malloy *et al*., 2021; Robinson & Cortes, 2022) [77, 97]. They have urged policymakers to prioritize funding for targeted initiatives, such as scholarship programs, mentorship opportunities, and after-school STEM programs, which support the engagement and success of underrepresented students in STEM (James & Davenport, 2020) [54]. Advocacy efforts have also emphasized the importance of institutionalizing policies that promote diversity and inclusion in STEM education, including the implementation of inclusive curriculum standards, the provision of professional development for educators, and the creation of inclusive learning environments (Gutiérrez & Jurow, 2020; Jones *et al*., 2023) [48, 58]. Furthermore, advocates have stressed the significance of data-driven policymaking, urging policymakers to collect and analyze disaggregated data on student outcomes in STEM to inform evidence-based policy decisions (Vasquez, 2022) [116]. Through their advocacy efforts at various levels, advocates strive to bring about transformative policy changes that foster inclusivity, equity, and opportunities for all learners in STEM fields.

Conclusion

Achieving STEM education for all necessitates implementing effective strategies that make science, technology, engineering, and math accessible to everyone. By recognizing and addressing the barriers that hinder equitable access, such as unconscious biases and limited resources, we can create a level playing field for learners from all backgrounds. Implementing inclusive teaching methods, promoting hands-on learning experiences, and leveraging technology can enhance engagement and comprehension in STEM subjects. Collaboration between educational institutions, policymakers, and the wider community is crucial to developing comprehensive and sustainable STEM education approaches. We can empower individuals, foster innovation, and contribute to a more equitable and prosperous society by ensuring that no one is left behind in accessing and benefiting from STEM education.

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