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Motivation and Persistence in STEM Education: Addressing Attrition in the STEM Pipeline

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Abstract

Despite job growth in science, technology, engineering, and mathematics (STEM) careers and an educational emphasis on developing STEM programs, there is still a shortage of graduates prepared to fill these jobs. This literature review examines the motivational factors that influence persistence in STEM and programs or curricular changes that encourage STEM participation and skill development. The lack of STEM participation threatens the health of national economies and equity, as gender and racial disparities disproportionately affect underrepresented groups. Key motivational factors that impact participation are self-efficacy, growth mindset, and belonging. Active learning that emphasizes personal growth and questioning, along with supportive learning environments, increases engagement. STEM learning should connect to real-life applications, and student benefit from participation in STEM opportunities in their community. Mentorship and role models help students envision themselves in STEM careers, particularly for underrepresented groups, helping them work past perceived barriers. Schools should implement STEM programs at the elementary level and continue to reinforce participation through various programs until graduation.

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Introduction

Science, technology, engineering, and mathematics (STEM) have become an area of focus in education to meet the growing need for a workforce that is increasingly interdisciplinary (Asunda, 2018). While the number of jobs in STEM careers is growing, there is a global shortage of qualified professionals to fill them. STEM education is seen as a strategic response to these challenges. However, schools have met difficulties because many students fall away from STEM studies during their educational path. This loss of potential students is most pronounced among women and underrepresented minorities. A lack of a unified STEM definition has led to inconsistent practice and research, with a lack of clarity about the level of integration that is needed. This literature review examines the following questions:

- What motivational factors influence student persistence in STEM education?
- What programs and curricular changes increase student participation in the STEM pipeline?

STEM

STEM combines science branches with an interdisciplinary approach that combines science, engineering, technology, and mathematics to expose students to how these subjects are applied in real life (Armtcu & Bal, 2023). The STEM emphasis in education was created to develop more positive student attitudes in STEM classes to foster greater interest in STEM fields (Farrell, 2023). This emphasis is based on the need to fill jobs that require mathematics and science skills (Waters & Orange, 2022), a job market that is growing without enough qualified graduates to fill positions (Flores, 2023). Despite efforts to increase participation in STEM fields, there is a global deficit of graduates, and the need is especially high in math-intensive careers (Ozturk, 2024).

The changing job market reflects the changing landscape of global problems and technological advances, requiring new skills for the workplace. Many students are not prepared to meet the needs of the future economy, where problem-solving skills and critical thinking are essential (Waters & Orange, 2022). The term *21st-century skills* refers to the skills needed to meet these needs and includes higher-thinking skills such as critical thinking, estimation, problem-solving, and reasoning, as well as social skills of cooperation, entrepreneurship, communication, creativity, and innovation (Armutcu & Bal, 2023). Students must understand the complex nature of problem solving in real life, where there may be more than one valid approach and more than one acceptable solution. Students experience various dilemmas and explore different strategies (Makonye & Moodley, 2023). The emphasis is not on what a student knows, but how they can apply that knowledge (Asunda, 2018). Traditionally, learning mathematics has focused on skills and routines, but computers are increasingly capable of performing these tasks. Therefore, education needs to emphasize modelling and applications (Kristensen et al., 2024). For STEM education, this often comes through an emphasis on problem-based learning (PBL), which has been shown to lead to increased retention, life-long learning skills, exposure to real-life experiences, and increased motivation towards STEM fields (Asunda, 2018).

STEM education has the potential to help students navigate through real-world problems by applying knowledge and skills from the individual disciplines to complex and interdisciplinary contexts (Kristensen et al., 2024). The interdisciplinary approach helps students make real-life connections, contributing to students' competence in complex contexts while promoting individual disciplinary knowledge and practices. STEM learning occurs through an engineering design process where they learn by doing, developing understanding by learning from mistakes and refining ideas (Margot & Kettler, 2019). Learners gain knowledge and skills in the disciplines of science, technology, engineering, and mathematics while focusing on creativity, critical thinking, and problem solving (Bayanova et al., 2023). Creating interest and engagement are important goals of STEM education to prepare a STEM workforce and make connections between the STEM disciplines (Margot & Keller, 2019).

Barriers and Challenges

Unfortunately, Asunda (2018) observed that there is a lack of clarity in defining STEM that reduces STEM education to more of a slogan. The lack of a clear definition has been a criticism of STEM, complicating research because of inconsistent implementation (Farrell, 2023). STEM lessons often lack clarity about what connections should be made or how learning will be assessed (Wang et al., 2022; Wiesselmann et al., 2021). There is no consensus on whether STEM is just an interdisciplinary approach or if it could place more emphasis on each individual discipline (Kristensen et al., 2024). Watson et al. (2022) found 9 different levels of STEM represented in literature: a reference to any one of the single disciplines, referencing science and math, separate science disciplines incorporating other science disciplines (such as chemistry and biology), individual disciplines (sometimes called *silos*), science and math connected by technology or engineering, coordination across any two or more disciplines, combination of two or more disciplines, integration across disciplines, or as a transdisciplinary course or program. Waters & Orange (2022) called for more case studies of STEM schools to develop common frameworks and language.

There is insufficient research to inform theory, policy, and practice when STEM may have multiple interpretations, including multidisciplinary, interdisciplinary, or transdisciplinary approaches (Goos et al., 2023). It is not always possible or desirable to teach every STEM concept through cross-disciplinary lessons because some concepts require individual attention. Wielselmann et al. (2022) found that inclusive schools that emphasize PBL lack an individual focus, leading math and science content to suffer. Makonye and Moodley (2023) found that students often do not recognize the mathematics in an integrated course. Furthermore, the math that is integrated into STEM activities is often at a low computational level, leading math teachers to believe their expertise is not needed for integration. In articles about integrated STEM lessons, Goos et al. (2023) found that math was rarely given attention and was mostly just a tool to support the learning of the other subjects. Through these lessons, students were not learning new math skills or deepening their mathematical thinking. Collaboration was often unbalanced, with science learning goals dominating the content for integrated lessons. This is unfortunate, because mathematical modelling is a powerful tool for understanding and predicting the world, and all branches of science require mathematical modeling (Armutcu & Bal, 2023). Most real-world problems are interdisciplinary, and mathematical modeling is a tool to express and solve unique problems.

Another barrier to integration is the demands of high-stakes testing. Schools are often reluctant to add STEM integration because they prioritize state mandates (Waters & Orange, 2022). Teachers are reluctant when standardized test scores are used for evaluation, questioning whether the STEM implementation will meet the required subject area curriculum (Watson et al., 2022). Furthermore, at least at the secondary level, departments and teacher training are still divided by discipline, and accountability is tied to discipline-specific standardized tests (Jiang, 2019).

The STEM Pipeline

With the number of jobs in STEM fields increasing, there is a need to produce more STEM university graduates (Chambers et al., 2022). A strong STEM workforce is needed for future economic prosperity and resilience, yet, despite efforts to boost STEM participation, there is a global deficit of graduates (Ozturk et al., 2024), especially in jobs requiring science and math training (Waters & Orange, 2022). STEM jobs are available, but there are not enough graduates to fill them (Flores, 2023). The term *STEM pipeline* refers to the track followed by young students through elementary to university graduation (Farrell, 2023). The term, explained Farrell, rose from the need to develop professionals from a young age for preparation in STEM fields. There is a need to encourage more students to gravitate towards STEM fields and prepare them to work in these fields (Bayanova et al., 2023).

However, the STEM pipeline is leaky. Initial interest in STEM is not enough because students either lose interest in STEM or abandon it (Farrell, 2023). These leaks happen at many levels of education for varying reasons. Flores (2023) found that the leakage begins as early as 5th grade for many girls, where they lose confidence in their STEM abilities. Moving on through 12th grade, interest in STEM careers continues to drop among minority groups and females as they become aware of social inequalities that act as barriers, while feeling helpless to effect systemic changes (Flores, 2023; Mulvey et al., 2023). Despite the growing job market and the emphasis on spending to encourage more students to pursue STEM careers, minority groups and females are underrepresented and earn significantly less than their White male counterparts. Flores argued that males have been encouraged towards STEM fields while teachers, social influence, and peers encourage women to perform in other fields. Students may have an interest in STEM, but the awareness of the barriers leads to the belief that it is unattainable or they do not belong (Mulvey et al, 2023).

Watson et al. (2022) recommended that STEM should be introduced at the elementary level, encouraging positive attitudes and engagement with STEM. As students continue through school, they begin to face barriers to persistence. Often, a parent's lack of STEM confidence or anxiety about STEM subjects is passed on to their children unintentionally. Math anxiety leads students to struggle in developmental math courses, deterring them from persisting in STEM (Samuel et al., 2023). Math anxiety leads to the avoidance of advanced study, especially by women and ethnic minority students by weakening resilience and persistence. This leads to decreased academic performance, which in turn increases educational disparities. The pipeline continues to leak at the university level, where many students abandon STEM majors after facing challenges. Chambers et al. (2022) found in a study at one institution that many students did not pass the first course in their STEM major, and most had left the STEM major before the end of their sophomore year, leading to a low 25% retention rate for STEM majors. To change these high attrition rates, students need to be prepared with the skills and mindsets to persist in the gate-keeper courses. Students often leave because of the perceived difficulty, poor learning environments and pedagogy, and a lack of support systems. Chambers et al. found the need to foster identity, commitment, and confidence in addition to developing skills.

These leaks disproportionately affect females and minority students (Farrell, 2023). Selective STEM schools are often highly competitive and have low minority representation (Wieselmann et al., 2021). STEM schools that emphasize equity provide a place to serve underrepresented youths. These schools encourage the enrollment of students regardless of past experience and lack of success in science and math, with the hope of developing interest and abilities in STEM. Studies have shown that these inclusive schools benefit students and contribute to increased equity. Ozturk et al. (2024) believed that promoting more interest in math-intensive fields is an important factor in closing the gender gap and pay disparities for women and racial minorities. Makonye and Moodley (2023) found that learners from historically oppressed groups benefited from learning from role models and mentors, especially in learning through practice situated in real-world activities. Dasgupta et al. (2022) found that girls were more interested in STEM careers and felt greater belonging in science and math when they observed female scientists working towards communal goals. Mulvey et al. (2023) encouraged out-of-school STEM experiences to increase interest among adolescents. Community engagement helps students feel connected and see the relevance of STEM in their community. It helps students see themselves in STEM to address problems that their community faces, helping them believe they could have a place in STEM.

Motivation

Motivation is an important factor for active engagement, interest, and achievement, and has a significant influence on a student's learning outcomes and career choices (Bayanova et al., 2023). Psychological factors involving belonging and perceptions of discrimination affect both classroom engagement and out-of-school engagement in STEM (Mulvey et al., 2023). Modern motivational theory emphasizes the importance of task value, goals, and beliefs in influencing motivation (Farrell, 2023). Success and engagement in the classroom are closely tied to indicators of motivation, including self-efficacy, task value, self-regulation, and learning goal orientation. Yeager and Dweck (2020) attributed the level of engagement and persistence to beliefs about their ability to achieve a goal, leading to either avoidance or engagement with difficult tasks. A helpless pattern will lead to avoidance when faced with obstacles, but a mastery-oriented pattern will seek out challenging tasks and maintain effort in the face of failures (Hargreaves et al., 2021). Researchers have found that active participation in discussions and questioning through STEM activities leads to higher STEM interest, increased academic success, and positive effects on daily awareness and life skills (Armtcu & Bal, 2023). One goal of STEM education is to improve the learners' satisfaction and motivation while decreasing stress (Dasgupta et al., 2022).

Self-efficacy

Math anxiety leads to negative cognitive responses, including feelings of helplessness and mental disorganization (Samuel et al., 2023). These feelings hinder learning, causing poor test performance and reinforcing self-doubt about math competence. This self-doubt leads students to withdraw from math-related activities. S*elf-efficacy* refers to the beliefs individuals have about their ability to achieve specific levels of performance to exercise influence over their life (Bandura, 1977). Bandura found that people avoid difficult situations when they believe they lack the skills to effectively engage. On the other hand, a person is likely to engage in an activity if they believe they are able to handle any difficulties that might arise. The individual's perception of their own efficacy is a predictor of whether they will persist, and persistence leads to outcomes that reinforce self-efficacy. Self-efficacy influences academic and career choices as well as performance outcomes (Flores, 2023). Students are less motivated to pursue goals that they do not believe they can accomplish (Farrell, 2023). Self-efficacy is closely tied to the student's *goal orientation* (choices about what goals to pursue), *task value* (how worthwhile a goal is worth pursuing when compared with the necessary effort), and *self-regulation* (the perseverance and discipline to achieve a goal).

Often, the move from elementary to middle school is a time when students display a decline in self-efficacy, likely from factors outside the classroom (Farrell, 2023). Self-efficacy is understood to be correlated with more positive participation in STEM activities, especially for minority and female students (Kramer et al., 2023). Kramer et al. also found that high-performing female students tended to have lower self-efficacy than lower-performing male peers. The lower-performing male students were more likely to pursue STEM due to their beliefs about their abilities. Kramer et al. encouraged STEM educators to build self-efficacy by using mastery performance strategies, vicarious experiences, and social persuasions. Vicarious experiences and social persuasion could involve, among other things, exposing students to speakers or role models representing diverse backgrounds. Mulvey et al. (2022) found that emphasizing the personal relevance of STEM led to students placing higher value on the work, and they reported higher self-efficacy, motivation, and achievement. Addressing knowledge gaps is an important factor in building self-efficacy (Dasgupta et al., 2022), so educators should encourage positive participation in STEM.

Self-efficacy is often built through past mastery performance, but it is also developed through vicarious experiences and social persuasions (Kramer et al., 2023). These experiences and persuasions include speakers, mentors, role models, and peers encouraging the pursuit of STEM careers. Self-efficacy is a strong predictor of a student's choices, effort, and perseverance in achieving goals (Farrell, 2023). Therefore, self-efficacy is a high predictor for the choice to pursue STEM (Kramer et al., 2023). Unfortunately, researchers have found that self-efficacy often drops about the time children transition from elementary to middle school, with many of the factors leading to this drop happening outside the classroom (Farrell, 2023). This drop in can affect student engagement, so it is important to implement strategies that strengthen self-efficacy.

Higher self-efficacy in STEM classrooms has led to students completing more tasks in project-based learning units (Farrell, 2023). If students do not believe they can accomplish a goal, they will be less motivated to try, so it is important to understand strategies to improve self-efficacy. Mulvey et al. (2023) found that connecting mathematics to socially relevant topics increased participation in their math classes. According to Dasgupta et al. (2022), the emphasis on personal relevance of STEM to real life leads students to place a higher value on the work, resulting in higher self-efficacy, motivation, and achievement. The value that students place on tasks is an aspect of expectancy-value theory, which addresses the desire to complete a task based on the value an individual places on that task (Farrell, 2023). Expectancy-value theory balances expectancy beliefs with subjective task values (Ozturk et al., 2024). Expectancy beliefs can be seen as the task-specific expectations of success based on self-efficacy. Subjective task values weigh perceptions about the value of achieving a goal against the perceived cost. These expectancy beliefs are closely tied to the career interests of adolescents towards math-intensive fields.

Growth Mindset

Learning through mistakes is often cited as an important aspect of the STEM learning framework (Margot & Kettler, 2019), mirroring the concept of productive failure that is a key part of the engineering process (Waters & Orange, 2022). This need to embrace failure appears to be at odds with traditional attitudes towards education that reward proficiency. This orientation is addressed through *incremental theory*, which holds that intelligence is something that can be developed and increased through effort and performance, and its counter *entity theory*, which finds intelligence to be a fixed attribute that cannot change even with effort (Bernardo et al., 2021). A person's beliefs towards either orientation are either a *fixed mindset*, that intelligence is a fixed talent, or a *growth mindset*, that intelligence can be developed over time through practice and performance (Samuel et al., 2023). Under a fixed mindset, low self-efficacy leads at-risk students to become self-sabotaging by exerting less effort. Feelings of anxiety lead to disengagement when the student feels doomed to failure despite their effort. The belief that abilities cannot change may lead students to feel like they do not belong in STEM, which will increase anxiety and lower their STEM interest (Canning et al., 2019).

Even proficient students suffer from a fixed mindset because they are less likely to attempt tasks that do not make them look good (Dweck & Yeager, 2019). The emphasis on performance goals leads students to learn through external motivations, by seeking favorable judgments about their competence from others (Hargreaves et al., 2021). This leads lower-attaining children to have a helpless attitude and higher-attaining students to avoid challenges. In either case, the student is sacrificing the opportunity for new learning out of a fear of making an error or appearing incapable. A fixed mindset can negatively affect students because they are less likely to seek feedback, less likely to check for errors, and are less likely to accept critical feedback (Samuel et al., 2023). Students with a fixed mindset are more likely to focus on competition, comparing themselves to other learners as a measure of their ability (Yeager & Dweck, 2020). As students reach higher levels of education, a fixed mindset might lead them to believe they cannot change how they perform (Chambers et al., 2022). They are less likely to try again after their first failure, preventing them from reaching their full potential. This view is often evident in mathematics, where students come to believe that mathematics is an innate ability, as they heard from parents or others (Ozturk et al., 2024). This leads some students to avoid math-intensive careers.

People with a growth mindset, on the other hand, believe their abilities are malleable and are developed through persistence, the use of learning strategies, and mentoring (Canning et al., 2019). Kramer et al. (2023) connected a growth mindset with a tendency to persist when faced with challenges and being motivated by the desire to improve ability. An individual with a growth mindset is more likely to persevere, seeing obstacles as difficult but achievable (Kroeper et al., 2022). Under a growth mindset, students will seek improvement for their own satisfaction and to gain competence (Hargreaves et al., 2021). Dweck and Yeager (2019) found that displaying a growth mindset increased educational outcomes because it led to challenge seeking and resilience. Growth mindset has been tied to positive learning behaviors, building self-efficacy, creativity, and a higher motivation for learning (Vongkulluksn et al., 2021). The belief that abilities can be developed means students are more likely to set mastery goals and persist despite challenges. Interventions that promote a growth mindset have been shown to relate to positive participation in STEM, especially for minority students (Kramer et al., 2023). Meta-analyses have found positive links between growth mindset and math engagement while improving academic outcomes, especially among at-risk subgroups (Mulvey et al., 2023).

Growth Mindset and Self-efficacy

Students' attitudes, beliefs about their ability, motivation, and cultural influences can affect how they view the potential growth of their intelligence, which may impact their interest in STEM careers (Flores, 2023). Teachers who understand that self-efficacy affects motivation should encourage students to overcome obstacles to build self-efficacy. Stohlmann (2022) found that students with a growth mindset are more likely to have higher self-efficacy. Building a growth mindset is not just about expending more effort, but also learning and trying new approaches and seeking assistance when it is needed. Students build self-efficacy when they experience success through learned behaviors. Yeagar and Dweck (2020) found that students with a growth mindset demonstrated more challenge seeking behavior, such as choosing to take and stay in more advanced mathematics courses in high school. Interventions encouraging a growth mindset have been found to have the most meaningful effect when participants are currently experiencing challenges or setbacks.

Challenges in Studying Beliefs

One criticism to growth mindset theories is that it is difficult to measure beliefs, and it is possible that factors other than growth mindset are responsible for academic achievement in these studies (Macnamara & Burgoyne, 2023). Macnamara and Burgoyne pointed out that growth mindset interventions also include teaching strategies for overcoming setbacks, normalizing mistakes, goal setting, and individualized study plans. Proponents counter that many studies have shown academic improvement in students, especially among vulnerable groups (Yeager and Dweck, 2020). Burnette et al. (2020) reported positive psychological outcomes of students expressing a growth mindset, including reduced anxiety and fewer symptoms of depression.

Studying STEM engagement through abstract mental processes creates challenges for researchers. Beliefs are complex and dynamic, not always internally consistent or coherent, often happen outside of conscious awareness, and evolve over time (Kramer et al., 2023). In one study into growth mindset and STEM, Kramer et al. found students expressing conflicting beliefs. They would talk about growth mindset ideas, where effort can increase intelligence, but then expose a fixed mindset by referring to innate abilities acting as a barrier. There was also a misalignment between the qualitative and quantitative findings, exposing incoherent beliefs about intelligence. Sisk et al. (2018) also noted that measuring mindsets is often on a subjective scale, and students may respond to questionnaires the way they think they should instead of their actual beliefs.

Many teachers also confuse growth mindset, which is a belief orientation, with the associated behaviors such as intellectual risk-taking (Clark & Soutter, 2022). Displaying specific behaviors is not always associated with beliefs and can be influenced by other factors. Some of the controversy around growth mindset is that academic success might be associated more with the learned skills taught alongside growth mindset rather than affective motivations. Measures of mindset that are tied to academic achievement measures, such as grade point average (GPA), could also be skewed, because students who have a growth mindset should be more willing to engage in more difficult coursework, risking a lower GPA for the sake of personal growth (Sisk et al., 2018). Dasgupta et al. (2022) questioned the high volume of research into abstract attitudes about STEM, where the actual behaviors and lived experiences of engagement in classrooms may be more significant.

Increasing Engagement

Educators should be asking how they can keep more students interested in STEM when the leaking STEM pipeline is leading to STEM jobs that are unfilled. Of course, achievement is important, but educators need to focus on keeping students engaged (Farrell, 2023). Clark and Soutter (2022) pointed to a body of literature stressing the importance of creating educational environments that are mastery-oriented, focus on learning over performance, emphasize thought processes over solutions, normalize confusion, genuinely value mistakes, foster positive learning behaviors through explicit instruction, and thoughtfully create safe classrooms and trust with students. Furthermore, knowledge is a product of the situations where learning takes place, so instruction must be placed within a context where students can meaningfully relate learning content to their lives (Koehler et al., 2013).

Developmental Stages

The emphasis on STEM learning should begin at the elementary level (Flores, 2023; Stohlmann, 2022; Waters & Orange, 2022; Watson et al., 2022). Early exposure increases the likelihood that students will build an interest in STEM careers (Flores, 2023) that will persist in later grades (Stohlmann, 2022). Students should be given experience in how STEM skills are connected to real-life applications and possible careers while building fundamental skills. Moving into early adolescence in the middle school grades, students are highly influenced by communal values and interests formed at this age are likely to persist through high school and predict university majors (Dasgupta et al., 2022). Algebra performance and interest in grade 8 are highly critical, as they are closely connected to later STEM motivation and interest.

Adolescence is when students begin to form a sense of their own identity, balancing the desire for peer acceptance with an awareness of approaching adulthood, particularly in recognizing their intellectual growth and the need to build skills for future economic independence (Parkay et al., 2014). The sense of belonging is especially important at this age, where students are motivated to engage when they are able to see themselves in STEM (Mulvey et al., 2023). Exposure to representative role models and mentors in STEM careers is an important motivator for career aspirations, especially for groups that are underrepresented or have historically faced barriers to STEM careers (Flores, 2023). Students who are fully emersed in STEM during high school are more likely to pursue STEM in university (Farrell, 2023).

Focus on Meaningful Content

The teaching of STEM subjects can often be a sanitized version of the real thing, carefully compartmentalized into individual skills. Teachers cannot just tell students STEM is relevant; the connections from in-class content to real-world applications need to be made explicit (Kramer et al., 2023). STEM activities should emphasize connections between classroom learning and out-of-school contexts (Scherer et al., 2019). Often, the emphasis on STEM is framed in terms of addressing economic concerns, both for national and individual benefit, but STEM also acts as a motivating force when students see the power it has to address ecological and cultural issues (Nicol et al., 2023). There are limitations to classroom teaching, and students should be exposed to the benefits of studying things in the natural world and in their communities.

Out of School Engagement and Activism

Experiencing STEM outside of the classroom provides several benefits for students. Ozturk et al. (2024) found that out-of-school opportunities such as programs at museums, zoos, and aquariums promote career interest and a sense of belonging, especially for traditionally marginalized students. Participation in STEM camps has a positive impact on students' career aspirations (Flores, 2023). STEM internship programs develop self-efficacy, goal orientation, and persistence (Farrell, 2023). Student engagement in a community-based STEM course was correlated with higher math and science proficiency (Mulvey et al., 2023). Mulvey et al. suggested that these programs encourage students to pursue STEM careers because they can see how STEM is relevant personally and to the future of their community. Some researchers have also pointed out that students from some demographic groups, particularly Black, Latinx, and Native American, are more likely to be influenced by community benefits than self-oriented reasons when choosing an educational path (Dasgupta et al., 2022). These experiences also offer opportunities for students to make connections with professionals in these fields who can serve as mentors and role models (Watson et al., 2022). Personal connections increase the likelihood that a student will consider a STEM field.

Often, subjects like math and science are not seen as community activities, but their applications in the real world affect communities (Dasgupta et al., 2020). There are many ethical dilemmas in the world that can be addressed through scientific research and technological development (Maass et al., 2019). Many students are motivated by opportunities for responsible citizenship and ethical stewardship of the planet. STEM can draw attention to issues of social justice and technology innovation for building a more just and beautiful world (Nicol et al., 2023). Community activism can encourage participation in STEM careers.

Subject Area Emphasis

Ensuring the integrity of the STEM pipeline requires that students have interest and the necessary skills. STEM lessons are often weakened by vagueness or uncertainty about what and how to assess the lessons, or even by what subjects and skills are being emphasized (Scherer et al., 2019; Wang et al., 2022). When integration takes place, it needs to be made explicit so learners understand the intentional connectedness of each discipline (Margot

& Kettler, 2019). Unfortunately, reviewing literature on STEM lessons reveals that most integrated lessons do not focus on mathematics, and integrated lessons are rarely used to support higher mathematical thinking (Kristensen et al., 2024). Students need to be able to apply math concepts to real-world situations, but building strong modeling capabilities requires abstract algebraic principles (Reinke, 2019). Similarly, technology is frequently used as a tool in STEM, but is rarely taught explicitly (Wieselmann et al., 2021).

Sometimes it is necessary to build on domain-specific skills. Problem-based learning (PBL) increases student engagement and motivation (Mujumdar et al., 2024). As students increase their interest in STEM, they will be more willing to engage with increasingly abstract concepts. Sun (2018) advocated PBL as a multidimensional approach for math that emphasizes both the sense-making aspect of problem solving and procedural fluency. Unfortunately, low-achieving students are often grouped into remedial tracks where they focus only on basic skills, missing the conceptually rich activities that would benefit them. Sun encouraged teachers to have high expectations for all students and value student ideas, representations, and strategies over correctness. Mistakes can become an opportunity for the class to engage in making meaning from mathematical processes.

Having high expectations still means that students need time to think deeply about learning. Galanti and Miller (2021) warned against rushing students through accelerated programs because students may focus on speed, memorization, and correctness without finding time to really do the math and internalize concepts. The core of mathematics is not the discrete skills students learn. Mathematics is about sense-making, which involves the ability to connect and reason.

School Culture

School culture reflects the school's norms, goals, and values (Waters & Orange, 2022). It is reflected through teaching and learning practices and organizational structures. A positive school culture will be reflected in behaviors that increase student engagement so that students can thrive and find academic success. Teachers need to lead the way by making students feel safe in taking risks and accepting failure. Developing 21st-century competencies requires an emphasis on collaboration and creativity, and the school culture should foster those values.

Encourage Growth Mindset

Creative thinking and a growth mindset toward learning can be threatened by a systemic promotion of conformist behaviors and competition, including comparisons between students (Hargreaves et al., 2021). Instructors and school culture play a critical role in building a growth mindset in students through their expectations and class norms (Chambers et al., 2022; Jarrard et al., 2025; Samuel et al., 2023, Wang et al., 2021). To succeed, students need to develop an attitude of pursuing growth rather than natural ability (Chambers et al., 2022). Teachers who believe students have fixed abilities were more likely to lower expectations for their students, sacrificing educationally rich activities for remedial work (Samuel et al., 2023). Canning et al. (2019) found that students from underrepresented groups had lower performance when they had fixed mindset STEM teachers, regardless of the race or ethnicity of the teacher. Perceptions about the instructor are often more important than the instructor's actual beliefs. Students whose instructor communicated growth mindset principles of effort and growth predicted higher grades, higher self-efficacy, and better expectations of fair treatment from the instructor (Jarrard et al., 2025).

Learning should be process-oriented, which involves frequent questioning, feedback, and providing opportunities for revision (Yan et al., 2021). Students should be active throughout the learning process (Armtcu & Bal, 2023). They should be asked to express problems in their own words, consider any research they may need to do to solve the problem, and reflect on their solution to express real-world meanings. One effective strategy is the use of ill-structured problems (Manalaysay, 2024). Ill-structured problems more closely represent real-world problems because there is no clear solution. Open-ended questions and ambiguity could be central to any meaningful STEM investigation (Goos et al., 2023). Often, students may need to interpret the question itself, meaning there is no one correct solution. Problems with no clear solution are often a key component of makerspace classrooms where students rely on 21st-century skills of collaboration, problem solving, creative thinking, and computational thinking (Vonkulluksn et al., 2021). Another key component of makerspace environments is the importance of failure in the engineering process. Collaborative learning environments lead to more positive educational outcomes than competitive environments (Dasgupta et al., 2022). This emphasis on community building encourages STEM participation, especially among minority and female students.

Parents

Communicating growth mindset principles and STEM opportunities to parents is also important (Watson et al., 2022). Parents who lack confidence in STEM knowledge often pass that on to their children, while parents who hold positive attitudes will pass on positive attitudes. Dweck and Yeager (2019) found that the kinds of feedback that parents gave their children played the highest role in a child's mindset. Watson et al. (2022) also found that students are most likely to follow the occupations of their parents, so schools should promote STEM opportunities to parents. Schools should actively raise awareness among parents, promoting the benefits of STEM learning and opportunities for their children to participate in STEM programs.

School Leaders

School leaders may see the need for change, but need to communicate a clear vision, support teacher growth, and promote teacher buy-in (Waters & Orange, 2022). When new curricula are implemented, teachers are usually the first group impacted (Watson et al., 2022). To build a school that emphasizes collaboration, creativity, and risk-taking, school leaders need to include teachers in the decision-making process and provide autonomy, while encouraging teacher collaboration (Goos et al., 2023). Rather than relying on a single leader, leadership roles should be distributed to emphasize a collaborative approach, building teacher motivation and sense of professional community (Wieselmann et al., 2021). Administrators need to focus on being instructional leaders rather than managers while providing opportunities for professional development and providing access to STEM experts. Effective STEM integration requires training and professional development opportunities should reflect what effective integration looks like (Havice et al., 2018).

Professional Development

Goos et al. (2023) credited teacher expertise as the most important factor for successful integration. However, many teacher education programs are still discipline-specific, and few teachers are trained in multiple STEM fields. Asunda (2018) found that teachers lacked the pedagogical knowledge to understand the complex interrelatedness of each STEM discipline. One approach is for interdisciplinary planning between subject area specialists, but these teachers still need to understand the philosophy behind the integration and share a common vision. Teachers need specific training on how to effectively integrate STEM subject matter (Flores, 2023). Havice et al. (2018) promoted the development of a clear conceptual framework that includes the role and purpose of STEM education and how individual content standards can be taught through an interdisciplinary approach.

Conclusion

STEM education needs to start early to face the challenge of an unprepared workforce. There is a need to both motivate students and to develop skills, beginning at the elementary level. Watson et al. (2022) argued that there should be more schools with a specific STEM focus, while introducing STEM programs into all schools. High schools should offer advanced STEM courses using pedagogical practices of inquiry, evaluating claims, and using evidence and reasoning. Schools should have more collaboration with STEM professionals and companies, while providing more STEM extracurriculars and summer programs. More opportunities for student engagement increase interest and develop ability.

A lack of a clear definition or framework for STEM has led to varied implementation and research. Some areas for future research are creating frameworks and definitions for clarity in lesson planning and research, the connections between affective dispositions towards STEM and intellectual skill development, and effective community STEM programs. When discussing specific STEM lessons or programs, studies should also be more explicit about the targeted disciplines, content, and level of integration. Bayanova et al. (2023) found that most studies were quantitative, but recommended more qualitative studies to explore the problems in STEM education, including the relationship between motivation and other variables. Bayanova et al. also encouraged more research at the elementary level to improve STEM attitudes at this formative age.

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