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The Persistent Problem of Undergraduate Student Attrition in STEM

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Abstract: Despite burgeoning federal funding, expanding educational research, and mitigating efforts, undergraduate STEM programs in the United States and globally continue to grapple with persistently high rates of student attrition. This comprehensive literature review synthesizes recent empirical research to better understand the underlying factors contributing to this ongoing challenge and to inform future directions for both research and practice. Our analysis identified several key trends. First, most attrition in STEM occurs within the first two years of study, particularly during enrollment in high-stakes "gateway" or "weed-out" courses that often act as barriers to progression. Second, student attrition is not solely a function of academic ability but is strongly influenced by a combination of academic performance (particularly poor grades), social dynamics (such as sense of belonging, perceived support from and trust in instructors, and experiences of alienation), and personal psychological factors (including interest in the subject, academic motivation, self-efficacy, identity development, and the presence or absence of a growth mindset). Third, the literature consistently highlights three intervention strategies as particularly effective in promoting student retention and success: peer mentoring, undergraduate research experiences (UREs), and supplemental instruction or tutoring programs. Additionally, our review underscores critical gaps in the existing research. Notably, much of the current scholarship is heavily centered on U.S. educational settings, with limited empirical exploration in international contexts, particularly in Latin America, Asia, and parts of Europe. Another area requiring further investigation is faculty training and preparation to support diverse student populations effectively. Based on this synthesis of current findings, we argue that interventions aimed at reducing attrition must go beyond merely encouraging students to persist; they must also be designed to foster student thriving and flourishing. This requires a holistic, multi-level approach that considers the interplay of micro-level (individual and interpersonal), meso-level (institutional and community), and macro-level (societal and cultural) factors that shape student experiences in STEM disciplines across different national contexts.

Keywords: undergraduate student attrition; university STEM education; persistence in undergraduate STEM; STEM underrepresentation.
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Introduction

Despite burgeoning federal funding, expanding educational research, and mitigating efforts, undergraduate STEM programs in the USA and other countries continue to suffer from widespread attrition (Chen & Soldner, 2013), with significant numbers of students changing majors to non-STEM fields (Dagley, Georgiopoulos, Reece, & Young, 2016), dropping out (transferring to other institutions), opting out (leaving college temporarily with the intent of returning) or stopping out (quitting higher education altogether) (Larsen et al., 2012). According to the Organization for Economic Cooperation and Development, which comprises 38 member countries, the completion rate for full-time bachelor's students who entered a STEM program was 68% in 2021 (OECD, 2022). In the same period, approximately 48% of US students who began a STEM major either dropped out or switched to non-STEM majors (National Center for Education Statistics, 2017; 2020; 2021; National Science Foundation, 2018; Porter, Chu, & Yvie, 2024).

Non-returning students' reasons for withdrawing from college vary widely depending on the unique characteristics and needs of the specific subpopulation to which they belong. For some, it is the result of pre-college experiences and backgrounds that students bring with them (e.g., psychological and cultural traits), whereas for others, departure is determined by experiences that students have during college (Graham et al., 2013; Hartwell & Gupta, 2019; Kuh & O'Donnell, 2013; Packard, 2016). Among the multitude of reasons commonly given for student withdrawal are inadequate preparedness, student cognitive inability, lack of connection (to college, content, and/or instructors), a cold classroom environment, conflicting expectations and epistemologies, etc. (Anfuso et al., 2022; Cromley et al., 2015).

The STEM attrition problem was further exacerbated by COVID-19. The pandemic led to increased dropout rates among STEM students, particularly due to challenges associated with online learning (e.g., reduced engagement) and lack of access to hands-on experiences in lab-based courses (Esquivel et al., 2023). Moreover, it disproportionately affected female students in STEM for whom work-life balance proved to be more difficult to achieve during the pandemic, leading to higher attrition in STEM fields (Esquivel et al., 2023). As a result, college retention rates saw a sharp decline, particularly for students who graduated from high school in 2019 and 2020 (College Board, 2021).

Another contributing factor to STEM attrition is growing public disenchantment with college in recent years due to a variety of reasons like affordability (high tuition costs), absence of adequate support systems, and concerns about job prospects. According to a recent survey (Strada Education Network & Gallup 2020), only 34% of students believed their degree would be worth the cost. Additionally, STEM programs have more expensive requirements (e.g., expensive textbooks, labs, and specialized equipment), which can exacerbate students' financial burden. Moreover, a 2018 Georgetown University study found that 43% of STEM graduates felt their degree did not prepare them well for their first job. A 2019 study by the University of Chicago reported that over 50% of students mentioned the difficulty of coursework and lack of adequate academic support as their top two reasons for leaving STEM (Ganapati & Ritchie, 2021). Increased interest in alternative pathways, mistrust in the higher education system, and cultural and political discontent compound the problem. As students increasingly question the value of a traditional college degree, more are inclined to leave STEM programs.

Better understanding the persistent problem of student attrition in STEM is essential not only because of the short-term retention challenges being faced by higher education institutions but also due to potential long-term implications for STEM workforce development. To shed some light on this problem, we conducted a comprehensive review of the recent literature on STEM undergraduate attrition. The specific objective of our literature review was to identify emergent themes in reported findings on student attrition in STEM, including influential factors, documented relationships, and established associations.

Like many other areas of scholarship, the study of undergraduate student retention is characterized by a degree of conceptual confusion with multiple constructs being used interchangeably and inconsistently, including *retention/persistence* and *attrition/turnover/departure/withdraw*. As used in this paper, the term *attrition* refers to students who decide to leave the undergraduate program originally chosen without a degree, including transfer-outs, opt-outs, and stop-outs. In contrast, the term *persistence* is used in reference to students entering undergraduate education and graduating with the degree they initially sought. Next, we describe how our literature review was methodologically approached.

Methodological Approach

To locate the relevant literature, we first searched for journal articles on academic databases such as EBSCO host and Scopus. The following are examples of combinations of descriptors that were used: STEM attrition or STEM retention or STEM withdraw AND higher education or university; science or engineering or mathematics, or technology AND undergraduate persistence. We also utilized various combinations of the following filters: source (peer reviewed, academic journals), geography (USA, Europe, Asia), etc. Our search was limited to the last fourteen years (2010–2024), a period of growing scholarly interest and research activity on student attrition particularly in fields like science education, STEM education, educational psychology, higher education, and educational leadership (our target fields). As part of our review, we first triaged the returned literature. Initial triage was followed by a more in-depth analysis wherein each publication was more closely reviewed.

Included in our literature review are empirical studies of actual as well as potential student attrition. The former refers to studies that directly examine how student attrition related to various factors (personal/psychological, structural/environmental, etc.) and attempted interventions (bridging courses, enriching programs, supports, etc.). An essential feature of these studies is the inclusion of longitudinal data on students that drop out of STEM majors, hence providing direct evidence of attrition (e.g., statistics and interviews with former students). As can be seen on Table 1, many of these studies focused on the interplay of attrition-related factors (achievement, interest, self-efficacy, gender, race, identity, integration, satisfaction, perception, attitude, belongingness, growth mindset, motivation, and college experience) that explicitly discussed how reported findings illuminated STEM student attrition.

In contrast, studies of potential attrition seek to indirectly gauge undergraduate attrition through survey of students who, though still enrolled in STEM majors, are considering dropping out. Rather than examining actual attrition, these latter studies examine potential attrition by focusing their analysis on student intention or inclination to drop out of STEM, likelihood of changing majors, etc. as self-reported by participants. A good example is Banchefsky et al. (2019) who examined associations between male and female students' sense of belonging and their intention to persist in physical science, technology, engineering, and mathematics majors. Whether these intentions were eventually enacted by students remained unreported.

Table 1

Studies Examining Actual Student Attrition in STEM

Publication	**Focus**
Baiduc et al. (2016)	Impact of undergraduate research experiences on student interest, self-efficacy, research skills and persistence in STEM
Cheng et al. (2018)	Impact of personal factors (interest and learning problems) on undergraduate student retention and academic performance
Bowman et al. (2021)	Impact of supplemental instruction on grades and retention
Chang et al. (2014)	Associations between pre-college factors and retention of students from underrepresented racial groups in STEM
Dagley et al (2016)	Impact of a learning community program on retention and graduation rates in STEM
Goy et al. (2018)	Women's representation and persistence in STEM in Malaysia
Hussain & Khader (2014)	Personal factors (interest in subject) causing student attrition and retention in engineering colleges of India
Johannsen, et al. (2013)	Former physics students' reasons for early departure in Sweden.
Kendricks et al. (2013)	Impact of mentoring to enhance academic performance and retention in STEM disciplines
Kramer et al. (2023)	Impact of teaching style (active student engagement vs. traditional lecture) on academic performance and completion of calculus course
Kuh et al. (2013)	How educational practices correlate with student engagement, achievement, retention, and graduation rates
Lane (2016)	Impact of enrichment program on student retention in the STEM disciplines
Lewis et al. (2017)	Influence of belonging and gender on student persistence (intended and actual)

Musah & Ford (2017)	Effectiveness of peer-based supplemental instruction on course grades and retention for various ethnic student groups
Rosenzweig et al. (2021)	How changes in career plans relate to persistence and attrition in biomedical fields
Watkins, & Mazur (2013)	Impact peer instruction on student attrition in physics
Weng et al. (2010)	Various factors (academic integration, social integration, encouragement from others, commitment to the institution, goal commitment, financial attitude, self-efficacy, and intent to persist) on student retention in Taiwan
Zeidenberg et al. (2012)	Relationship between student grades in introductory courses and community college completion

Faced with a small number of journal articles from countries other than the US, we decided to also include academic books (e.g., edited volumes, encyclopedias) and reports by educational agencies. Found online, this supplemental literature helped expand the focus of our review to a more inclusive international level. Ultimately, the returned literature comprised 77 US-based articles (70%), 25 articles (22%) focused on European countries (UK, Netherlands, Finland, Norway, Sweden, Denmark, Russia, Ireland, Italy, Spain, and Germany), and 9 articles (8%) focused on Asian countries (Korea Rep., Taiwan, Japan, Indonesia, Thailand, India, and Türkiye).

To ensure a consistent focus, several exclusion criteria were also used. More specifically, we excluded studies focused on K-12 students (e.g., their perceptions of STEM majors), studies of graduate-level STEM education (e.g., doctoral students), general studies of undergraduate student attrition not focused specifically on STEM majors, and practitioner articles devoid of systematic empirical examination.

Application of these inclusion and exclusion criteria ultimately resulted in the compilation of a dataset comprising a total of 111 peer-reviewed studies (103 journal articles, 4 book chapters, and 4 reports). Approximately 80% of these (N=88) were studies of actual student attrition, whereas the remaining 20% (N= 23) were studies of potential student attrition. Moreover, rather than centered on a particular research venue or field, 53% of the returned publications (N=59) were isolated studies of US educational contexts, each published in a different journal across various academic fields, thus revealing a US-centric research base that was highly disconnected and characterized by a general lack of international coordination of research efforts.

Main Themes

Four major themes emerged from our review of the returned literature, namely student academic performance and interest, social influences on student attrition, underrepresented students' attrition, and attrition-focused interventions. These themes are now considered.

Theme 1: Academic Performance and Interest

Clear evidence was found that most attrition in STEM occurs during the first two years of postsecondary education (Chen & Soldner, 2013; Porter, 2024), when students are taking introductory courses, making it critical to identify which courses experience the most attrition. Commonly identified as "gatekeepers," "gateway courses" or "obstacle" courses, these classes are characterized by high enrollment and high failure rates, preventing many students from completing degrees and therefore deserving special attention from researchers. Among obstacle courses in the STEM fields are *Introduction to Computer Applications and Concepts*, *General Biology*, *Precalculus I*, and *General Biology II* (Zeidenberg et al., 2012) as well as *Introductory Physics* (Porter, 2024). In these courses, there appears to be a strong correlation between academic performance and student attrition. The lower the grades earned by students, the higher the possibility of dropping out (Chen & Soldner, 2013; Zeidenberg et al., 2012). In particular, failing these courses can have a strong negative impact on students, drastically increasing their chances of dropping out of STEM early in their programs.

The above findings are consistent with shock-induced perspectives on student retention. As Pleskac et al., (2011) posits, getting a bad grade constitutes a "shock to the system", that is, a jarring life event to which many students are particularly sensitive and one that can reliably predict student withdrawal decisions. Causing disturbance to students' academic lives, such a shock can trigger psychological processes related to quitting (withdraw cognition), hence increasing the prospects of an eventual departure. Receiving a bad grade also triggers *cognitive dissonance* (a mental state of puzzlement and a need to somehow account for such unexpected experience) particularly in students who hold strong personal beliefs (e.g., believes him/herself to be a good student) (Millar & Tanner, 2011). One way to resolve the dissonance is to rationalize the result (e.g., one can blame the instructor for not teaching, decide that the test is a poor measure of his or her ability, that the test was poorly written, etc.). Another way to deal with this dissonance is to avoid it by not taking the test or dropping out from college was a way to protect her strongly held identity.

Academic performance has in turn been clearly linked to student interest in STEM. Interest is a key factor in both recruiting and retaining first year undergraduates in STEM (Packard, 2016). Maintaining the interest that initially pulls students toward STEM but often fades after the early years of undergraduate schooling is essential. Interest provides students with purpose and authentic reasons for learning and remaining in STEM education (Hartwell & Gupta, 2019). Its importance is particularly made evident by Rowland et al. (2019) whose literature review revealed that interest has been featured in hundreds of articles in the field of biology education.

Across the reviewed studies, interest is shown to be an important source of student motivation, engagement, retention, and success in STEM (Baiduc et al. 2016; Beauchamp et al., 2022; Cheng et al., 2018; Fendos et al., 2022; Hussain & Khader, 2014; Kaleva et al., 2019; Rosenzweig et al., 2021; Rowland et al., 2019; Wild & Reef, 2023; Zavala et al., 2019). Interest provides students with purpose and authentic reasons for learning and remaining in STEM, promoting their engagement in curiosity-driven actions like asking questions out of seeking of the positive feelings found in the pursuit of knowledge in a domain. Rather than being a fixed psychological trait that some students are born with, interest develops overtime, being influenced by teaching approaches (Cui, 2022).

Studies of attrition-related factors emphasize that high-performing students are usually interested in studying topics that can positively impact the world (Lukes & McConnell, 2014). Moreover, interest can be both increased and maintained by providing students opportunities to see the relevance of STEM studies. This can be accomplished for instance by illustrating to students the usefulness of the studied content through reflective journals that direct students to see connections of the content beyond the classroom into potential career impacts (Cromley et al., 2016; Zavala, 2019). Affording students opportunities to see connections through writing tasks throughout the semester can increase their interest in STEM (Cromley et al., 2016).

Across the above studies, interest is clearly linked to student performance as well as attrition (both actual and potential). However, students in introductory courses can have varied interests, leading to the need for individual exploration of interests (Hartwell & Gupta, 2019). Such a complication can be addressed by making a diversity of topics available for exploration as part of mentored research programs (Fendos et al., 2022). By utilizing interest and curiosity inventories, offering choice of study, and providing hands-on research experiences, higher educators can leverage the power of interest and curiosity to help STEM retention.

Theme 2: Social Influences on Student Attrition

The reviewed literature also provided compelling evidence that undergraduate student attrition in STEM is linked to social factors like *belonginess*. Grounded in social psychology theories (Baumeister & Leary, 1995), studies in this area embrace the premise that students have a basic need to feel a sense of belonging, that is, feel that they are connected to a particular social context and accepted by others (Wilson & VanAntwerp, 2021). Students whose belonging needs are unmet struggle to perform well, increasing their likelihood of leaving their chosen major. In this body of work, a theoretical distinction is often made between *social belonging* and *ability belonging*. The former refers to students' sense of relational bonds and interpersonal relationships, whereas the latter concerns students' sense of fit with an environment based on perceived academic ability, that is, whether the student feels that s/he possesses abilities, skills, and knowledge that are comparable to one's peers and that STEM requires (Banchefsky et al., 2019).

Whether or not students feel like they belong in a course or program is particularly important for STEM students from underrepresented backgrounds (Wilson & VanAntwerp, 2021). Edward, Barthelemy, and Frey (2022) reported a direct interaction between students' social belonging and course performance in a *General Chemistry 1* course. Banchefsky, Lewis, and Ito (2019) found that women reported lower ability belonging than men in foundational calculus or physics courses. End-of-semester social belonging and ability belonging predicted intentions to persist in STEM. Cwik & Singh (2023) described how women had a lower sense of belonging and grades than men in an introductory algebra-based physics course for bioscience majors, and that the students' sense of belonging played a key role in predicting students' grades in the course. Lewis et al. (2017) found gender disparities on sense of belonging in STEM favoring men. Moreover, sense of belonging explained persistence intentions and actual persistence in STEM coursework for women, more so than for men. González-Pérez et al. (2022) describes how lack of belonging was a major factor for woman who had left engineering programs after having faced internal barriers, stereotypes and external obstacles. These studies consistently show that undergraduate students' sense of belonging in STEM classes not only plays a key role in shaping course outcomes but also influences student attrition.

Another interpersonal factor shown to influence student attrition is *trust in the instructor* (i.e., their perceptions of the instructor's understanding, acceptance, and care), which has been shown to correlate with students' final grades in active learning classrooms (Cavanagh et al., 2018). Examined in multiple studies (Cavanagh et al., 2018; Ream et al., 2014; Wang et al., 2021), trust is conceived as an attitude of positive expectation and willingness to depend on another and a generalized expectancy of good will. A trusting relationship builds over time. As a person interacts with others, s/he evaluates whether they are trustworthy based on emergent perceptions of expertise (knowledgeable), integrity (adherence to a set of principles), and benevolence (good intention). A person deemed to be trustworthy is seen as dependable. Someone who others can confidently rely on regarding the truth, fairness, and respect. Earning others' trust encourages deference, cooperation, and willingness to take risks. For instance, in a classroom setting, trust can play a role in students' decision to publicly pose a question or make a comment given the risk of negative evaluation or criticism. Putting themselves in such a vulnerable position requires trust.

The reviewed literature provides compelling evidence of the critical role that relational factors play in influencing students' decisions to leave STEM. Yet, undergraduate STEM courses are frequently taught by highly accomplished scientists who tend to undervalue the importance of instructor-student relationships (Christe, 2013), prioritizing content delivery over meaningful interpersonal engagement. This emphasis on transmitting scientific knowledge often fosters a kind of *social blindness* — an inability or unwillingness to recognize how their interactions with students impact the learning environment. As a result, instructors may behave in ways that seem impersonal, uncaring, or even dismissive, whether intentionally or not. Unsurprisingly, many students report experiencing a classroom climate characterized by hostility, detachment, and a perceived lack of care from their professors. Addressing this persistent issue requires not only acknowledging the foundational importance of social relationships in the learning process but also adopting pedagogical practices that foster supportive, empathetic, and human-centered connections between instructors and students within the context of higher STEM education.

Theme 3: Underrepresented Students' Attrition

The existing literature highlights how student attrition is particularly accentuated among STEM students from underrepresented social groups such as women and Black students (Chang et al., 2014; Crisp et al., 2015; Watkins & Mazur, 2013; Wilson & VanAntwerp, 2021). Students from underrepresented populations commonly face unique hurdles that impede their persistence and thriving/flourishing in higher education, including racial and gendered microaggression, imposter syndrome, difficulty integrating into the culture of a department, and problems with their advisor (Burt et al., 2019; Robinson et al., 2016). Moreover, a scarcity of female and underrepresented minority professionals combined with extended exposure to biased media images (Olsson & Martiny 2018; Steinke, 2017) make them feel like they do not belong in scientific fields and STEM careers (Kricorian et al., 2020; Rogers & Pagano, 2022).

From a social justice education perspective (Sensoy & DiAngelo, 2017), the persistent attrition of women and Black students in undergraduate STEM reflects a process of *social minoritization*. Through systemic power dynamics that place these groups at a structural disadvantage, they are not merely underrepresented but actively *minoritized* — assigned to a marginalized, non-dominant social status within the STEM context. Their numerical underrepresentation is deeply rooted in systemic inequities, including limited access to high-quality education, financial barriers, and the scarcity of relatable role models. These structural disadvantages are frequently misinterpreted or rationalized by peers and instructors as individual deficits—such as a presumed lack of ability, motivation, or academic preparedness. Confronted with an unlevel and often unsupportive academic landscape that undermines their sense of belonging and questions their capacity to succeed, these students become increasingly likely to withdraw from STEM fields.

The above research also suggests that underrepresented students are prone to experiencing feelings of *alienation* - a problematic state of estrangement or dissociation from a particular activity as a result of failure to achieve self-realization (Leopold, 2022). As research shows, one's social life can give rise to dysfunctional feelings of disconnection, meaninglessness, detachment, and powerlessness, which in turn fosters dissatisfaction, inferior performance, and quitting (Chiaburu, Thundiyil, & Wang, 2014). The impossibility of articulating oneself in a particular social role leads to one living one's life as an alien. Likewise, it makes sense that undergraduate students may experience STEM college life as lacking meaning and authenticity, hence becoming alienated from it.

On the other hand, the reviewed literature also clearly shows that several factors can positively influence underrepresented students' academic achievement and degree completion in undergraduate STEM majors. For Latina/o students, these include: (1) sociocultural characteristics and pre-collegiate academic experiences, such as parental education, socioeconomic status, and high school achievement; (2) internal characteristics like high academic self-confidence, identity, coping styles, motivation and commitment levels; and (3) college-related characteristics, including financial aid, full-time status, high GPA, interactions with supportive individuals, and satisfactory or good perceptions of the campus climate (Crisp et al., 2015). Although there are many factors that are outside of the college's domain, research shows that the chances of underrepresented students completing their STEM degrees can be increased by mentoring (Beauchamp et al., 2022; Dickens, Ellis, & Hall, 2021), modifying college polices to promote equity (Dickens, et al., 2021), and providing more culturally relevant experiences (Dickens, et al., 2021). Such measures have been shown to be effective in disrupting social minoritization in undergraduate educational settings where STEM is learned.

Instructional approaches that engage underrepresented students in learning experiences that more authentically replicate the professional work done by scientists were also shown to be effective. One such approach is modeling-based instruction wherein students build, validate, and deploy scientific models as part of inquiry laboratories and activities. Previously examined in the context of calculus-based, introductory physics courses (mechanics, and electricity and magnetism), such a teaching approach effectively promoted positive attitudinal shifts (Brewe, Traxler, de la Garza, & Kramer, 2013) as well as improved and more equitable conceptual understanding (Brewe et al., 2010). Likewise, women, Hispanic, and Black students achieved deeper understanding of calculus, obtained higher grades, and developed improved self-confidence in calculus classrooms where instructors actively and collaboratively engaged them (Castillo et al., 2022; Kramer et al., 2023). Across these studies, student-centered approaches characterized by task variety, clear and timely feedback, and a degree of autonomy (freedom and discretion to perform) are shown to be effective in countering underrepresented student attrition.

Theme 4: Attrition-Focused Interventions

Three main types of interventions were consistently highlighted as being effective in the existing literature, namely peer mentoring, undergraduate research experiences, and tutoring.

Peer Mentoring. Mentoring was commonly utilized to aid in STEM persistence and retention of students, particularly those from under-represented groups. Kendricks et al., (2013) reported that mentorship was the single greatest contributor to their overall success. Similarly, Zaniewski and Reinholz (2016) found that 98% of participants in a mentoring program were satisfied with their experience, citing benefits both academically and personally. Kricorian et al. (2020) reported that a matched mentoring program for women and students from underrepresented minorities helped promote a growth mindset and a sense of belonging in STEM. Estrada et al. (2018) described how short-term mentoring aided in all three vectors of social influence: science efficacy, science identity, and values. In addition, in the long-term, identity and values became more predictive of STEM persistence, particularly of under-represented minority participants. And Kornreich-Leshem et al. (2022) reported that mentoring by *learning assistants* in STEM classes helped undergraduate students develop metacognitive awareness as well as disciplinary identity. These studies consistently demonstrate that mentorships are integral in forging critical STEM values, identities, and mindsets that can effectively maintain student retention.

Another emergent theme was how the value of mentorship in STEM retention originates from its power to foster a sense of social connection. This is emphasized in Beauchamp et al.'s (2022) examination of a high-school-to-college bridging program that combined experiential learning with mentorship. Across four years, they studied minority students who spent seven weeks during the summer after their high school graduation in an urban ecology program. Under-represented youth expressed positive views of mentoring, stating that it had affected their sense of social connection. Similarly, Dickens et al. (2021) found that faculty mentoring of Black women by other Black women who understood their experiences helped them develop a sense of social connection.

In addition to social connection, the reviewed literature highlights the need for strong mentor-mentee relationships, especially those that critically teach diversity and equity inclusion. Stelter, Kupersmidt, and Stump's review of this literature (2021) supports this contention. In their meta-analysis of the literature, they found that strong mentor relationships are predicated on four major conditions, namely that mentors are trained: (1) in the reasons behind disparities in diversity and equity inclusion and how to explain these to their mentees; (2) on how to handle situations in which their mentees feel a stereotype threat or a microaggression; (3) on acting as a positive role model and promoting their mentee to also act in a positive manner; and, (4) on program-specific items to ensure that mentees are fully aware of opportunities and deadlines.

Peer mentoring is an effective educational intervention because it creates a supportive learning environment where students can receive guidance from those who have recently navigated similar academic and social challenges. Compared to faculty-led mentoring, peer mentors tend to be perceived as more approachable and relatable, which lowers barriers to seeking help and fosters open communication. This dynamic promotes the development of growth mindsets, academic self-efficacy, and metacognitive skills, as mentees see firsthand examples of how "others just like them" have succeeded. Additionally, peer mentors serve as tangible role models, demonstrating that persistence and success in STEM are attainable. Ultimately, peer mentoring not only supports academic success but also strengthens students' sense of belonging, identity, and connection to the STEM community.

Undergraduate Research Experiences (UREs). A second type of educational intervention commonly used to promote student retention was infusing the undergraduate STEM curricula with authentic research experiences. Central to the pedagogical design of these student-directed research experiences is nurturing student curiosity and interest. In one program, students' motivation and interest superseded the weight of academic transcripts during the application and review process (Cianfrani, 2020). The program also sought to capitalize on students' interest by having them design their own research, culminating in student-driven capstone projects. Selection of students is addressed in other innovative ways with programs evaluating not just academic success but student interest and curiosity levels during selection to undergraduate STEM programs (Baiduc, 2016).

In many URE programs, students were supported with scaffolding through frequent meetings with mentors. The scientific work both fostered and followed curiosity with science study and curiosity driving and supporting the other. A study of the *Biomedical Career Enrichment Program*, which offers internships as well as academic and career support, discovered that underrepresented groups were motivated by interest and experiential learning connected to career paths and were drawn to these programs out of interest and curiosity (Bhatt, 2020). A common pedagogical feature of these programs is that they are not entirely lecture-based, often engaging students in project-based learning (Wei & Ford, 2015).

Lane (2016) also examined the effects of a successful STEM enrichment program (> 63% retention and >76% persistence of students from underrepresented groups). As part of this program, African Americans, Latino, and southeast Asian-American students majoring in STEM fields were provided with holistic support, which included pragmatic (academic, professional, and practical) and psychological support (dealing with the racial realities of students of color). The STEM enrichment program's success was attributed to multiple factors, including: (1) *community building* by fostering a familial environment and nurturing student, peer, staff, and mentor relationships; (2) *catalysts of STEM identity development* - opportunities for STEM professionals to provide students with training and mentoring; and (3) *proactive care* rather than being reactive, that is, making students aware of potential difficulties and how to overcome them before they occur.

The main reason for UREs' effectiveness is the powerful combination of skill-building, mentorship, and identity formation. By engaging in meaningful, hands-on experiences that connect classroom learning to authentic scientific research, students develop a deeper understanding of scientific concepts, learn how to apply theoretical knowledge to practical problems, and build critical thinking, problem-solving, and analytical skills that traditional lecture-based courses may not fully cultivate. Additionally, participation in research fosters a sense of belonging and strengthens students' identification with STEM disciplines. The mentorship component common to UREs further amplifies their impact, as close relationships with faculty and research staff provide not only technical guidance but also professional socialization.

Tutoring/Supplemental Instruction (SI). Supplemental Instruction was one of the most popular methods used to improve student performance in STEM courses. SI typically involved some form of peer instruction, small-group activity, extra worksheets, practice tests, and/or guided discussion outside of class time (Musah & Ford, 2017; Dawson et al., 2014). SI Leaders are students who have previously been successful in the course, have effective communication skills, and are motivated to help others (Anfuso et al., 2022). However, unlike a traditional recitation model, SI Leaders do not simply give additional instruction to attending students, but rather they create active lesson plans that foster interactive cognitive input from the group of students in attendance (Anfuso, 2022). SI is also distinguished in that it does not specifically target high-risk students or those confronting academic distress; instead, it is often connected to high-risk courses such as first year or "gateway" STEM courses.

SI participation was correlated with higher course grades and lower DFW (Drop, Fail, Withdraw) rates, being particularly beneficial for underprepared academically disadvantaged students (Achat-Mendes et al., 2020). Furthermore, it was observed that there are larger gains from frequent SI attendance by academically disadvantaged students who entered college with lower high school GPAs, compared to students who did not require remediation

(Yue et al., 2018). Reports indicate that SI and similar peer-led academic support models particularly benefit students from historically underserved populations in their STEM courses (Bowman et al., 2021; Rabitoy et al., 2015; Yue et al., 2018).

Anfuso et al. (2022) found that SI attendance was positively correlated with improved course outcomes for students identifying with all racial/ethnic groups, and that the degree of benefit increased with increasing attendance of SI sessions, resulting in drastically reduced DFW rates. However, it was also observed that while SI disproportionately benefitted less prepared students and thus helped to close achievement gaps related to college preparedness/prior academic experience, it did not equalize final course outcomes between similarly prepared students identifying with historically underrepresented and non-HU groups (Anfuso et al. 2022).

In a study aimed at assessing the differential impacts of SI on transfer and non-transfer college undergraduates, Musah & Ford (2017) found that SI improved outcomes overall, but that non-transfer students benefitted to a greater degree than transfer students, in the form of higher grades and pass rates. Their findings suggest that peer-based SI is a useful method to improve undergraduate student performance, but more research is needed on ways to enhance the effectiveness of interventions in improving the performance of transfer undergraduate students in STEM fields.

Overall, recent research on the impact and outcomes of SI reveals that it is an effective approach for improving student performance outcomes in college courses, with disproportionately larger positive impacts on students from historically underserved populations. Nevertheless, the findings also show that it does not fully compensate for the systemic differences in K–12 preparation that leads to inequities in college performance between students identifying with historically underrepresented and non-historically represented groups (Anfuso et al. 2022).
The effectiveness of supplemental instruction stems largely from its leveraging of principles of social learning and active engagement. Unlike passive learning environments, SI sessions encourage students to collaboratively solve problems, articulate their reasoning, and clarify misconceptions with guidance from a trained peer leader. This collaborative format fosters a sense of belonging and community. Additionally, because SI Leaders have recently mastered the course material themselves, they are well-positioned to identify common misunderstandings and present concepts in ways that are relatable to current students. This peer-led structure also reduces the intimidation that students may feel when asking questions in traditional instructor-led settings, thereby increasing the likelihood that students will engage with difficult material and persist in challenging STEM courses.

Literature Limitations

In addition to the above empirical trends, our review also revealed important shortcomings in the literature on undergraduate STEM retention. A noticeable limitation is that existing studies have focused primarily on students (i.e., helping them overcome their deficiencies, difficulties, and challenges), discounting the possibility of the faculty also needing support in the form of professional development and pedagogical training. This one-sided focus suggests a problematic deficit-oriented assumption that the problem of attrition lies entirely with the students themselves, that is, that undergraduate students quit simply because they lack what it takes to succeed in STEM. By default, faculty's abilities (pedagogical, social, epistemic) are ruled out *a priori* as potential contributing factors. Such a limitation can be partially reflective of resistance from full-time STEM professors, particularly in research-intensive universities, who may not see the value of exposure to pedagogy and whose professional identities are often exclusive of education (i.e., who see themselves exclusively as scientists/researchers rather than educators). However, as argued by Dewsbury (2017), STEM faculty development is essential to promote a shift in the mindsets of STEM instructors from focusing on student deficits and to change campus culture in ways that can effectively address the problem of STEM student retention. This argument is corroborated by Benabentos et al.'s (2021) survey of the instructional practices of biology, chemistry, and physics faculty across research-intensive institutions, which revealed that engagement in professional development, was associated with greater use of student-centered strategies in upper-division courses. Future studies will need to examine ways to change professional culture in higher education institutions in ways that can effectively encourage STEM faculty to see themselves as educators (i.e., promote educator identity development) and help them recognize the value of educational training.

Another important limitation is that existing literature is dominated by studies conducted in U.S. educational settings, with approximately 70% of the reviewed research originating from the U.S. This geographic concentration limits the generalizability of findings as student experiences, educational systems, cultural norms, and policy environments vary significantly across countries. Limited research has been conducted in international contexts such as Europe and Asia, despite clear evidence that gender disparities in STEM are global issues. For instance, studies from European countries like Sweden (Johannsen et al., 2013), Finland (Kaleva et al., 2019), and the Netherlands (Holmegaard, Madsen, & Ulriksen, 2014) confirm that male dominance in STEM persists even in nations with relatively progressive gender equality policies. However, the factors influencing these disparities differ somewhat from the U.S. context. In Europe, barriers are often linked to persistent traditional gender norms, the challenge of constructing desirable academic and professional identities for women, perceptions of STEM disciplines as rigid, inflexible, and incompatible with broader life aspirations, and the lack of accessible female role models within STEM fields. This highlights the importance of considering how cultural expectations and identity formation processes intersect with academic pathways. Similarly, research on undergraduate STEM attrition in Asian contexts remains sparse. Yet, the limited evidence available suggests a complex picture. For example, in Malaysia—a conservative Muslim country—gender gaps in STEM participation are reportedly smaller or comparable to those in the U.S. (Goy et al., 2018), possibly reflecting different societal structures, family expectations, or educational policies that influence women's participation in STEM differently from Western contexts. The lack of broader international research leaves significant gaps in understanding how interventions successful in the U.S. might need to be adapted or reimagined in different cultural and educational systems. Without expanding the scope of research beyond the U.S., the development of truly global, culturally responsive strategies to improve gender equity in STEM remains constrained.

Beyond Europe and Asia, empirical research on undergraduate student attrition in STEM remains especially limited, with significantly fewer studies conducted in regions such as Latin America. Nonetheless, preliminary evidence suggests that STEM attrition is indeed a pervasive and pressing issue in Latin America, shaped by a distinct set of socio-economic, cultural, and institutional factors. For instance, Castro (2023), in a dissertation study (not formally included in this review), conducted an in-depth analysis of student withdrawal patterns at the University of São Paulo — Brazil's largest and most prestigious public university. His findings underscore a stark disparity in attrition trends across academic disciplines between 2018 and 2022 (see Figure 1). Specifically, undergraduate majors within the pure STEM fields such as Mathematics, Physics, Astronomy, and Meteorology exhibited some of the highest attrition rates at the institution. By contrast, professional disciplines like Engineering and Medicine showed markedly lower dropout rates, largely attributed to their stronger perceived pathways to stable employment, higher income, and greater socio-economic mobility.

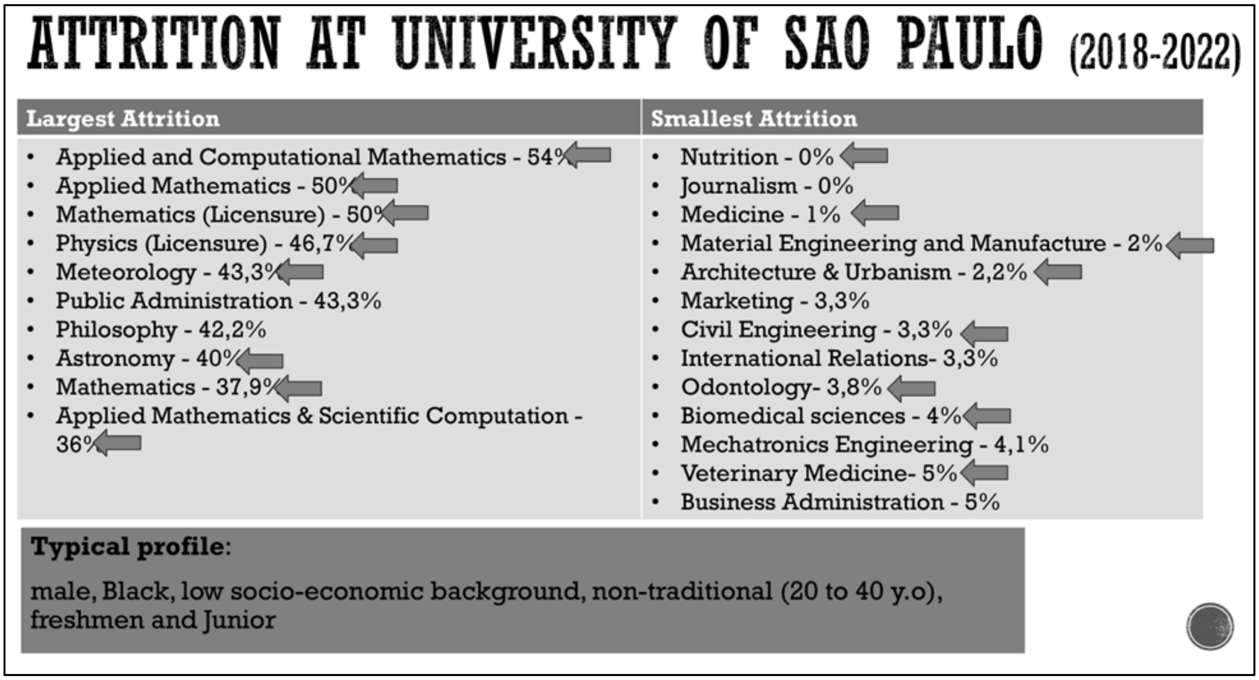
The study also revealed that attrition in Brazilian STEM programs disproportionately affects non-traditional student populations. Those most vulnerable to withdrawal were often older, Black males from lower socio-economic backgrounds who faced the dual pressure of managing academic demands while also providing financial support to their families. This intersection of economic hardship, racial inequities, and the demands of higher education creates a compounded risk factor that may not be as prominent in higher-income countries with stronger financial aid infrastructures.

These findings highlight how, in the Brazilian context — and likely across other parts of Latin America —financial pressures emerge as a dominant driver of attrition, perhaps to a greater extent than in wealthier nations where institutional financial supports are more robust. The stark contrast in attrition rates between fields perceived as economically lucrative (e.g., Engineering, Medicine) and those viewed as offering fewer immediate financial returns (e.g., pure sciences) further underscores the role of economic incentives in shaping student persistence decisions.

Given the limited scope of current research, there is an urgent need for further empirical studies that explore how financial stressors, race, age, and broader socio-economic conditions interact with educational experiences to influence attrition in STEM fields across Latin America. Moreover, comparative research that examines how these patterns differ from or mirror those in other regions—such as North America, Europe, Asia, and Africa—could yield valuable insights into both universal and context-specific factors driving STEM attrition globally. Without such research, efforts to design effective interventions may risk being overly influenced by models derived from U.S.-centric or Eurocentric contexts, which may not fully capture the realities faced by students in the Global South.

Figure 1

Undergraduate Majors with Highest Attrition Rates at the University of São Paulo



Discussion

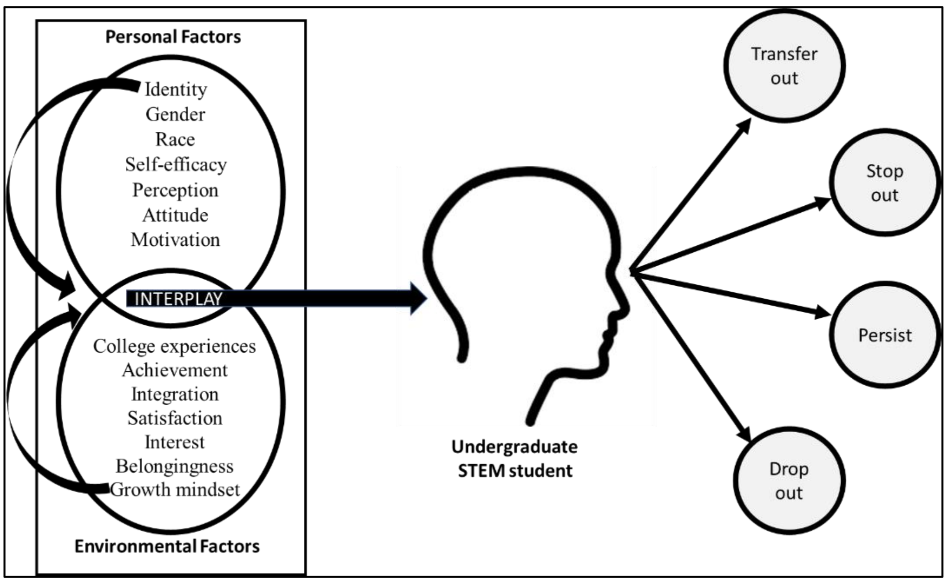
The present review of the literature on undergraduate student attrition in STEM highlights an educational phenomenon characterized by highly complex and reciprocal interactions between internal factors (e.g., self-efficacy, sense of belonging, identity formation, and academic integration) and external factors (e.g., campus climate, institutional policies, support systems, and broader sociocultural norms). Rather than being attributed to a single, static determinant such as cognitive ability, demographic background, or prior academic achievement, the decision-making process regarding persistence in STEM is best understood as a dynamic, developmental process shaped by the student's continuous experiences and interactions within their educational ecosystem.

Combined, the reviewed studies paint a theoretical picture of student attrition in undergraduate STEM as a sociopsychological phenomenon at the intersection of the self and the environment (Figure 2). Central to this phenomenon is the interplay of personal factors (identity, gender, race, self-efficacy, perception, attitude, and motivation) and social factors (college experiences, achievement, academic and social integration, satisfaction, interest/curiosity, belongingness, growth mindset).

Collectively, the reviewed studies converge to depict student attrition in STEM as a *sociopsychological phenomenon occurring at the intersection of the individual and the environment* (see Figure 2). Central to this phenomenon is the dynamic interplay of personal factors—such as identity, gender, race/ethnicity, self-efficacy, mindset, attitudes, and intrinsic motivation — and social factors —including academic achievement, quality of institutional support, peer interactions, perceptions of fairness, belongingness, and satisfaction with the academic and social environment. Importantly, this literature suggests that even when individual students possess the cognitive capabilities to succeed in STEM, the absence of adequate environmental supports or the presence of hostile climates can significantly undermine persistence. Therefore, reducing attrition and fostering persistence requires not only psychological interventions aimed at strengthening individual resilience but also systemic, institutional, and cultural changes that create more equitable, supportive, and inclusive learning environments in STEM fields.

Figure 2

Student Attrition in Undergraduate STEM as Interplay of Personal and Environmental Factors



Overall, there was strong consensus in the reviewed literature that the decision-making process or cognitive pathway followed by undergraduate students when considering whether to withdraw from a STEM program inevitably involves their level of satisfaction—or lack thereof—with their academic experience. This is made particularly clear through the lens of *investment theory* (Rusbult, 1980), a theoretical framework increasingly adopted in research on undergraduate attrition in STEM fields. Originally developed to explain how individuals decide whether to maintain or dissolve romantic relationships, investment theory posits that commitment to any relationship — including an academic one — is driven by the degree of satisfaction experienced within the relationship. Applied to student attrition, this means that whether a student decides to “break up” with their academic institution or program is heavily influenced by how satisfied they are with their current educational experience—whether they feel supported, engaged, and successful. When satisfaction is low — due to factors such as poor academic support, lack of belonging, or negative classroom experiences — the likelihood of withdrawal increases, especially if the student perceives that better alternatives exist, such as transferring to another major, institution, or exiting higher education entirely. Moreover, the weight of past investments (e.g., time spent on coursework, financial costs, personal sacrifices) can either encourage students to persist despite dissatisfaction or exacerbate regret if they feel those investments are leading nowhere. This theoretical framing is particularly valuable because it captures not only the rational calculations students make but also the emotional dimensions of persistence and departure decisions, offering a comprehensive lens through which to design interventions that enhance student satisfaction and retention in STEM.

When students are well—meaning they are satisfied, feel supported, and experience a sense of belonging—they are more likely to thrive academically and personally. This well-being enables them to persist in their programs even when facing significant hardship, adversity, or misfortune (Krishnakumar et al., 2022). A focus on thriving, and related concepts such as flourishing, shifts the emphasis away from deficit-based models that frame student failure as inevitable or even desirable. Instead, it promotes the idea that academic environments should be designed to cultivate student growth, resilience, and long-term success. This perspective challenges the traditional and often counterproductive narrative that gateway STEM courses should function as "weed-out" mechanisms—deliberately difficult courses designed to filter out students perceived as lacking the aptitude for STEM. Research increasingly suggests that such exclusionary practices disproportionately harm students from underrepresented groups, first-generation college students, and those from less academically privileged backgrounds. Rather than accurately identifying who is "fit" for STEM, these practices often reflect structural inequities in prior educational opportunities. Emphasizing thriving reframes the role of gateway courses and the broader educational experience from one of gatekeeping to one of cultivating potential. It recognizes that when institutions prioritize student well-being — through supportive learning environments, meaningful mentorship, accessible resources, and inclusive pedagogies — students are not only more likely to persist but also more likely to excel. This approach aligns with broader movements in higher education aimed at fostering equity, inclusion, and the holistic development of learners, ultimately benefiting both individual students and the STEM fields that depend on diverse talent and perspectives.

Preventing or mitigating undergraduate student attrition in STEM will require a far more comprehensive and holistic understanding of the roots of this problem — an understanding that moves beyond the standard *variable-centered approach* and *psychological interventions* that have dominated much of the recent research. While variable-centered models, which isolate factors such as self-efficacy, motivation, or mindset, have yielded valuable insights, they often oversimplify a problem that is inherently multifaceted and embedded in broader social contexts. As our literature review has demonstrated, STEM attrition is not merely the result of individual-level deficits but is instead a highly complex and dynamic social phenomenon that unfolds across multiple, interrelated levels. At the *micro level*, factors such as individual student experiences, self-perception, identity development, and interpersonal relationships with peers, mentors, and faculty play a critical role. At the *meso level*, interactions between individuals and the groups or institutions to which they belong — including academic departments, universities, and peer communities — shape whether students feel a sense of belonging, support, and inclusion within STEM cultures. Finally, at the macro level, larger societal structures and forces — including systemic inequalities, gender norms, economic barriers, and cultural narratives about who belongs in STEM — exert significant influence on student pathways and outcomes. Addressing this pervasive and deeply rooted problem, therefore, requires adopting *systems thinking*, recognizing that individual behaviors and outcomes are inseparable from the broader relational, institutional, and societal dynamics in which they are embedded. Effective solutions must be multi-layered, integrating psychological, sociological, and structural interventions that work in concert across these levels to foster sustainable change in STEM education and retention.

Moving forward, future research on STEM attrition will benefit significantly from engaging with broader scholarship on general student attrition that has yet to be fully extended or applied to STEM-specific educational contexts. A particularly compelling example is the work of Pleskac et al. (2011) on the concept of *shocks to the system*. This framework challenges the dominant assumption that student attrition is primarily a gradual process driven by the slow accumulation of dissatisfaction or disengagement, which can be effectively predicted by linear models such as *early warning systems* (Bernacki et al., 2020). Instead, Pleskac and colleagues argue that sudden, disruptive life events—such as receiving an unexpectedly poor grade, experiencing the death of a family member, facing financial hardship, or encountering a demoralizing academic failure—can serve as critical tipping points that precipitate abrupt decisions to leave an academic program. This perspective underscores the importance of recognizing that even students who appear stable and successful may be vulnerable to sudden attrition if adequate support systems are not in place to help them navigate these unforeseen challenges.

In addition, future research should more fully explore the applicability of promising psychological interventions within STEM contexts. For instance, *mental contrasting interventions* (Bernacki et al., 2023; Hensley et al., 2021) equip students with strategies to mentally simulate potential future obstacles and develop concrete implementation plans to overcome them. This proactive approach has shown promise in fostering resilience and adaptive coping skills but has not yet been extensively tested in STEM learning environments, where high cognitive load and performance pressures are common. Similarly, retrieval practice interventions (Cogliano et al., 2021; Cogliano et al., 2022; Wang et al., 2023) focus on enhancing students' ability to retain and retrieve information over time, while simultaneously improving their *metacognitive awareness* — their ability to accurately monitor their own understanding and test performance. Given that poor academic performance often acts as both a practical and psychological barrier to persistence in STEM, interventions that strengthen learning efficiency and confidence may directly impact attrition rates.

However, implementing these interventions within STEM education also presents potential complications and contextual challenges. First, STEM courses frequently involve large class sizes and fast-paced curricula, which may limit opportunities for individualized or small-group interventions that require careful scaffolding and reflection. Additionally, the diversity of STEM disciplines—with varied learning goals, content complexity, and assessment formats—may demand tailored adaptations of these psychological strategies, complicating their broad application. Moreover, students from underrepresented groups may face intersecting systemic barriers such as stereotype threat, implicit bias, or lack of representation, which may reduce the effectiveness of interventions focused solely on cognitive or metacognitive skills without addressing underlying social and structural inequities. Finally, the high stakes and competitive nature of STEM programs may exacerbate students' stress and anxiety, potentially interfering with their willingness or ability to engage fully with these interventions. These challenges underscore the need for future research to carefully consider not only the efficacy of psychological interventions but also their feasibility and integration within the complex social and academic environments of undergraduate STEM education.

The extent to which these interventions, developed primarily in general education or psychological research contexts, are transferable to the unique challenges and cultures of undergraduate STEM education remains an open and pressing question. Addressing this gap would require empirical studies that examine not only the efficacy of these interventions for academic outcomes but also their impact on broader factors linked to persistence, such as sense of belonging, self-efficacy, and identity development in STEM. Furthermore, it is essential that future research considers how these strategies can be tailored to meet the needs of students from historically underrepresented groups, who often face compounded academic, social, and structural barriers. Ultimately, expanding the research base in this direction holds the potential to equip educators and institutions with more effective, evidence-based tools—not only to help students persist but also to enable them to thrive and flourish within STEM fields.

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