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REVIEW

Cultivating resilience in science, technology, engineering, and mathematics education

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ABSTRACT

Resilience plays an essential role in engineering education, as it affects not only students' academic performance and professional achievements (*e.g.*, adaptability, self-efficacy, self-control, optimism, persistence) but also the professional and personal well-being of both students and educators. This review focuses on resilience in education for science, technology, engineering, and mathematics (STEM) majors, highlighting distinct conceptualizations of resilience, recent empirical research on resilience in STEM education, and the role of discourses, narratives, and social interactions in enhancing resilience enactment. In conclusion, we emphasize the need for pedagogical strategies to foster resilience enactment in STEM education and propose possible directions for future research.

Key words: science, technology, engineering, and mathematics education, resilience, engineering, pedagogy

INTRODUCTION

The role of resilience in science, technology, engineering, and mathematics (STEM) education—teaching and learning in field—is increasingly pronounced given the unique challenges and rigorous demands that students and educators face in these disciplines.[1] With the fast-pace technological developments and transformations, it is more than ever critical for STEM education to prepare students and educators to the challenges associated with volatile, uncertain, complex, and ambiguous (VUCA) social and professional environments to ensure sustainable learning and innovation in a fluctuating environment.[2] In this light, constructing resilience through communication and education can be a crucial way to support students and educators in STEM. On the one hand, resilience may impact academic performance and professional achievement of STEM students, with factors such as adaptability, self-efficacy, self-control, optimism, and persistence serving as key protective elements.[3] On the other hand, resilience is crucial for educators in STEM who face numerous challenges such as adapting to educational policies, meeting diverse student needs, and working in often under-resourced environments.[4] STEM educators' resilience may influence their personal well-being and professional longevity and effectiveness, which in turn can play a role in student outcomes and quality of education.[5] Therefore, fostering resilience among STEM students and educators is essential for creating robust educational ecosystems.

In this review, we draw on recent resilience research in STEM education, focus specifically on how resilience can be enacted and sustained through discourses and interactions and how communicative strategies can be developed to support students and educators in navigating their disciplinary demands. Understanding the interplay between individual characteristics, social support systems, and communicative practices can contribute to a comprehensive framework for enhancing resilience in educational settings and potentially enhance

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academic success and personal development. In what follows, we first introduce definitions of resilience in related disciplines, then review relevant resilience research in STEM education, and conclude with suggestions for future research and practice.

CONCEPTUALIZATIONS OF RESILIENCE

Resilience is a multifaceted concept that encompasses an individual or a community's capacity to withstand, adapt to, and recover from adversities and challenging situations and reflects dynamic processes involving interactions among personal characteristics, social networks, and environmental factors.[6–8] Importantly, resilience concerns not only bouncing back to a previous state but also the potential for growth and transformation in response to disruptive and difficult events.[9,10]

Scholars in psychology typically define resilience as one's ability to maintain or regain mental health in the midst of adversity (*e.g.*, trait orientation of resilience).[11] The process-oriented approach views resilience as involving cognitive and behavioral processes that enable individuals to cope with stress and hardship. These processes may include positive self-perception, problem-solving skills, and the capacity to regulate emotions effectively.[8,12] From a sociological perspective, resilience extends beyond individual attributes and processes of resilience to social systems and structures. Communities and organizations can enact resilience through collective actions, social support networks, and institutional responses that mitigate the impacts of crises. The level of community resilience is often gauged by the extent to which it can prepare for, respond to, and recover from various disruptions, such as natural disasters, economic downturns, or social upheavals.[13]

In comparison, communication researchers approach the construct of resilience through how individuals and groups use communicative practices to construct and negotiate resilience. The communicative construction of resilience emphasizes the role of language, narratives, and social interactions in shaping resilient identities and practices embedded in everyday life.[14,15] From this perspective, communication plays a crucial role in enhancing the enactment of resilience by enabling the sharing of information, fostering social support, and facilitating collective problem-solving.[16]

One important theoretical perspective within the study of resilience in communication is the communication theory of resilience (CTR).[10,16] CTR provides a comprehensive and heuristic framework for understanding how resilience is constructed and enacted through communication processes.[17] According to CTR, resilience is constructed through five interrelated processes: crafting normalcy, affirming identity anchors, maintaining and using communication networks, putting alternative logics to work, and acknowledging negative feelings while foregrounding productive actions.[16] CTR's focus on resilience as accumulated and enacted through communication processes may be especially useful in educational contexts. By focusing on these communicative processes, educators can create supportive atmospheres that not only enhance academic performance but also equip students with necessary discursive resources to navigate challenges, adapt to changes, and thrive in diverse learning and teaching environments in STEM fields.

RESILIENCE IN STEM

In recent years, scholars have called for more emphases and research on resilience in STEM education. In engineering education, for example, Hunsu *et al.*[18] argued that engineering programs typically focus on cognitive and technical skill development but tend to overlook resilience as "a crucial life skill", especially given its critical role in helping students navigate and overcome academic challenges. The scholars discussed resilience as a multi-dimensional construct and called for a broader integration of resilience theories into engineering education research to better support students' mental health and academic success.

Recent empirical resilience research in STEM education identified a series of predictors and outcomes of resilience. For example, Carnell and colleagues examined potential protective factors of resilience among engineering students, focusing on adaptability, self-sufficiency, self-control, optimism, and persistence.[19] With a sample of undergraduate engineering students enrolled in a statics course (a critical and challenging component of the engineering curriculum), the researchers found that transfer students who often faced additional stressors related to adapting to a new academic environment exhibited lower levels of resilience and poorer academic performance compared to their non-transfer counterparts. Different from previous studies that oftentimes focused on technical skills and cognitive strategies for problem-solving as key factors in STEM education,[20] this study underscored the pivotal role of resilience in the academic success of STEM students and highlighted the need for educational strategies to enhance resilience.

Importantly, STEM students at different stages of their learning programs may face unique challenges that necessitate resilience enactment. For instance, Saxena and Variawa focused on the prevalence and role of resilience in the eudaimonic well-being of first-year

undergraduate engineering students.[21] Their findings indicated a low prevalence of both eudaimonic well-being and resilience among the participants, with the mean scores for both measures being significantly lower compared to other empirical studies. This suggests that first-year engineering students may struggle with stressors related to their transition into university life and contributes to understanding mental health and well-being challenges faced by first-year engineering students, highlighting the importance of resilience as a potential intervention point. Hall *et al.*[22] focused on secondary school students and investigated the psychological processes associated with resilient and non-resilient responses to academic challenges. Using linguistic analysis, the research identified differences between high and low resilient students and found that students with lower levels of resilience exhibited higher instances of anger, which was often directed toward a perceived lack of teacher support and internal feelings of frustration and inadequacy. This finding underscores the importance of teacher-student relationships in fostering resilience and suggests that enhancing perceived teacher support could mitigate anger and improve resilience. Taken together, these studies emphasize the necessity of understanding the specific psychological processes that accompany resilience to develop targeted interventions in STEM education at different stages.

In addition, it is equally important to examine how resilience manifests in STEM educators, as the resilience of STEM teachers not only affects their professional longevity and well-being but also significantly impacts student outcomes and the overall quality of education. For instance, Wright and colleagues addressed the critical issue of STEM teacher shortages and the importance of developing professional resilience to enhance retention and effectiveness, highlighting the high teacher attrition in STEM fields exacerbated by challenging working conditions, lack of preparation, and insufficient support, especially in high-poverty schools.[4] The researchers proposed a revised Teacher-Centered Systemic Reform (TCSR) model and emphasized the need for professional development programs that not only focus on student needs but also on enhancing teachers' adaptive capacities. This adaptive capacity can potentially facilitate effective responses to the dynamic and often turbulent educational landscapes, thereby fostering resilience. The ecological adaptive capacity framework from environmental science also can be adapted to inform teacher professional development, focusing on resilience through the ability to navigate change and maintain effectiveness despite adversity.[4]

Scholars also investigated resilience in STEM education across different cultural contexts. Li constructed a multi-subject ecological system for STEM education in China and suggested the need for a learning ecosystem that is productive, enduring, and resilient, especially cultivating the resilience to recover interest in learning.[23] Zhang *et al.*[24] identified "students with resilience" from those with lower socioeconomic status based on Programme for International Student Assessment (PISA) data from four Chinese provinces. They also suggested strategies to enhance the scientific literacy of students from low socioeconomic backgrounds, such as stimulating motivation and confidence for learning, increasing study time, and enhancing teacher support.

RESILIENCE AND MINORITY GROUPS IN STEM

A significant portion of the literature on resilience in STEM education addressed the important issue of resilience for individuals who identify as gender and/or racial minorities who often face additional challenges and barriers, including systemic inequities, underrepresentation, and limited access to resources and support networks.[25,26] These challenges can significantly impact their educational and professional experiences. Understanding the unique obstacles and stressors faced by minority students and educators in STEM is crucial for developing targeted interventions that promote inclusivity, equity, and resilience.

Indeed, the resilience of individuals with minority identities (*e.g.*, gender and race) in STEM fields, particularly women or people of color, has been a subject of increasing scholarly attention. For example, Dutta delved into the narratives constructed by women in STEM careers to understand their resilience against organizational and sociocultural barriers.[27] The research highlighted the chronic underrepresentation of women in STEM fields globally, with specific attention to Singapore's cultural contexts. This region, although having a higher percentage of women in STEM compared to many Western nations, still exhibits significant gender-based challenges. Previous studies identified the attrition of women from STEM due to gendered barriers such as lack of mentors, masculine organizational culture, and absence of role models.[28,29] Dutta extended this literature by examining how women navigated these barriers through storytelling and resilience, emphasizing the role of communication in facilitating these processes and how women in STEM careers use narratives to make sense of and respond to their professional challenges.[16,27,30]

Regarding individuals who belong to racial minority groups, Mkhize investigated resilience and self-efficacy as critical factors influencing the academic success of nontraditional black engineering students in South Africa.[25] The case study of a successful engineering student from a disadvantaged background revealed that

resilience, characterized by strong self-confidence and coping skills, played a crucial role in academic achievement. Despite numerous socio-economic challenges, resilience and self-efficacy were instrumental in the student's persistence and success in engineering studies.[25] In a similar vein, Ozis *et al.*[31] investigated the impact of undergraduate research on the resilience of minority students in STEM, focusing on a Native American female student who was also a first-generation college student. Faced with multiple layers of minority status, including gender, ethnicity, and first-generation college attendance, the study showed how undergraduate environmental engineering research programs could enhance STEM student resilience through experiential learning and mentorship by providing not only technical skills but also critical soft skills such as self-efficacy, academic writing, and public speaking. Importantly, the study highlighted that the support from a mentor with similar minority status significantly contributed to student resilience, enabling effective navigation of the academic and personal challenges encountered. Additionally, Gonzalez *et al.*'s study showed that, for Latina students in STEM, resilience can be fostered through a combination of internal motivations and external supports, such as family encouragement and peer networks.[32] The presence of role models and mentors who shared similar cultural backgrounds also was found to be instrumental in helping Latina students navigate the academic and social challenges of STEM environments. Taken together, these findings suggest that institutions should prioritize creating inclusive research opportunities and mentorship programs that address the unique challenges faced by minority students.

In Chinese contexts specifically, Yang employed a fuzzy-set Qualitative Comparative Analysis (fsQCA) to identify configurations that fostered the professional development willingness of female STEM students.[33] These configurations included an environment free from gender stereotypes, settings devoid of perceived gender isolation, and situations with female role models. Research by Chen *et al.*[34] on middle school students' attitudes toward STEM learning revealed notable gender differences, suggesting a need for targeted encouragement and support to maintain female students' interest and engagement in STEM fields. Yuan and Zhao examined the learning disparities faced by primary school girls in STEM education and identified that social prejudice, lack of self-efficacy, and the absence of role models served as significant barriers for primary school girls in STEM education.[35] They highlighted the need for social, school, and family efforts to provide an optimal learning environment and cultural atmosphere for girls in STEM education.

CONCLUSION

In sum, a synthesis of current literature on resilience within STEM education suggests several key themes that underscore the multifaceted nature of resilience and its critical role in both student and educator experiences. First, resilience is one of the key determining factors of academic performance, mental health, well-being, and professional longevity, particularly within high-demand contexts of STEM disciplines. Research consistently demonstrates that resilience can enhance students' ability to overcome academic challenges and support educators in managing their professional responsibilities effectively. Secondly, individuals who identify as members of minority groups (*e.g.*, gender, sexual, and racial minorities) in STEM face additional challenges that necessitate structural support, supportive communities, mentorship, and inclusive practices to enhance resilience. Last, recent research highlights a shift towards understanding resilience as communicative processes, emphasizing the interplay of language, narratives, and social interactions in fostering resilience.

Based on these themes, future research should aim to develop comprehensive and integrative frameworks that encompass the various dimensions of resilience in STEM education. Given the unique challenges faced by students and educators in these fields, it is crucial to consider resilience as a multifaceted construct influenced by different personal, social, and environmental factors. Studies also should explore how these factors interact to influence resilience. For instance, integrating the CTR with educational psychology and sociocultural theories may contribute to understanding how resilience can be fostered through individual and collective efforts. In addition, future research should also investigate context-specific strategies for enhancing resilience in STEM, particularly within the Chinese educational contexts. For example, exploring how traditional Chinese cultural values, such as collectivism and respect for authority, influence resilience can provide valuable insights.[36] Additionally, future research should examine the effectiveness of specific interventions that aim at facilitating resilience enactment in different educational settings. Research in this area could involve experimental designs to test the efficacy of various strategies in enhancing resilience among STEM students and educators.

Several practical strategies can be recommended. It would be beneficial to students to incorporate resilience-building and problem-solving activities into the curriculum, encourage critical analyses and self-reflection, provide mentorship programs, and help create supportive peer networks. For educators, offering professional development focused on adaptive capacities, fostering supportive communities among

teachers, and addressing systemic discrimination and inequality in educational policies and resource allocation are essential. For individuals who identify as members of minority groups, implementing targeted interventions that promote inclusivity and provide additional support, such as providing mentors, counselors, and coaches and culturally responsive teaching practices, is crucial.

DECLARATIONS

Author contributions

Sung E: Conceptualization, Writing—Original draft. Liu L: Conceptualization, Writing—Review and Editing. Kuang K: Conceptualization, Writing—Review and Editing. All authors have read and approved the final version of the manuscript.

Ethics approval

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Conflict of interest

The authors declare no conflict of interest.

Data availability statement

There is no data set associated with the present study.

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