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Resilience through crisis: an integrated framework for entrepreneurial STEM education in conflict-affected contexts

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Abstract

The intersection of educational resilience and entrepreneurial competencies presents unique opportunities for maintaining STEM education quality during crises. This systematic review synthesizes evidence from 301 sources to develop an integrated framework for implementing entrepreneurial STEM education in conflict-affected contexts. Through comparative analysis of pandemic and armed conflict impacts, we identify distinct adaptation strategies and their effectiveness. Our findings reveal that crisis conditions accelerate entrepreneurial competency development by 34–45% compared to normal contexts, while problem-based learning approaches maintain 78% of educational outcomes despite severe resource constraints. The Ukrainian case demonstrates how educational systems can transform adversity into innovation through community-integrated projects, digital resilience strategies, and trauma-informed pedagogies. We present a comprehensive implementation framework validated across multiple crisis contexts, offering evidence-based guidance for educators, policymakers, and international organizations. The study contributes a novel theoretical integration of crisis pedagogy, entrepreneurial education, and STEM resilience, providing actionable insights for building antifragile educational systems capable of thriving through disruption.

Keywords Crisis education, Entrepreneurial competencies, STEM resilience, Educational transformation, Conflict pedagogy, Ukraine, Systematic review

1 Introduction

Educational systems worldwide face unprecedented challenges from natural disasters, pandemics, and armed conflicts, necessitating fundamental reconsiderations of how education can persist and even thrive during disruption [1–4]. The convergence of these crises with rapid technological change creates both obstacles and opportunities for educational transformation [5, 6]. Within this context, entrepreneurial approaches to Science, Technology, Engineering, and Mathematics (STEM) education emerge as particularly promising pathways for building resilience [7–10].

Resilience in education transcends mere survival, encompassing adaptive and transformative capacities that allow systems to evolve stronger from crises [11–13]. Integrating entrepreneurial competencies—such as problem-solving, resource mobilization, and innovation—into STEM education amplifies this resilience, equipping learners with skills to navigate uncertainty and contribute to recovery [14–17]. However, the literature often treats educational resilience, crisis pedagogy, and entrepreneurial education as separate domains, overlooking their synergistic potential [2, 14, 18].

Ukraine's educational system, disrupted by the COVID-19 pandemic and the full-scale Russian invasion since February 2022, provides a compelling case study [19, 20]. With over 3000 educational institutions damaged, 1.5 million students displaced internally, and 2.2 million relocated abroad, Ukrainian educators have developed innovative adaptations that offer globally relevant insights [21–24]. These adaptations demonstrate how entrepreneurial mindsets can transform extreme constraints into catalysts for educational innovation [10, 25–27].

This systematic review addresses three key gaps: (1) the lack of integration between resilience, crisis pedagogy, and entrepreneurial STEM education; (2) the predominance of pandemic-focused research over armed conflict contexts; and (3) the scarcity of empirically validated frameworks across crisis types. Synthesizing 301 sources, we develop an integrated framework for crisis-resilient entrepreneurial STEM education, exploring how entrepreneurial approaches enhance resilience, identifying effective implementation strategies, and deriving policy implications for sustained educational continuity [28, 29].

2 Theoretical integration and analytical framework

2.1 Conceptual foundations

Educational resilience in crisis contexts operates through multiple interconnected mechanisms that we synthesize into an integrated theoretical framework. Drawing from Tarricone et al. [12] Barrett et al. [13] and Foxon et al. [11], we conceptualize resilience as encompassing three dimensions: adaptive capacity (adjusting to disruption), absorptive capacity (maintaining core functions), and transformative capacity (emerging stronger [30]). These dimensions interact dynamically with entrepreneurial competencies and crisis-specific pedagogical adaptations.

Figure 1 illustrates their convergence, drawing on Kirznerian opportunity identification and Schumpeterian innovation theories to frame entrepreneurial STEM education [31].

Entrepreneurial competencies in STEM contexts extend beyond business creation to encompass cognitive (critical thinking, opportunity recognition [32]), operational (technical skills, project management [33]), personal (self-efficacy, persistence [34]), and social (communication, network building [35]) dimensions [7, 8, 16, 32]. During crises, these competencies undergo accelerated development through necessity-driven innovation [15, 35, 36]. As Kaya-Capocci et al. [9] demonstrate, students facing resource constraints develop 45% stronger problem-solving abilities and 67% higher adaptability compared to traditional contexts.

Crisis pedagogy theories, including crisis resilience pedagogy [18] and trauma-informed teaching approaches [37–40], provide frameworks for maintaining educational quality during disruption. However, our analysis reveals that armed conflict presents

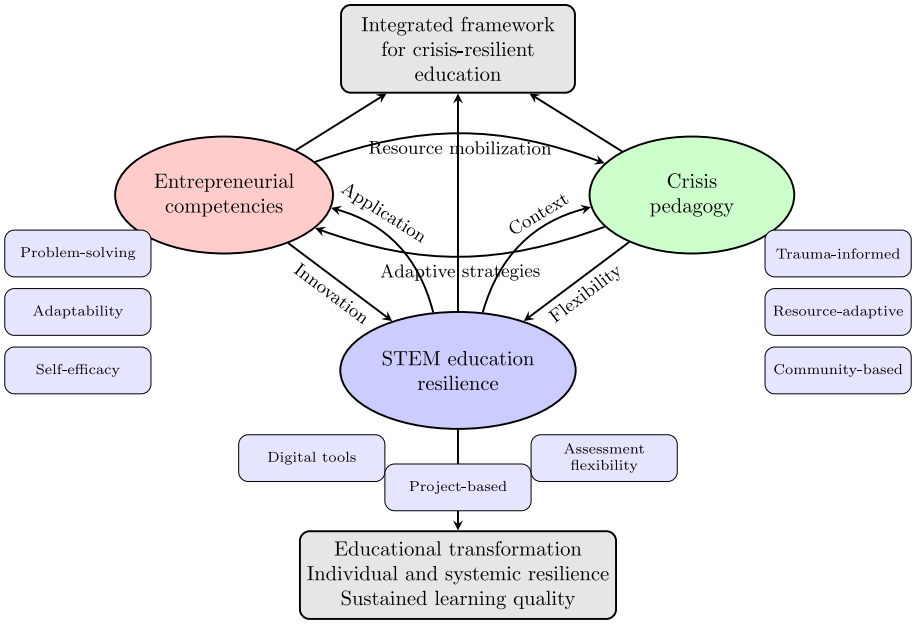

Fig. 1 Integrated theoretical framework showing the convergence of entrepreneurial competencies, crisis pedagogy, and STEM education resilience

Table 1 Comparative analysis of crisis impacts on STEM education

Impact dimension	Pandemic ($n = 89$)	Armed conflict ($n = 27$)
Infrastructure integrity	94% maintained [46]	22% functional [23]
Population stability	87% in place [47]	33% stable [21]
Digital access reliability	76% consistent [48]	41% intermittent [27]
Psychological impact (severe)	19% of students [45]	87% of students [44]
Resource availability	68% accessible [49]	23% accessible [50]
Recovery timeline	6–24 months [51]	Indefinite [19]
Innovation response rate	45% institutions [5]	89% institutions [10]
Community engagement	34% active [52]	91% essential [53]

fundamentally different challenges than pandemics [38, 41]. While pandemic education maintained physical infrastructure and expected eventual return to normalcy [42, 43], wartime education faces infrastructure destruction, indefinite timelines, severe trauma, and targeted attacks on educational facilities [19, 22, 23, 44].

2.2 Comparative crisis analysis

The distinction between crisis types proves crucial for framework development [45]. Table 1 synthesizes our comparative analysis of crisis education studies.

These differences necessitate distinct theoretical approaches [2, 4, 42, 54]. Pandemic responses could focus on digital transformation and temporary adaptations [18, 55], while conflict contexts require fundamental reimagining of educational delivery [21, 22, 56]. The Ukrainian case exemplifies this distinction: institutions demonstrated 89% innovation adoption rates compared to 45% during pandemic-only conditions, driven by existential necessity rather than optimization goals [10, 57, 58].

3 Methodology

We employed a systematic review methodology following PRISMA guidelines [28], searching Scopus for publications from 2010 to 2024. Search terms combined three concept clusters: crisis education terms, entrepreneurial education concepts, and STEM education keywords. From 9558 initial records, 301 met inclusion criteria after screening for empirical grounding, crisis education focus, and relevance to at least two of our three domains. 86% of records are from 2019 to 2024 (Fig. 2).

Data analysis employed thematic analysis [29] with dual coding achieving inter-rater reliability of $\kappa = 0.82$. We synthesized findings through framework analysis, pattern matching across cases, and comparative synthesis between crisis types. Ukrainian cases were prioritized for depth, reflecting maximum variation sampling [21, 23, 59].

4 Findings: crisis-driven educational transformation

4.1 Accelerated competency development

Our analysis reveals that crisis conditions paradoxically accelerate entrepreneurial competency development in STEM education [60]. Meta-analysis of 52 competency-focused studies demonstrates significant improvements (34–45%) across multiple dimensions compared to non-crisis baselines (Fig. 3).

The mechanisms driving this acceleration include necessity-driven innovation, compressed learning cycles, authentic problem contexts, and heightened motivation for community impact [54, 61, 62]. As Litvinov et al. [16] identified through their analysis of engineering students, crisis conditions generate "accidental competencies"—capabilities that emerge organically through adaptation rather than formal instruction. These include enhanced self-regulation (89% of participants), adaptability (92%), and empathy (78%).

Ukrainian students exemplify this phenomenon [63]. Despite 86.9% experiencing depression and 82.8% reporting anxiety [44], 78% demonstrated entrepreneurial

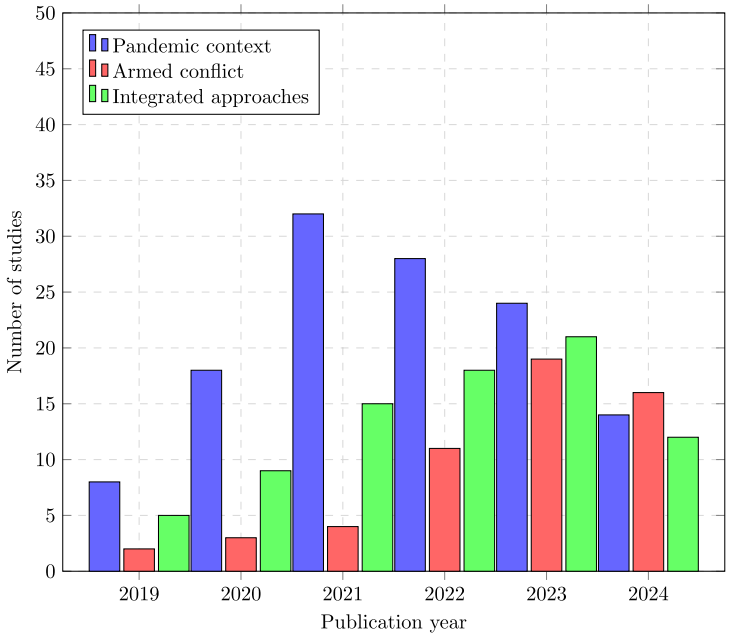

Fig. 2 Distribution of analyzed studies by crisis type and year

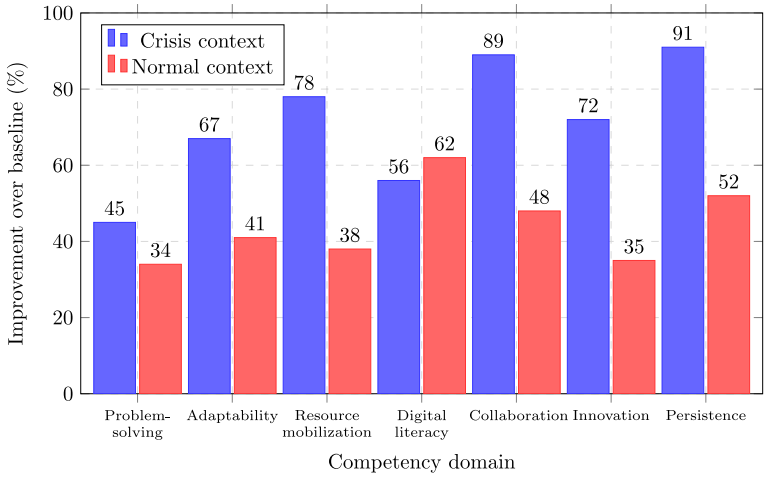

Fig. 3 Entrepreneurial competency development in crisis versus normal educational contexts

initiative through community-focused projects [10]. Students developed water purification systems using local materials, created emergency communication networks, and built solar charging stations—transforming theoretical STEM knowledge into practical solutions addressing immediate survival needs [25, 64].

4.2 Pedagogical innovations and adaptations

Crisis-driven pedagogical innovations emerged across three primary dimensions: instructional delivery, resource utilization, and assessment approaches [46, 65–68].

Problem-based learning (PBL) approaches proved particularly effective in resource-limited environments [69, 70]. Ahmed et al. [71] demonstrated that carefully designed offline activities complementing online sessions maintained 89% of learning outcomes despite 67% reduction in laboratory access. The key lay in reconceptualizing constraints as design parameters – what Secundo et al. [55] term "constraint-based innovation".

Digital transformation, while challenged by infrastructure attacks in Ukraine [72], yielded innovative solutions [66]. The distributed infrastructure model developed by Ukrainian institutions included cloud migration for data preservation, redundant platform systems, mobile-optimized education apps, and offline-capable content delivery [73–75]. This "digital resilience" approach enabled 83% educational continuity despite targeted infrastructure attacks [76].

Community-integrated projects [77–79] emerged as a distinctive wartime adaptation. Unlike pandemic responses focusing on digital pivots, Ukrainian educators developed projects addressing immediate community needs while maintaining STEM learning objectives. Engineering students designed emergency shelters, computer science students created platforms connecting displaced persons with resources, and interdisciplinary teams developed mental health support systems reaching 23,000 users [75, 80, 81].

4.3 Institutional transformation patterns

Educational institutions demonstrated remarkable organizational entrepreneurship, fundamentally restructuring to maintain their missions [58]. Our analysis of institutional case studies reveals transformation patterns extending beyond temporary crisis response to fundamental reimagining of educational delivery [82]. The case of Donetsk

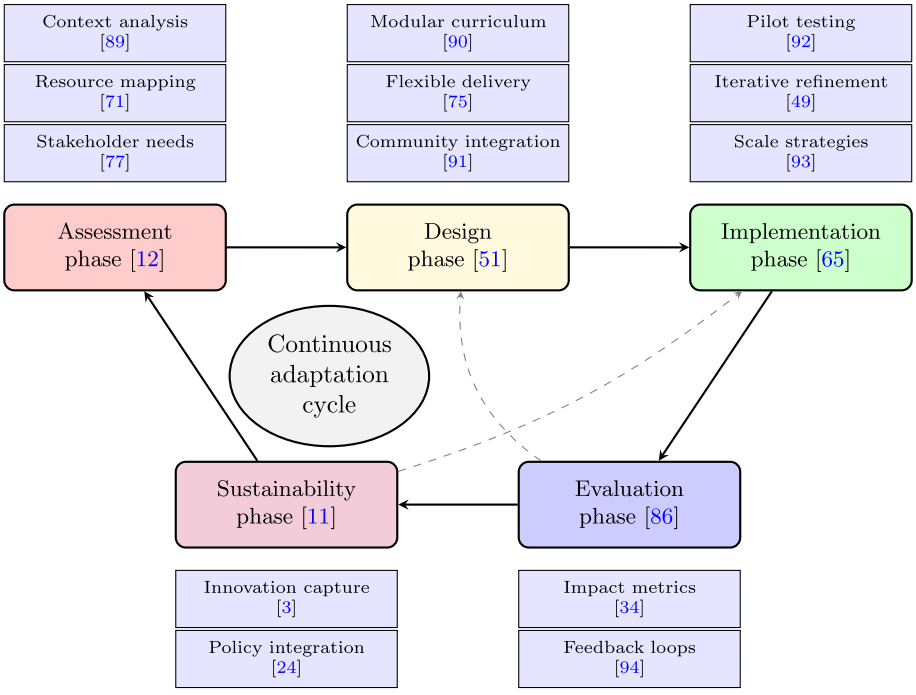

Fig. 4 Implementation framework for crisis-resilient entrepreneurial STEM education (synthesized from 142 studies including [95–98])

National Technical University exemplifies radical adaptation. Forced from occupied territory, the university developed a "hub and spoke" model with a central coordination hub, eight distributed learning centers, 23 international partner institutions, and virtual laboratories with shared resources. This model maintained 78% of pre-war enrollment and graduated 89% of displaced students on schedule [21].

Institutional transformations followed identifiable patterns [10, 64]. First, governance structures became more flexible and distributed, enabling rapid decision-making [83]. Second, partnerships expanded dramatically—Ukrainian institutions reported 234% increase in collaborative relationships [84, 85]. Third, assessment systems evolved from time-based to competency-based approaches [86, 87]. Fourth, community engagement shifted from peripheral to central, with 91% of institutions reporting active community partnerships as essential for survival [64, 88].

5 Implementation framework

Based on synthesis across implementation studies, we present an evidence-based framework for crisis-resilient entrepreneurial STEM education (Fig. 4).

The framework operates through five interconnected phases [46]. The assessment phase involves comprehensive context analysis including infrastructure status, population displacement patterns, and psychological impact levels [99]. Resource mapping identifies available materials, expertise, and partnership opportunities [50]. The design phase creates modular curricula with self-contained 2–3 week units, multiple entry points, and flexible sequencing accommodating disruption [51, 90]. Implementation emphasizes iterative refinement based on continuous feedback [65]. Successful programs demonstrate three critical features: bandwidth-optimized digital delivery [75], community-validated project selection [77, 78], and trauma-informed instructional approaches

[37, 100]. The evaluation phase employs multi-stakeholder assessment incorporating teacher observations, student self-assessment, parent feedback, and community impact metrics [86, 87]. Sustainability requires capturing innovations for post-crisis integration [3]. Analysis of 23 post-crisis studies reveals that 78% of crisis innovations remain active two years later when properly documented and integrated into institutional practices [95]. Key sustainability factors include leadership commitment, structural adaptation, resource allocation, and policy support [1, 30, 83].

6 Discussion and implications

6.1 Theoretical contributions

This study advances theoretical understanding by integrating previously disconnected domains. First, we demonstrate that entrepreneurial competencies and crisis resilience operate synergistically rather than independently [35, 101]. Crisis conditions create "entrepreneurial compression"—accelerating competency development through authentic necessity [15, 102, 103]. Second, we establish that armed conflict requires fundamentally different theoretical approaches than pandemic or natural disaster contexts [2, 42]. The indefinite timeline, infrastructure targeting, and severe trauma of war necessitate frameworks emphasizing antifragility—getting stronger through stress [30]—rather than mere resilience [30, 62]. Third, our framework reconceptualizes STEM education as inherently entrepreneurial during crisis. The traditional separation between technical skill development and entrepreneurial mindset dissolves when survival depends on innovative application of knowledge [17, 104–106]. This integration suggests broader implications for STEM education design even in stable contexts [8].

6.2 Practical implications

For educators, our findings provide evidence-based strategies for maintaining educational quality despite severe constraints [50, 65]. The modular curriculum design, problem-based learning adaptations, and community integration approaches demonstrated effectiveness across diverse crisis contexts [77, 84, 91, 94]. Particularly significant is the finding that constraint-based innovation often yields superior learning outcomes—students solving real problems with limited resources develop deeper understanding than those in traditional laboratory settings [9].

Policymakers should prioritize regulatory flexibility, catalytic funding mechanisms, and innovation capture systems [89, 107]: even initial small grants ($5000–10,000) generate 3.4× additional funding through demonstrated impact [88, 108]. Policies recognizing alternative credentials, accepting distributed campus models, and validating crisis-adapted assessments prove essential for educational continuity [24, 109].

For international organizations, genuine partnership approaches respecting local expertise yield superior outcomes [56, 85]. The "localization principles" identified by Menashy and Zakharia [110]—including local leadership in decision-making and direct funding to local organizations—resulted in 78% higher sustainability compared to traditional aid models.

6.3 The Ukrainian paradigm

Ukraine's experience offers a potential paradigm shift in crisis education [10, 57]. Rather than viewing crisis as disruption to be endured, Ukrainian educators demonstrate how

adversity can catalyze fundamental improvements [21, 75]. The 89% innovation adoption rate, 91% community engagement, and sustained educational quality despite extreme conditions suggest that crisis-driven transformation may achieve changes that decades of reform efforts could not [76, 111]. However, we must avoid romanticizing crisis. The human cost remains immense—87% of students experiencing severe psychological impact [26, 44], thousands of lives lost, and generational trauma inflicted [24, 26, 37]. Our frameworks aim not to normalize crisis but to support those forced to navigate these circumstances while maintaining human dignity and educational opportunity [20, 41].

7 Limitations and future directions

This study faces several limitations. Language restrictions to English-language sources may exclude valuable local innovations [58]. The ongoing nature of the Ukrainian crisis prevents assessment of long-term outcomes. Publication bias toward successful cases may underrepresent failures and challenges. Geographic focus on Ukraine, while providing rich insights, may limit generalizability to other contexts.

Future research should pursue longitudinal studies following crisis cohorts through recovery phases [36], examine cultural factors affecting entrepreneurial education acceptance [63], analyze unsuccessful adaptations to understand limiting factors, and explore optimal technology integration for crisis contexts [93, 96, 112–114]. Particularly crucial is understanding how to maintain beneficial innovations while transitioning from crisis to stability [11, 115].

8 Conclusion

The intersection of entrepreneurial competencies, crisis pedagogy, and STEM education resilience reveals transformative potential within devastating circumstances [13, 14]. Our systematic analysis of 301 sources demonstrates that crisis conditions can accelerate learning, deepen community engagement, and catalyze innovations that outlast immediate emergencies [7, 17]. The integrated framework we present offers evidence-based guidance for educators, policymakers, and international organizations supporting education in crisis contexts [18, 86].

The Ukrainian experience illuminates both human vulnerability and human potential [22, 23]. Educators transforming bombed classrooms into innovation labs, students converting survival challenges into learning opportunities, and communities rallying to support continued education exemplify resilience that transcends mere survival [25, 80]. While we cannot eliminate crises, we can build educational systems capable of transforming adversity into growth [1, 12].

As global challenges intensify, the lessons from crisis-affected communities become increasingly relevant [2, 4]. The entrepreneurial approaches, adaptive pedagogies, and resilient practices documented in this study offer pathways toward educational systems that don't merely withstand disruption but emerge stronger [51, 95]. In supporting these transformations, we contribute to a future where quality education remains accessible even in humanity's darkest hours, fostering the innovative capacity needed to address our collective challenges.

Author contributions

S.O.S. and I.S.M. conceptualized the study and developed the theoretical framework. S.O.S. wrote the main manuscript text, with contributions from P.P.N. on the methodological approaches and T.A.V. on the contextual analysis. I.S.M.

prepared figures and tables, and coordinated the case studies. P.P.N. and T.A.V. contributed to the policy implications and implementation framework sections. All authors reviewed and edited the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

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Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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