1.1. STEM Education Landscapes: A Comparative Bibliometric and Pedagogical Overview of Canada and Ukraine

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Abstract*. This chapter provides a comprehensive comparative analysis of STEM education in Canada and Ukraine, integrating bibliometric mapping, qualitative content analysis, and comparative synthesis. Drawing on over 21,000 publications indexed in the Web of Science, including more than 850 Canadian and 85 Ukrainian works, the study examines national trajectories, institutional priorities, and pedagogical innovations. The findings demonstrate that Canada has solidified its position as a global leader, bolstered by mature research infrastructures, comprehensive policy frameworks, and extensive international collaborations. Canadian STEM education emphasizes teacher preparation, equity, diversity, and inclusion (EDI), the integration of Indigenous and multicultural knowledge systems, and a strong tradition of informal learning environments such as science museums and afterschool clubs. Emerging trends highlight digital pedagogy, immersive technologies, and gamified approaches, situating STEM as a vehicle for civic engagement, sustainability, and social justice. In Ukraine, STEM education has evolved rapidly, despite economic and wartime challenges, reflecting the country's adaptability and innovation under constraint. Pedagogical universities integrate STEM modules into teacher training, emphasizing visualization, modeling, and competency-based approaches. Practices include cloud-based platforms, augmented and virtual reality, and experimental adoption of generative AI to foster research skills and reflective thinking among pre-service teachers. Ukraine also demonstrates strong alignment with the Sustainable Development Goals (SDGs), expanding STEM into non-formal settings through STREAM centers, gamification, and project-based initiatives that extend access to underserved and displaced learners. The comparative analysis reveals complementary strengths. Canada offers institutional maturity, inclusivity, and ethically grounded pedagogy, while Ukraine exemplifies resilience, rapid digital adoption, and crisis-driven innovation. Equity and inclusion remain divergent: Canada benefits from systemic frameworks for gender and refugee support, while Ukraine continues to face acute regional and infrastructural disparities. Nevertheless, both*

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contexts demonstrate the potential of STEM education to act as a driver of societal transformation, whether through stability and policy coherence (Canada) or through adaptive experimentation and resilience (Ukraine). The chapter concludes that cross-national collaboration between Canada and Ukraine could generate mutually beneficial outcomes. Canada may learn from Ukraine's agile innovation cycles, while Ukraine could adapt Canada's inclusive and policy-supported models. Together, they offer distinct but complementary pathways for reimagining STEM education as context-sensitive, ethically informed, and future-oriented, capable of addressing the intertwined challenges of technological disruption, sustainability, and social resilience.

***Keywords**: STEM education; Canada; Ukraine; comparative analysis; teacher education; digital transformation; visualization; inclusive pedagogy; bibliometric analysis; educational innovation.*

Introduction

STEM education, encompassing science, technology, engineering, and mathematics, is widely recognized as a driving force behind innovation, economic development, and societal transformation in the 21st century. Across the globe, governments and institutions have intensified efforts to implement STEM programs that not only equip learners with technical knowledge but also cultivate critical thinking, creativity, collaboration, and problem-solving skills. Recent scholarly works underscore the need for integrative and context-responsive STEM models that reflect local challenges while engaging with global scientific and technological frontiers.

In the Canadian context, research highlights the expansion of STEM education into realms of ethics (Steele, 2016), the integration of Indigenous knowledge, and the adoption of transdisciplinary inquiry (Takeuchi et al., 2020). Teacher education has emerged as a pivotal site for enacting these changes, with universities designing STEM courses that promote equity, inclusivity, and socially relevant pedagogies (Babb et al., 2016; Estaiteyeh & DeCoito, 2023).

Meanwhile, in Ukraine, STEM education has become a strategic priority in the wake of digital transformation and geopolitical crisis. Studies by Semenikhina et al. (2022, 2023), Drushlyak et al. (2023), and others document the use of cloud-based platforms, modeling tools, visualization techniques, and AI-driven simulations to support future mathematics and informatics teachers. Despite resource limitations, Ukrainian educators have demonstrated remarkable resilience and innovation, positioning STEM as a vehicle for societal adaptation and recovery.

Given these trajectories, a comparative analysis of STEM education in Canada and Ukraine is timely and necessary. It enables the identification of shared priorities, divergent pathways, and complementary innovations. Such an analysis supports evidence-based dialogue on the future directions of STEM education, particularly in the context of preparing teachers and shaping inclusive, future-ready societies.

The *aim of this chapter* is to examine and compare the bibliometric landscapes and pedagogical practices of STEM education in Canada and Ukraine, with a focus on teacher training, digital integration, inclusivity, and sociocultural framing.

This chapter is structured as follows: presents a bibliometric overview of global STEM education research, highlighting publication dynamics and Canada's and Ukraine's positioning; explores STEM education in Canada, emphasizing teacher education, EDI principles, Indigenous knowledge, and digital pedagogy; analyzes STEM education in Ukraine, focusing on digital tools, modeling, AI, inclusivity, and responses to wartime challenges; offers a comparative synthesis of both national experiences, identifying overlaps, differences, and mutual learning opportunities; concludes with key insights, implications for global STEM development, and suggestions for future collaborative research.

Research Methods and Data Sources

The research presented in this chapter employs a mixed-methods approach that combines bibliometric analysis with qualitative content analysis and comparative synthesis. The aim was to explore both the scope and the nature of STEM education scholarship and practices in Canada and Ukraine. The study relied on the following data sources and methodological procedures:

1. Bibliometric Analysis. Data were retrieved from the Web of Science (WoS) database using the keyword query “STEM education” across the fields of title, abstract, and keywords. The

analysis included publication counts by year, country, author affiliation, document type, and citation metrics. A focused comparison of Canadian and Ukrainian STEM research output was conducted, with a specific focus on national trends, influential authors, and thematic areas of focus.

2. Qualitative Content Analysis. A purposive sample of peer-reviewed publications by Canadian and Ukrainian authors was analyzed to identify dominant themes, models of teacher education, pedagogical strategies, and sociocultural framings of STEM. These included recent empirical studies, conceptual frameworks, and case-based reports from national and international journals, as well as proceedings from relevant conferences.

3. Comparative Synthesis. Based on the extracted data and thematic insights, a comparative analysis was carried out to examine both convergence and divergence in STEM education priorities, practices, and innovations across the two countries. The synthesis emphasized not only pedagogical content but also the underlying assumptions about equity, inclusion, crisis response, and societal development.

The study draws on over 40 publications authored by Ukrainian researchers in the field of STEM education (2015–2025), as well as more than 30 recent studies and policy-oriented works from the Canadian context. The results were further supported by Web of Science analytics and visualized using charts and tables to illustrate publication dynamics and thematic clustering.

Findinfs

Bibliometric Landscape of STEM Education

The quantitative analysis revealed that STEM education has evolved into an interdisciplinary research area since the early 2000s, with a significant increase in publications occurring after 2010. Canada demonstrates relatively high activity (850 papers), while Ukraine is at the stage of institutionalizing STEM research (85 papers), but is actively integrating into the international space, especially through joint publications and conferences.

Bibliometric analysis serves as an effective tool for assessing the scope, dynamics, and focus areas of scientific research within a specific field. This subsection presents an overview of publication activity related to STEM education based on data retrieved from the Web of Science Core Collection (WoS). The keyword query 'STEM education' was applied to the 'topic' field (including title, abstract, and keywords), yielding a comprehensive sample of publications directly related to educational aspects of STEM.

As of August 2025, the WoS database contained 21,794 scholarly publications on STEM education (Figure 1).

Figure 1 presents the annual trend in STEM education publications from 1976 to 2025.

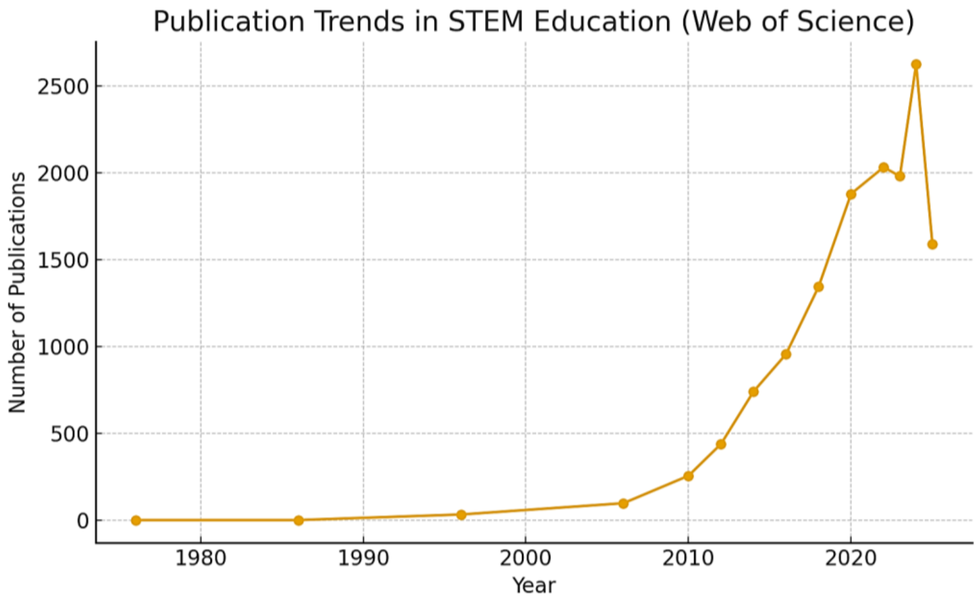

Figure 1. Publication Trends in STEM Education (Web of Science, 1976–2025)

The figure illustrates the annual number of publications indexed in Web of Science that include 'STEM education' in the title, abstract, or keywords. A significant increase in output is observed since 2010, reflecting growing scholarly interest in the field.

If the search is limited to titles only, the total is 2,638, including 82 publications associated with Canadian authors and 22 with Ukrainian authors. These figures reflect a substantial level of global interest in the topic, though with marked variability in regional representation.

Since the mid-2000s, there has been a steady increase in the number of STEM education publications. A sharp rise was observed starting in 2015, with peak outputs recorded during the 2020–2024 period, coinciding with the COVID-19 pandemic and a global shift to digital learning models. In 2024 alone, more than 2,600 works were published, while the first eight months of 2025 yielded nearly 1,600 publications. These trends confirm the consolidation of STEM education as a leading topic in educational scholarship, shaped by digitalization, labor market transformation, and global crises.

Geographically, STEM education research is represented by authors from 167 countries (Figure 2).

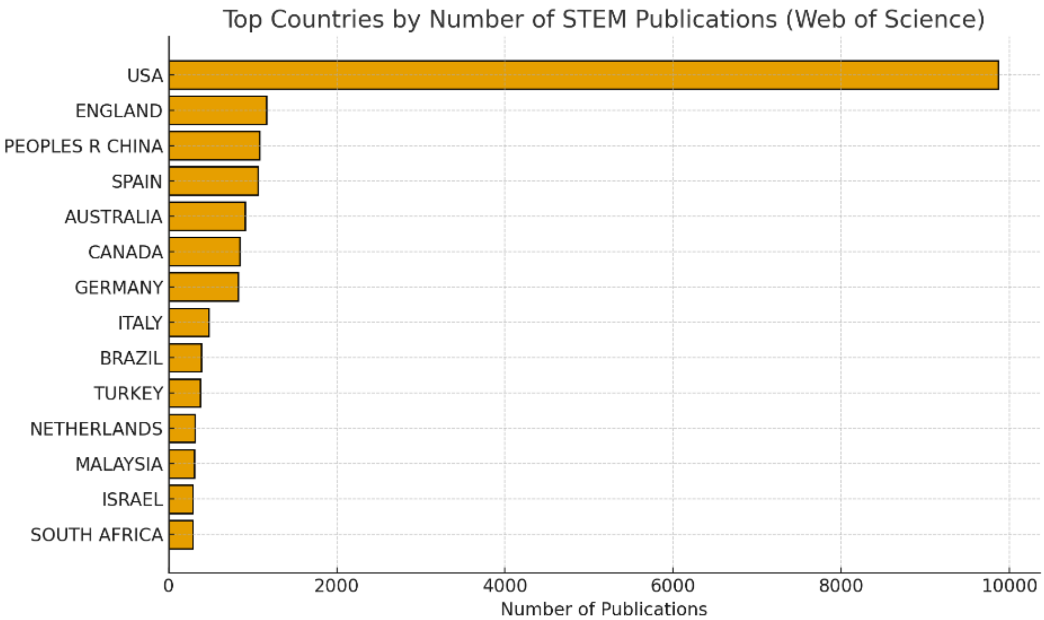

Figure 2. STEM Education Publications by Country

The leading contributors include the United States, China, Spain, the United Kingdom, Germany, and Canada. Canada ranks sixth globally with 850 publications, while Ukraine holds the 49th position with 85 publications, indicating steady but still modest integration into the global STEM discourse.

The majority of documents in the sample are research articles published in peer-reviewed journals, comprising roughly two-thirds of the total. Conference proceedings account for about 20 percent, particularly from events such as EDUCON, ICERI, and MIPRO. A smaller portion consists of review articles, book chapters, and other formats, collectively reflecting the formation of a multidimensional interdisciplinary research field.

Among the most prolific authors are Charles Henderson, Gillian Roehrig, Tamara J. Moore, Siddika Selcen Guzey, and Gabriel-Miro Muntean. These scholars represent leading universities in the United States, Ireland, and beyond. Their work focuses on integrating STEM education into school and university curricula, as well as teacher training and digital learning innovation.

The list of most cited works further illustrates the influence of foundational research. Notable among them are Kelley and Knowles' (2016) conceptual model of integrated STEM education, English's (2016) perspectives on K–12 STEM integration, and interdisciplinary teaching strategies proposed by Asghar et al. In the Canadian context, Blotnicky et al. (2018) stand out with a study on the connection between STEM career awareness and student motivation.

A key aspect of understanding the landscape of STEM research in Canada involves identifying the leading academic institutions contributing to the field. Based on data from the Web of Science, the following table (Table 1) presents the top Canadian universities and research centres ranked by the number of publications related to STEM education. This information highlights the institutional distribution of research efforts and serves as an indicator of regional academic capacity and specialization in STEM pedagogy, policy, and innovation.

This institutional breakdown confirms the dominance of large research-intensive universities, particularly the University of Toronto, UBC, and McGill, in shaping the STEM education discourse in Canada. Notably, a strong representation from both anglophone and francophone institutions (e.g., Université de Montréal) reflects the country's bilingual academic landscape.

Table 1. Canadian Institutions with the Highest Number of STEM Education Publications (Web of Science)

Rank	*Institution Name*	*Number of Publications*
1	University of Toronto	159
2	University of British Columbia	97
3	McGill University	79
4	University of Calgary	72
5	University of Alberta	52
6	University of Ottawa	48
7	University Health Network, Toronto	44
8	Western University / University of Western Ontario	42
9	Simon Fraser University	39
10	Université de Montréal	37
11	University of Victoria	29
12	Queen’s University Canada	28
13	University of Waterloo	26

Furthermore, the presence of medical and research networks, such as the University Health Network, underscores the interdisciplinary nature of STEM and its applications in health and the applied sciences. These institutions not only lead national scholarly output but also play a pivotal role in setting pedagogical trends, forming policy recommendations, and training the next generation of STEM educators.

Ukrainian contributions include Kupets (2016) on the education employment mismatch and Kramarenko et al. (2019) on the use of augmented reality in mathematics instruction. To better understand Ukraine’s contribution to STEM education research, it is important to examine the institutional affiliations of the most active authors. Based on publication data from the Web of Science, Table 2 below presents Ukrainian institutions ranked by the number of their publications related to STEM education. While the overall volume remains modest compared to global leaders, these institutions represent the emerging centers of expertise and innovation in the Ukrainian STEM research landscape.

Table 2. Ukrainian Institutions with the Highest Number of STEM Education Publications (Web of Science)

Rank	*Institution Name*	*Number of Publications*
1	Ministry of Education and Science of Ukraine	73
2	Dragomanov Ukrainian State University	10
3	National Academy of Educational Sciences of Ukraine	8
4	National University of Life and Environmental Sciences of Ukraine	8
5	Borys Grinchenko Kyiv Metropolitan University	7
6	State University Kyiv Aviation Institute	6
7	Kherson State University	5
8	Oleksandr Dovzhenko Hlukhiv National Pedagogical University	5
9	Taras Shevchenko National University of Kyiv	5
10	Zhytomyr Ivan Franko State University	5
11	Donetsk State University of Internal Affairs	4
12	Igor Sikorsky Kyiv Polytechnic Institute	4

Despite the relatively small number of entries compared to the Canadian or global context, the Ukrainian landscape exhibits a diverse range of institutions contributing to STEM education scholarship. The strong presence of the Ministry of Education and Science of Ukraine as the top contributor indicates the role of policy-oriented and state-sponsored research. Pedagogical universities (e.g., Dragomanov, Hlukhiv, Zhytomyr) and classical universities (e.g., Taras Shevchenko National University of Kyiv) play a leading role in STEM-related teacher training and educational innovation. Notably, technical institutions like the Kyiv Polytechnic Institute are beginning to feature more prominently, signaling growing interdisciplinary interest.

This distribution reflects both the institutional decentralization of Ukrainian research and the ongoing efforts to integrate STEM education into broader educational reforms, often under the constraints of war, economic challenges, and digital transformation. Continued growth in publication output from these institutions will be critical for establishing Ukraine's presence in global STEM education discourse.

Among the scholarly works that have had the greatest impact on the development of STEM education research, both Canadian and Ukrainian authors are prominently represented. The most cited publication is by Howard et al. (2021), which presents a meta-analysis within the framework of Self-Determination Theory and highlights the fundamental role of motivation in educational outcomes. Noteworthy among Canadian researchers are Beauchamp (2015) and Abrami et al. (2011), who have analyzed innovative approaches in teacher preparation and online learning design.

The study by Blotnicky et al. (2018), conducted in Canada, examines the relationship between knowledge of STEM careers and motivational factors among middle school students and stands out as one of the most cited empirical investigations in the field of STEM education.

On the Ukrainian side, the most frequently cited work is that of Kupets (2016), which, although focused on education–job mismatch, provides valuable insights into the challenges facing the STEM labor market. Also noted are studies dedicated to augmented reality in STEM teaching (Kramarenko et al., 2019), neuropsychological approaches to instruction (Voznyuk et al., 2021), and a terminological analysis of the concept of STEM education (Stryzhak et al., 2017).

These studies are published in journals from major academic publishers, including Springer, Elsevier, IEEE, and Taylor & Francis, as well as specialized Canadian and Eastern European journals, confirming the interdisciplinary and technology-oriented nature of the field.

In summary, STEM education has developed into a conceptually rich and interdisciplinary research domain, spanning pedagogy, psychology, ICT, engineering, and the social sciences.

Canada demonstrates sustained research activity with a focus on inclusion and pedagogical innovation. Although Ukraine's volume of publications remains modest, the country has shown rapid growth in digital, visual, and competency-based STEM models and is increasingly integrated into international academic networks through joint publications, conferences, and experimental pedagogical initiatives.

STEM Education in Canada: Practices and Research Approaches

Canada consistently ranks among the global leaders in STEM education research, benefiting from well-established infrastructures, diversified funding, and strong international collaboration networks. Its scholarly output frequently appears in high-impact journals and is highly cited, underscoring the country's integration into global research ecosystems (Zhan et al., 2022). This bibliometric strength provides a stable foundation for advancing innovative pedagogies and teacher preparation models.

In recent years, Canada has consolidated its position as a global leader in STEM education, not only through policy commitment and curriculum innovation, but also through the depth and diversity of its scholarly research. STEM education in Canada has evolved beyond the traditional technocratic paradigm to embody a multidimensional and critically engaged framework that integrates equity, Indigenous perspectives, digital transformation, and sustainability ethics.

A bibliometric and thematic review of Canadian publications from 2020 to 2025 reveals that teacher education remains the most actively researched and published area, accounting for approximately 28% of all scholarly contributions on STEM education during this period. This prominence reflects a national consensus that the future of STEM depends not only on student access but on educators' preparedness to facilitate interdisciplinary, inquiry-driven, and inclusive learning environments.

Institutions such as the University of Calgary and the University of British Columbia have played a foundational role in reshaping STEM teacher preparation. For example, the Werklund School of Education has developed courses that blend core scientific content with pedagogical inquiry and reflective practice, enabling pre-service teachers to design, implement, and critically analyze STEM units across disciplinary boundaries. These courses are informed by a three-phase pedagogical model described by Tsybulska et al. (2018), which moves from collaborative inquiry to design and then to field-based implementation, emphasizing the importance of experiential learning for internalizing STEM's transformative potential.

In parallel, Canada has institutionalized Equity, Diversity, and Inclusion (EDI) frameworks across STEM teacher education. Research by Estaiteyeh and DeCoito (2023) has demonstrated that explicit training in differentiated instruction significantly enhances pre-service teachers' ability to respond to diverse learning needs and cultural backgrounds. Their findings are consistent with broader national efforts to ensure that STEM learning is inclusive, representative, and socially responsive.

Another defining element of Canadian STEM education is its commitment to multicultural and multilingual integration. Bilingualism (English–French) is not only a linguistic feature but also a pedagogical asset, as programs deliberately address cultural diversity, equitable participation, and gender inclusivity (Frontiers in Education, 2024). Indigenous perspectives are complemented by broader multicultural frameworks that recognize Canada's heterogeneous student population.

A notable feature of Canadian STEM education is its deep and sustained engagement with Indigenous knowledge systems. Scholars such as Ji (2021) and Nicol et al. (2023) highlight how land-based education, Indigenous languages, and local epistemologies are being woven into mainstream STEM programs. The Canadian Light Source (CLS) initiative exemplifies this integration, offering programming where students explore chemistry and physics through culturally situated inquiry, in partnership with Indigenous communities and elders. Such efforts shift the focus from decontextualized content to locally grounded, relational approaches to science and mathematics.

Ethical and sociocultural considerations have also become central to the Canadian STEM agenda. Building on foundational critiques by Steele (2016), recent research emphasizes STEM as a medium for civic engagement, social justice, and ecological sustainability. Nicol et al. (2019, 2023) propose a “STEM as place” framework that redefines mathematics education as a relational practice, prioritizing connections between learners, communities, and the natural environment over narrow metrics of productivity or economic efficiency. These arguments resonate with the work of Yanez et al. (2019), who advocate for production pedagogy models that empower students to become agents of change within their own sociotechnical ecologies.

Alongside these pedagogical and ethical dimensions, digital transformation has become a defining feature of STEM education in Canada. From early integration of virtual reality and clickers (Lakshminarayanan & McBride, 2015) to more recent frameworks like ACT-STEM (Wu et al., 2021), the emphasis has shifted toward developing computational thinking, data literacy, and digital fluency. Milner-Bolotin (2017) outlines a model of digitally supported inquiry in which teacher candidates engage with peer instruction, collaborative design tools, and real-time data collection, experiencing the affordances and limitations of digital environments first-hand.

Canadian STEM research also engages with questions of immigration and educational access. As Boyd and Tian (2018) demonstrate, immigrants with STEM degrees, particularly those educated outside Canada, the US, the UK, or France, often face systemic barriers to employment and professional recognition. Picot and Hou (2018) similarly note a persistent earnings gap between Canadian-born and immigrant STEM graduates, which raises concerns about both credential portability and labor equity. Responding to these concerns, Le Pichon et al. (2025) propose a comparative curriculum analysis framework for assessing the STEM readiness of refugee students and developing culturally responsive diagnostic tools. This emerging strand of research foregrounds the importance of equitable access to STEM learning across migration trajectories.

Canadian research also demonstrates a strong emphasis on informal learning environments. Science museums, afterschool clubs, and national STEM competitions are integrated into policy frameworks and supported by research–practice partnerships. These settings provide authentic contexts for inquiry, reinforce curricular learning, and expand access to STEM for underrepresented groups.

Together, these thematic strands illustrate the pluralistic nature of Canadian STEM education research (Fig. 3). While no single narrative dominates, the literature converges on several shared priorities: preparing reflective and adaptive educators, embedding STEM in ethical and cultural contexts, promoting inclusive and relational pedagogies, and leveraging digital tools to enhance inquiry and access. The Canadian case demonstrates that STEM education, when meaningfully situated, can serve not only as a conduit to economic opportunity but as a medium for critical, creative, and collective engagement with contemporary challenges.

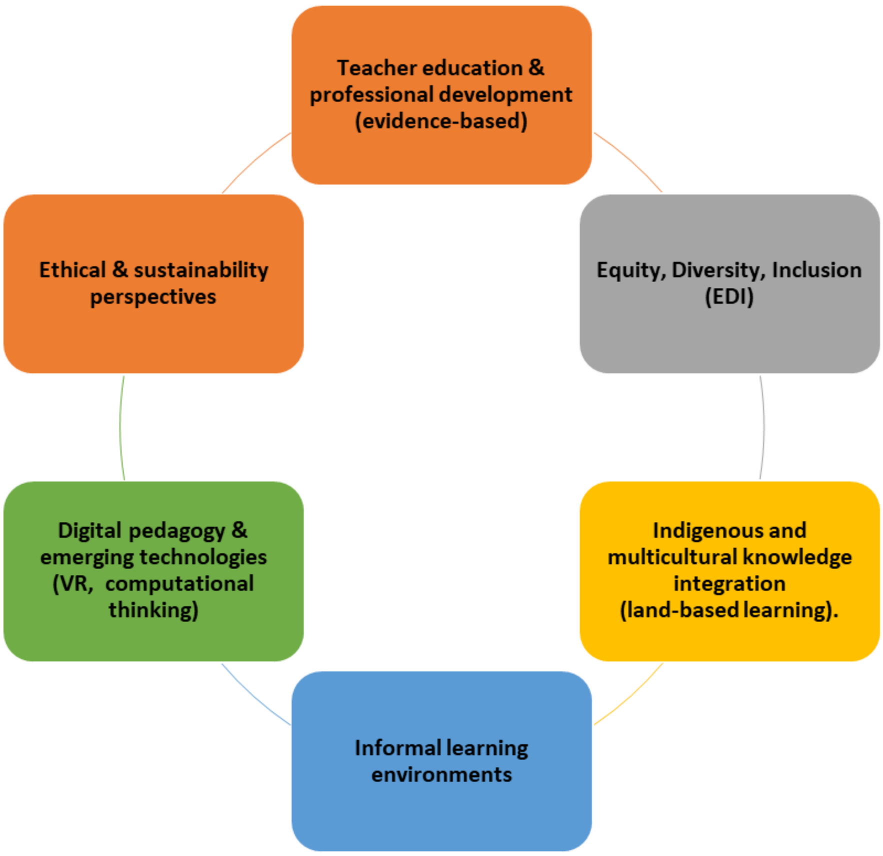

Figure 3. STEM Education Research Trends in Canada (2020–2025) with an expanded thematic focus, including informal learning environments and emerging digital innovations

This evolving landscape of STEM education in Canada demonstrates not only thematic breadth but a clear epistemological shift from standardized, discipline-driven approaches to more situated, relational, and ethically grounded models of teaching and learning. By integrating Indigenous worldviews, embracing digital and AI-powered tools, and addressing systemic inequities, Canadian educators and researchers are reimagining STEM as a means to achieve inclusive and sustainable futures. The Canadian case thus offers both a mirror and a map: a mirror reflecting the complex intersections of science, society, and identity, and a map for other nations seeking to reposition STEM education as a force for human flourishing and global justice.

Recent advances highlight Canada's exploration of immersive and gamified approaches, such as metaverse applications that create interactive STEM environments and motivate sustained engagement (Chen et al., 2023). These innovations, supported by robust infrastructure and teacher professional development, signify the country's ability to experiment with next-generation pedagogies.

STEM Education in Ukraine: Practices and Research Approaches

Ukraine's STEM education research landscape has expanded rapidly over the past five years, with bibliometric mapping showing concentration in metropolitan centers such as Kyiv and Lviv. While citation impact remains limited, international collaborations are gradually increasing, providing visibility despite scarce domestic funding and infrastructural constraints (Zhan et al., 2022; Freeman et al., 2019). Since the early 2010s, STEM education in Ukraine has undergone rapid evolution into a dynamic field, shaped by national educational reforms, technological advancements, and, in recent years, the exigencies of war. Despite enduring structural challenges, including underfunding, limited infrastructure, and the migration of academic personnel, Ukrainian researchers and educators have devised innovative practices, particularly in STEM-related teacher education. The period from 2020 to 2025 marks a decisive shift toward competency-oriented, digitally enriched, and research-informed

STEM strategies, positioning Ukraine as a responsive and experimental context within global STEM transformations.

The most prominent field of activity concerns the institutional integration of STEM in teacher training programs. Ukrainian pedagogical universities, such as Sumy State Pedagogical University, National University 'Chernihiv Collegium', and Dragomanov Ukrainian State University, have systematically integrated STEM modules into pre-service education for future teachers of mathematics, physics, and informatics. These modules emphasize dynamic visualization, mathematical modeling, algorithmic thinking, and cross-disciplinary project-based learning. Semenikhina et al. (2022) and Drushlyak et al. (2023) document how STEM is not treated as an isolated subject but rather as a vehicle for the formation of integrated methodological thinking. Moreover, this integration often relies on individualized tasks, micro-research, and simulation-based exercises, forming an early culture of educational inquiry among students.

At the policy level, Ukrainian STEM education is closely aligned with the UN Sustainable Development Goals, particularly through emphasis on student motivation, critical thinking, and public–private partnerships in education (EJSD, 2023). These initiatives position STEM not only as a curricular innovation but also as a societal tool for advancing sustainability and civic responsibility.

A second major focus lies in the digitalization of STEM learning and the active promotion of visual thinking. Cloud-based platforms, such as GeoGebra, Desmos, and Tinkercad, are increasingly used in both school and university-level instruction. Ukrainian researchers, particularly those affiliated with regional STEM laboratories, have designed numerous interactive learning scenarios that combine dynamic geometry, parametric transformations, and BYOD-based strategies such as QR code tasking and mobile simulations. These tools not only support cognitive visualization but also facilitate inclusive learning, especially for students with different learning profiles or access needs. The use of visualization is further positioned as a metacognitive tool in developing spatial reasoning and systemic problem-solving among teacher trainees. Beyond cloud-based platforms such as GeoGebra and Desmos, Ukrainian teachers increasingly experiment with augmented and virtual reality. Tools like Google Expeditions and Google Lens have been piloted to increase student motivation and support blended learning (Shapovalov et al., 2018). However, challenges persist, including limited Ukrainian-language interfaces and uneven teacher awareness, which constrain broader adoption.

Another growing vector of research is inclusive and competency-based STEM education. Ukrainian studies emphasize accessibility, adaptability, and personalization of digital STEM content to reflect the needs of students with disabilities, refugees, and learners from rural or underserved areas. Researchers such as Drushlyak et al. (2023) propose competency models that integrate media literacy, critical thinking, and collaboration into science and math instruction. Additionally, interdisciplinary and transdisciplinary efforts, particularly those aligned with STEAM frameworks, have found traction in non-formal settings such as digital camps, maker spaces, and thematic STEM festivals supported by local education authorities and NGOs. Despite progress, Ukraine continues to face persistent regional disparities and gaps in teacher preparedness for implementing systemic STEM initiatives. Surveys indicate low awareness of global STEM programs among pedagogical students and practicing teachers. These challenges underscore the need for sustained professional development frameworks that are comparable to those in Canada.

Perhaps the most experimental domain is the integration of AI and reflective technologies into pre-service STEM teacher education. Recent studies (Drushlyak et al., 2025; Semenog et al., 2025) document pilot projects in which ChatGPT and other generative tools are used to support the development of linguistic creativity, research planning, and genre-based writing among teacher candidates. AI is not merely used as a technological aid, but as a pedagogical actor, one that reshapes assessment strategies, fosters reflexive dialogue, and supports meta-level thinking about scientific communication and pedagogical modeling. Such innovations signal a growing Ukrainian contribution to AI-mediated didactic design in STEM.

The full-scale war in Ukraine since 2022 has forced educators and students into high-adaptation modes, giving rise to new resilience-oriented STEM practices. These include mobile learning kits, Arduino-based micro-infrastructures, and the use of large-scale 3D printing for rebuilding educational spaces. Pedagogical research is increasingly focusing on trauma-informed education, emotional self-regulation, and the integration of STEM into psychological support systems and urban resilience projects. This wartime context has paradoxically accelerated digital innovation and amplified international collaboration among Ukrainian STEM scholars and global partners.

Overall, Ukrainian STEM education between 2020 and 2025 exemplifies a practice-rich, adversity-informed, and digitally enhanced ecosystem. Although challenges remain, Ukrainian educators continue to demonstrate strong capacities for adaptive innovation, methodological experimentation, and collaborative knowledge building. Their practices enrich the international conversation not only through digitalization and visual tools but also by offering an example of education as a source of resilience, transformation, and hope under extreme conditions.

The thematic distribution of STEM practices in Ukraine between 2020 and 2025, as illustrated in Figure 4, highlights the field’s multidimensional character and its responsiveness to both educational reforms and sociopolitical disruptions. Teacher training and institutional integration remain the structural backbone of STEM development, while digitalization and visual tools provide the primary means of pedagogical enhancement. Simultaneously, growing attention to inclusion, AI experimentation, and wartime resilience strategies reflects Ukraine’s ability to reposition adversity into innovation. This complex ecosystem of practices not only mirrors global STEM priorities but also makes a unique contribution to the discourse on education as a driver of social stability, technological progress, and human-centered transformation. Ukrainian STEM education, therefore, offers a valuable case for understanding how pedagogical ingenuity can flourish even in constrained and turbulent conditions.

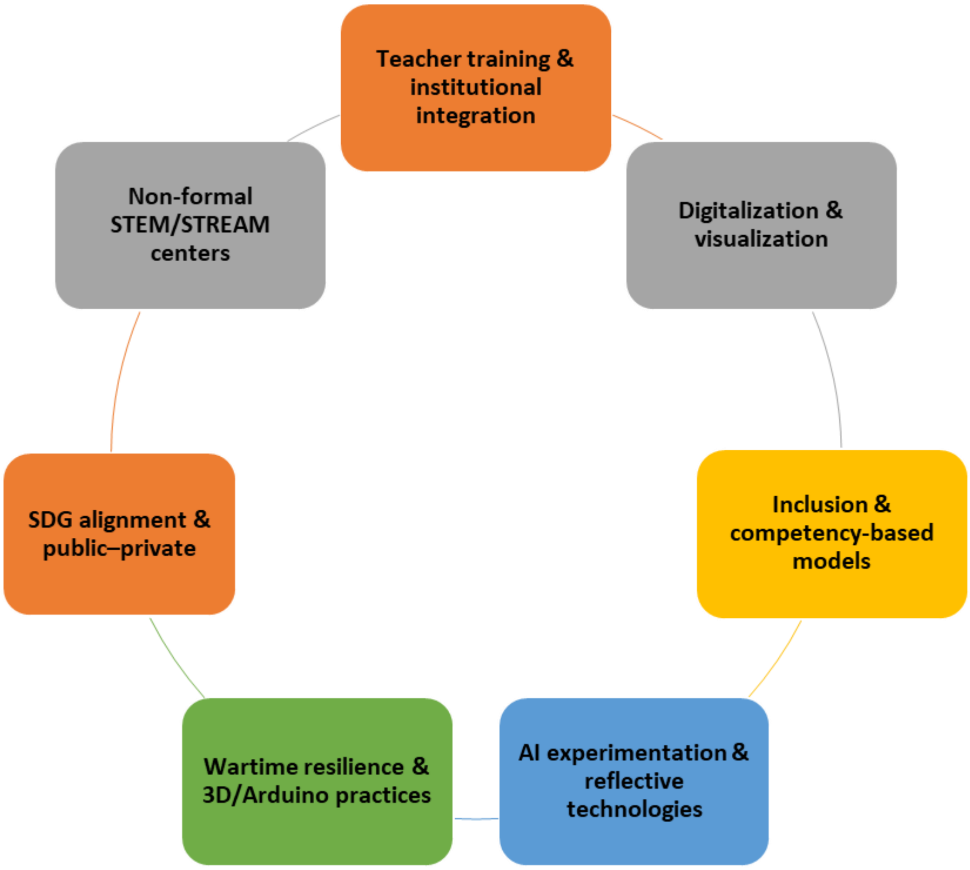

Figure 4. Thematic distribution of STEM education practices in Ukraine (2020–2025), expanded to include SDG alignment, AR/VR applications, and non-formal STEM/STREAM initiatives (Montessori, gamification).

In addition to formal education, Ukraine has witnessed the rapid emergence of STEM and STREAM centers, often supported by NGOs and municipal authorities. Innovative approaches include integrating Montessori principles and gamification techniques to foster curiosity, collaboration, and soft skills among learners (Chilvers, 2025). Such non-formal environments enrich the overall STEM ecosystem and extend access beyond traditional classrooms.

Comparative Analysis of STEM Education in Canada and Ukraine

This section presents a comparative analysis of STEM education development in Canada and Ukraine, based on the previous sections. While the two countries differ significantly in terms of geopolitical context, economic capacity, and educational infrastructure, both have demonstrated a growing commitment to advancing STEM through innovative, digitally enhanced, and socially responsive practices.

Table 3 below summarizes key comparative dimensions of STEM education in Canada and Ukraine. The table highlights divergences in research output, pedagogical models, informal education, and funding structures.

Table 3. STEM Education in Canada vs. Ukraine

Aspect	*Canada*	*Ukraine*
Bibliometric Output	Global leader, high-impact, high citation	Growing rapidly, mostly centered in key cities
Key Research Topics	Inclusivity, assessment, teacher PD, EdTech	SDGs, motivation, non-formal STEM, gamification
Pedagogical Model	Inquiry- & project-based, multicultural	Transition to constructivism, some didactics
Informal Education	Strong (museums, clubs), regular curriculum review	Rapid growth of STEM/STREAM centers; urban focus
Funding & Collaboration	Robust, international, and cross-sector partnerships	Limited, driven by individual schools/cities
Regional Reach	Nationwide, equity focus	Regional gaps: best resources in Kyiv, Lviv
Curriculum Alignment	Frequent updating, policy-driven innovation	Ongoing reform, emphasis on SDGs

A radar plot (Figure 5) synthesizes six dimensions along which STEM education in both contexts may be compared: policy and governance, equity and inclusion, digital integration, teacher training, ethical and cultural framing, and crisis-driven innovation. The radar chart is complemented by a comparative table for detailed analysis.

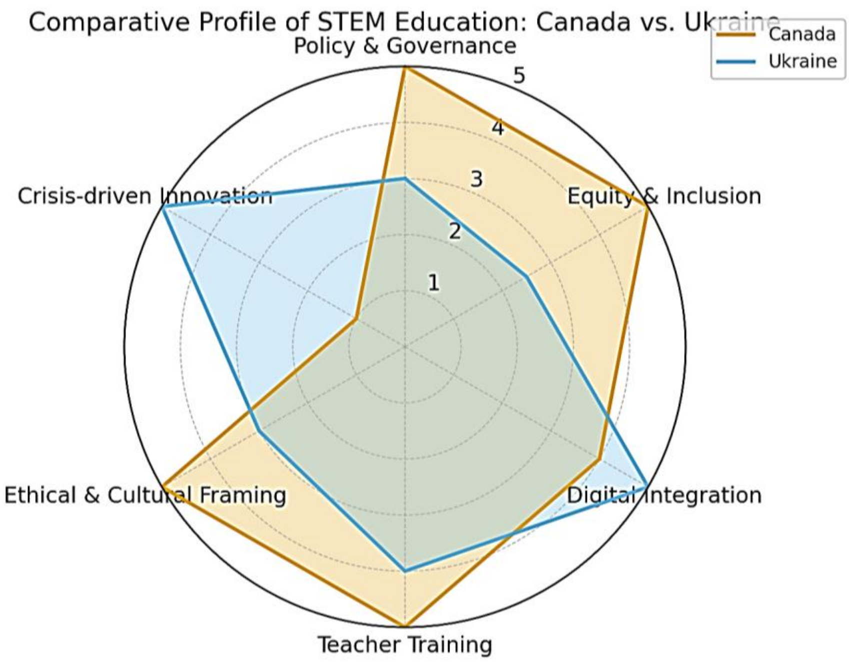

Figure 5. Comparative Profile of STEM Education: Canada vs. Ukraine

Canada exhibits strong performance across policy, inclusion, ethics, and teacher preparation. With stable funding, decentralized governance, and sustained policy efforts, Canadian institutions have successfully integrated STEM within broader educational goals, including environmental sustainability, social justice, and Indigenous reconciliation. Teacher education programs routinely address equity, interdisciplinary integration, and the ethical implications of scientific literacy.

Ukraine, by contrast, demonstrates its strengths in digital integration, methodological innovation, and adaptability in crisis situations. The widespread use of cloud-based tools, dynamic visualization platforms, and mobile learning technologies, accelerated by the war, has created a fertile ground for experimentation. While Ukraine's centralized governance and limited funding present challenges, these constraints have catalyzed the design of creative tasks, personalized learning, and AI-assisted pedagogy in STEM teacher training.

In terms of equity and inclusion, Canada leads with established frameworks for differentiated instruction and refugee support, whereas Ukraine is in the process of building inclusive strategies under the dual pressures of digital inequality and population displacement. Ethical and cultural dimensions are more thoroughly developed in Canadian discourse, especially through the integration of Indigenous worldviews and place-based mathematics. Ukrainian research, though less developed in this regard, is beginning to incorporate trauma-informed and resilience-centered pedagogies. Equity and inclusion remain crucial points of divergence. Canada has well-established frameworks for differentiated instruction, gender mainstreaming, and refugee support, supported by a significant body of empirical research (Zivot et al., 2020). In contrast, Ukraine continues to grapple with sharper gender and regional inequities, with fewer systemic interventions and a limited evidence base (Zhan et al., 2022).

The final comparison dimension, crisis-driven innovation, highlights Ukraine's unique contribution to global STEM education. The war has forced institutions to redesign educational delivery, incorporate trauma-sensitive approaches, and utilize technology in unprecedented ways. This stands in contrast to Canada, where crisis response has not been a dominant theme in STEM education research.

Taken together, the comparative profile suggests complementary strengths. Canada offers a stable, mature, and critically reflective STEM ecosystem that is well-aligned with humanistic and ecological values. Ukraine, meanwhile, provides a living laboratory of resilience, agility, and digital transformation under pressure. Collaboration between the two contexts could yield mutual benefits: Canada can learn from Ukraine’s rapid innovation cycles, while Ukraine could draw on Canadian experience in inclusive policy design and ethical framing.

Another notable difference lies in the ecosystems of knowledge production. Canadian researchers publish predominantly in high-impact international journals, shaping global STEM discourse (Li & Xiao, 2022). Ukrainian outputs, by contrast, remain concentrated in conference proceedings and local journals, which affects citation impact and visibility. These disparities highlight structural inequalities in research capacity, but also underscore Ukraine’s potential for growth through international partnerships and funding support.

The radar chart visually underscores the divergent yet complementary trajectories of STEM education in Canada and Ukraine. Canada's strengths lie in its institutional stability, long-standing policy frameworks, and integrated equity and ethics agendas. Ukraine, in contrast, demonstrates exceptional adaptability, with innovation largely driven by necessity and accelerated through crisis. The juxtaposition of these profiles reveals valuable opportunities for cross-contextual learning. While Canada may offer structural models and ethical guidance, Ukraine contributes with agile pedagogical experimentation, rapid digital adoption, and a resilience-based orientation. Together, they represent distinct but equally vital contributions to the global evolution of STEM education.

Discussion and Outlook

Reconceptualizing STEM Education: From Instrumentalism to Human-Centered Integration

The comparative analysis of STEM education in Canada and Ukraine suggests a significant paradigm shift in both contexts: STEM is no longer confined to its technical or economic roots but increasingly positioned as a multidimensional framework that incorporates equity, ethics, interdisciplinarity, and sustainability. This is particularly evident in Canadian research, where STEM is framed through ethical imperatives (Nicol et al., 2023), Indigenous epistemologies (Ji, 2021), and inclusive pedagogies (Estaiteyeh & DeCoito, 2023). Ukraine, by contrast, demonstrates an agile reconfiguration of STEM in response to educational disruptions, notably through digital visualization (Semenikhina et al., 2022), AI-assisted creativity (Drushlyak et al., 2025), and resilience-oriented instructional design during wartime.

In addition to formal schooling, informal and non-formal STEM environments have emerged as critical spaces for innovation and equity. An important dimension that emerges from the comparative analysis is the role of informal and non-formal learning environments. In Canada, science museums, afterschool clubs, and national competitions are systematically integrated into the STEM ecosystem and supported by long-term policy frameworks and research–practice partnerships. In Ukraine, non-formal STEM and STREAM centers, often organized by NGOs or municipal authorities, have become vibrant hubs for experimentation, introducing Montessori methods and gamification. While Canada exemplifies structural stability and curricular integration of informal STEM learning, Ukraine illustrates how grassroots initiatives can extend access and inspire curiosity even under constrained conditions.

These trajectories illustrate how STEM education evolves not only in alignment with global pedagogical trends but also in response to localized challenges. The transformation is not merely curricular; it is conceptual, shifting from STEM as a means of skill acquisition to STEM as a medium for critical engagement and societal transformation.

Bibliometric Trends and Research Gaps

The bibliometric data confirms a dramatic growth in global and national interest in STEM education, with a more than tenfold increase in publications between 2010 and 2024. Canada ranks among the top six countries globally, with 850 indexed publications, while Ukraine, although occupying the 49th position, shows a steep upward trajectory, particularly since 2020. Notably, over 60% of Canadian publications explicitly address teacher training, equity, or place-based learning, whereas Ukrainian research is concentrated around digital tools, modeling environments, and educational adaptation under duress.

Despite the increase in volume, several research gaps remain. For instance, very few studies from either country employ longitudinal designs to track the long-term impact of STEM interventions. Similarly, while AI and data science are frequent topics in Ukrainian practice-oriented studies, Canadian scholarship remains more focused on theoretical and cultural critiques. There is limited empirical research comparing the effectiveness of AI-assisted instruction versus traditional STEM pedagogies across both systems.

Another trend that warrants attention is the alignment of STEM education with the United Nations' Sustainable Development Goals (SDGs). Canadian approaches primarily frame sustainability through ethical, ecological, and place-based perspectives, connecting learners with environmental responsibility and civic engagement. Ukraine, by contrast, adopts SDG-oriented strategies at the policy level, positioning STEM as a tool for addressing urgent social challenges such as resilience, equity, and sustainable urban development. This contrast highlights how distinct socio-political contexts influence the orientation of STEM education toward sustainability.

Structural and Thematic Complementarities

The radar comparison (Figure 5) reveals areas of complementary expertise. Canada demonstrates institutional maturity in STEM policy, social justice integration, and ethical reflection, while Ukraine leads in agile digitalization, rapid pedagogical adaptation, and mobile/remote learning strategies. These profiles suggest mutually beneficial opportunities for knowledge exchange.

For example, Canadian teacher education programs could incorporate Ukrainian strategies for visual task variation and micro-research in applied STEM disciplines. Ukrainian institutions, in turn, may benefit from Canadian models of sustained professional development in inclusive and differentiated instruction, particularly in multilingual or multicultural classrooms. Collaborative doctoral training, co-authorship networks, and virtual STEM labs could foster meaningful academic exchange.

Complementarities are also visible in the adoption of emerging technologies, which both countries approach in distinct ways. The expanded analysis also highlights the growing role of emerging technologies in STEM pedagogy. In Canada, immersive metaverse platforms and gamified approaches are gradually entering mainstream higher education, supported by strong infrastructure and professional development programs. Ukraine, on the other hand, demonstrates a more experimental adoption of augmented and virtual reality, cloud-based mobile simulations, and applications utilizing Arduino or 3D printing. Despite resource limitations, these innovations illustrate how technology integration can be leveraged for resilience and renewal in times of disruption.

Critical Reflections and Theoretical Implications

The divergence between Canadian and Ukrainian approaches also highlights theoretical tensions within the global

STEM discourse. Canadian literature often draws on sociocultural theory, decolonial critique, and ecological systems frameworks, emphasizing place, narrative, and relationality (Steele, 2016; Nicol et al., 2019). Ukrainian work, conversely, tends to be grounded in cognitive and systems theory, emphasizing modeling, standardization, and functional adaptation, particularly visible in work on dynamic geometry environments, computer simulations, and testable performance indicators (Semenikhina et al., 2023).

This divergence raises important epistemological questions. Revisiting the theme of equity and inclusion further illustrates these epistemological contrasts. Equity and inclusion remain central yet divergent issues across both contexts. Canada benefits from institutionalized frameworks that support differentiated instruction, bilingual programming, gender parity, and refugee support, all of which are reinforced by a robust body of empirical research. Ukraine, by contrast, continues to face acute gender and regional disparities in STEM participation, compounded by uneven access to digital infrastructure and insufficient systemic teacher preparation. These differences underscore the need for Canada to share its inclusive policy frameworks and for Ukraine to adapt them to local socio-economic realities. Should STEM education prioritize cultural relevance and social cohesion, or technological competence and adaptability? Can these objectives be harmonized in cross-contextual models of teacher education? The dialogue between Canadian and Ukrainian perspectives may offer not only answers, but entirely new research questions at the intersection of pedagogy, ethics, and digital futures.

Outlook and Future Research Agenda

The comparative insights presented above invite a broader synthesis of the Canadian and Ukrainian cases. Taken together, these insights suggest that Canada and Ukraine embody complementary approaches to STEM education. Canada provides a model of institutional maturity, cultural inclusivity, and ethically grounded STEM pedagogy. Ukraine provides a living example of digital resilience, wartime innovation, and the integration of experimental AI. The juxtaposition of these trajectories reinforces the argument that STEM education is not monolithic but context-sensitive: it can either stabilize and expand existing systems, as in Canada, or catalyze transformation under crisis, as in Ukraine.

Cross-national collaboration between the two systems could therefore be especially fruitful, combining stability with agility, ethical grounding with rapid innovation.

Building on the identified trends, we propose several priority directions for future research and bilateral cooperation:

1. Longitudinal Evaluation: Systematic tracking of STEM teacher education models over multiple cohorts in both countries, with attention to inclusive and digital competencies.

2. AI-Mediated Pedagogy: Cross-cultural examination of AI’s role in STEM instruction, including co-design of ethical frameworks for classroom use.

3. Place-Based and Trauma-Informed STEM: Integration of Indigenous and post-crisis models of STEM education to foster culturally grounded and psychologically safe learning.

4. Digital Ecosystems for Bilateral Collaboration: Creation of virtual STEM labs, co-authored open-access teaching modules, and multilingual repositories of visual and adaptive tasks.

5. Assessment and Metrics: Development of common indicators to evaluate STEM-related soft skills, ethical reasoning, and reflexive thinking among students and teachers.

So, STEM education in Canada and Ukraine offers contrasting yet complementary narratives: one grounded in institutional continuity and critical reflection, the other in urgency, adaptability, and digital innovation. Together, they challenge linear or universalist models of educational development. Instead, they suggest that effective STEM education must be context-sensitive, ethically informed, and future-oriented. As global crises, ranging from climate change to technological acceleration and armed conflict, reshape educational priorities, the Canadian and Ukrainian experiences offer instructive templates for resilience, relevance, and renewal in STEM education.

Conclusion

The comparative study of STEM education in Canada and Ukraine, supported by bibliometric and qualitative analyses, reveals both global alignments and local specificities that are shaping the future of education in the digital and post-industrial age. This chapter demonstrated that while STEM education has become a near-universal priority, its implementation, framing, and perceived purposes vary significantly across sociopolitical contexts.

First, the bibliometric analysis confirms the dynamic growth of STEM-related scholarship globally, particularly over the last decade. Canada ranks among the top contributors, reflecting strong institutional, governmental, and scholarly engagement with STEM as a driver of innovation and societal equity. Although Ukraine holds a modest position in global bibliometric rankings, its publication activity in STEM education has grown steadily, particularly in areas such as digital pedagogy, teacher training, and competency development.

Second, the review of Canadian practices reveals a well-established infrastructure for STEM education reform, characterized by long-term investments in teacher education, the integration of Indigenous knowledge systems, and a deep engagement with issues of ethics, equity, and sociocultural responsiveness. STEM in Canada is not limited to content mastery; it is framed as a medium for fostering citizenship, ecological awareness, and interdisciplinary inquiry. The Canadian model underscores the importance of EDI (Equity, Diversity, Inclusion) and place-based learning as foundational elements of future-oriented education.

A notable finding concerns the role of informal and non-formal STEM learning environments. In Canada, science museums, afterschool clubs, and citizen science initiatives are firmly embedded in policy frameworks and curricular innovation, reinforcing the inclusivity and sustainability of STEM education. Ukraine, by contrast, demonstrates a rapid expansion of STEM and STREAM centers, often initiated by NGOs, municipalities, and grassroots networks. These centers experiment with Montessori methods, gamification, and project-based activities, illustrating how non-formal learning can broaden access and cultivate curiosity even under resource-constrained or crisis conditions.

Third, the Ukrainian experience showcases adaptability, innovation under constraint, and rapid digital transformation. Amidst economic and geopolitical challenges, Ukrainian educators have leveraged open digital platforms, modeling tools, and AI technologies to create resource-efficient and pedagogically effective STEM learning environments. The emphasis on visual thinking, inclusive digital access, and the development of critical competencies reflects a pragmatic response to contemporary needs, including those shaped by wartime realities. Moreover, Ukrainian STEM research increasingly reflects a commitment to aligning with international standards and networks, positioning the country as an active participant in global educational discourse.

The analysis also highlights how STEM education is becoming increasingly aligned with broader societal agendas and technological advancements. Ukraine has explicitly integrated STEM education into its pursuit of the United Nations Sustainable Development Goals, positioning it as a vehicle for sustainability, resilience, and civic responsibility. Canada frames sustainability more through ethical and ecological perspectives, linking STEM with place-based education and environmental stewardship. At the same time, both contexts are engaging with emerging technologies: Canada is institutionalizing immersive platforms such as the metaverse and gamified higher education, while Ukraine is pioneering experimental applications of augmented/virtual reality, Arduino, and large-scale 3D printing. Together, these trends highlight the dual importance of sustainability and innovation in shaping future-ready STEM ecosystems.

Fourth, the comparative analysis highlighted both convergence and divergence. Both countries prioritize interdisciplinary teaching, teacher capacity-building, and the integration of modern technologies. However, the philosophical and structural underpinnings differ: Canada's model is supported by stable governance and a long history of progressive education policy, whereas Ukraine's model is marked by resilience, urgency, and innovation born of necessity. This juxtaposition presents a valuable opportunity for mutual learning. Canada can benefit from Ukraine's agility in digital and crisis-driven pedagogies, while

Ukraine may draw from Canada's experiences in institutionalizing inclusive and ethically grounded STEM education.

Overall, the comparative insights suggest that Canada and Ukraine contribute complementary strengths to the global STEM landscape. Canada offers a model of systemic stability, inclusive policy frameworks, and ethically grounded pedagogy, while Ukraine exemplifies resilience, digital adaptability, and rapid innovation in the face of crisis. Cross-national collaboration could therefore be especially beneficial: Ukraine could draw on Canadian experience in institutionalizing equity and policy design, while Canada could learn from Ukraine's agile adoption of digital tools, experimental AI applications, and resilience-oriented pedagogies. This complementarity demonstrates that effective STEM education is not universal but context-sensitive, shaped by local needs, resources, and cultural priorities, yet enriched through international dialogue and cooperation.

In conclusion, STEM education in both contexts proves to be not only an academic or economic imperative but also a reflection of broader societal values and priorities. As the world grapples with environmental challenges, technological disruption, and political instability, the role of STEM education in shaping responsible, capable, and critically minded citizens becomes more important than ever. Cross-national dialogue, research partnerships, and co-developed frameworks between countries such as Canada and Ukraine can serve as catalysts for more equitable, adaptive, and socially relevant models of STEM education worldwide.

Limitations of the Study

Despite the comprehensive nature of this analysis, several limitations should be acknowledged. First, the bibliometric component was based solely on data from the Web of Science database. As a result, it does not fully reflect the scope of national publications in Ukraine, particularly those published in Ukrainian-language journals not indexed in WoS. Therefore, the true extent of STEM-related research in Ukraine may be underestimated.

Second, the data exhibit a certain asymmetry: Canada, with its well-established institutional research infrastructure, has produced significantly more STEM publications. This creates a disparity in the comparative analysis, although the quality and contextual value of Ukrainian publications, especially those focused on crisis-responsive strategies and digital innovations, demonstrate substantial potential not always captured by quantitative metrics.

Additionally, the analysis of STEM practices in both countries was based primarily on academic publications and policy documentation. It did not include empirical measurement of student or teacher outcomes. Future research could benefit from comparative studies that examine learning outcomes, pedagogical effectiveness, and the long-term impact of various STEM teacher education models.

Finally, although the data set includes publications up to 2025, the rapidly evolving context, particularly in relation to digital transformation, AI integration, and the war in Ukraine, demands continuous monitoring and reevaluation of trends. The dynamic nature of these developments limits the predictive power of current analyses and highlights the need for ongoing, longitudinal research.

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