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Review Article

Mapping the Kazakhstani STEM Education Landscape: A Review of National Research

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ABSTRACT

The aim of this study was to map the current status of STEM education in Kazakhstan. The study encompasses 24 studies selected through a literature search in Google Scholar, ERIC, Web of Science, and Scopus. The descriptive characteristics of the reviewed studies reveal a significant increase in STEM education publications in Kazakhstan since 2019, indicating a growing emphasis on this field. The reviewed studies, spanning the years 2019 to 2023, included diverse formats such as journal articles, conference proceedings, book chapters, theses, and review articles. Notably, the reviewed studies involved participants from both K-12 and university levels, with a particular focus on female students in some studies. The thematically organized findings of the reviewed studies highlighted challenges faced by STEM education in Kazakhstan, including students' perceptions about STEM subjects and careers, school environment and educational culture, and societal and gendered expectations. Creating interactive learning environments, addressing biases, dismantling gender stereotypes, and challenging traditional norms were identified as crucial steps to encourage the participation of young women in STEM disciplines. This study contributes to understanding STEM education in Kazakhstan and provides a foundation for future cross-country comparisons, emphasizing the necessity for adaptable approaches in designing and evaluating STEM initiatives in evolving educational contexts.

Keywords: STEM education, Kazakhstan, barriers to STEM education, student attitudes, women in STEM

INTRODUCTION

Since independence in 1991, Kazakhstan has prioritized modernizing its educational system to international standards and teaching approaches, and has heavily invested in doing this (see Bridges, 2014; Mahon and Murphy, 2019; Massyrova et al., 2015; McLaughlin et al., 2023; Nazarbayev University Graduate School of Education, 2014; Nuriyev et al., 2018), including developing relationships with foreign universities (Astana Times, 2022). Given these long-term investments and the increased focus internationally on the fields of science, technology, engineering, and mathematics (i.e., STEM), from individual and integration perspectives alike, it is important to locate a country's positioning of STEM – in both practice and policy with respect to its education and growth – so that various metrics about STEM can be monitored over the coming decades. To date, there has been no review of the nationally conducted research on STEM disciplines and education in Kazakhstan, which could determine this positioning. This study maps the research that has been conducted on STEM education in Kazakhstan and identifies challenges therein. This mapping allows both a determination of what is known and trends in STEM research, as well as recommendations with respect to STEM education and research. The following research questions shape this study:

1. What key constructs are examined in relation to students' learning in STEM education in Kazakhstan?
2. Which are the most salient concerns for STEM education in Kazakhstan?

Understanding the Concept of "STEM"

Over the last fifty years, science education has shifted from thinking about science as individual science subject silos (e.g., biology, chemistry, physics, engineering) to a recognition that success in any science discipline relies on a variety of investigation skills and conceptual frameworks that also integrate with knowledge and concepts from other disciplines. In the early 1970s, sociology of science scholars were studying laboratory-based science research describing the importance of technology and applied mathematics skills in that research (e.g., Latour and Woolgar, 1979; Traweek, 1988). Later field-based studies identified that many aspects of successful academic science investigation required technology skills that were practical and applied as opposed to academic and conceptual (Nutch, 1996; Roth and Bowen, 1999, 2001). In the past couple of decades, a more formal recognition of the need for a combination of conceptual and applied science, mathematics, and technology competencies in research has occurred.

The acronym STEM, representing the subjects Science, Technology, Engineering and Math, emerged in the early 2000s as a way of discussing concerns about the global economic downturn as related to science and technology areas (Krug and Shaw, 2016), with the argument being made that improving STEM skills would lead to greater economic productivity (Dodge, 2015). This original use of the acronym STEM was a way of discussing the combined economic importance of the four disciplines (both currently and in the future) that made up its acronym, but they were still often individual subject silos with little or no integration (see Clark, 2013), reflecting its origins. As Shanahan et al. (2016, p. 130) noted, "STEM began its life as little more than a convenient term for organizing allied areas of research and funding." In higher education, a review of STEM on university websites even now will reveal that it is often still discussed as individual subjects at the course level under the umbrella of STEM university programs, such as science and engineering (there are exceptions to this, see Penprase, 2020). Moreover, the concept of economic importance is often discussed from the perspective of the number of graduates there are from STEM programs (Archer et al., 2023; Morgan and Kirby, 2016; Yore et al., 2013), who these graduates are and lack of representation of identity groups (Bonardi et al., 2023; Corrigan et al., 2023; Piatek-Jimenez et al., 2018), and success and needs in the job market (Archer et al., 2023; Science, Technology and Innovation Council, 2015).

The achievement gap identified with respect to STEM is described in two different ways. In developed economies, it is often noted that STEM fields are dominated by the presence of Caucasian males, and that women (and other gendered groups) and other "persons of color" groups are generally under-represented in STEM fields (Archer et al., 2023; Bonardi et al., 2023). Beyond this, the achievement gap in STEM is also noted between western countries, such as the Canada, United States, and the UK, and economically developing nations, like Turkey and Kazakhstan (which, in 2018, respectively ranked 8th, 25th, 13th, 40th and 62nd on total PISA scores; OECD, 2019). Collectively, there are efforts in a broad range of jurisdictions to close the achievement gap (see Compeau, 2023), whether it be gender or socioeconomic, and in some instances, there is some evidence of success with this (Blustein et al., 2013; Dubrovskiy et al., 2022; Konowitz et al., 2022). Moreover, promotion of STEM in K-12 education encourages students to pursue STEM areas as a career choice (Franz-Odendaal et al., 2016) and is therefore part of the solution to the shortage of STEM workers (c.f., Hira, 2019; Salzman and Lieff Benderly, 2019; Smith and White, 2019). This might be particularly true with the promotion (and improvement) of mathematics education, as the numeracy skills related to it are often seen as the "the gatekeeper of science, technology, and engineering" education (Yore et al., 2013, p. 89).

Despite STEM originally being an acronym of "discrete disciplinary areas" (Krug and Shaw, 2016), there have been calls for greater integration of STEM subjects in lower education (Basham and Marino, 2010; Ryu et al., 2019), such that K-12 schooling has begun to approach STEM education from a more integrated perspective, with some arguing that it can now be seen as a "metadiscipline" (Kennedy and Tunnicliffe, 2022, p. 13). For instance, several authors have adopted the perspective that activities that involve meaningful learning outcomes from two or more of the four STEM disciplines should be considered STEM activities (Bowen et al., 2023a; Milford and Tippett, 2016; Moomaw, 2013). This type of integration is often involved with play activity in early years education (preschool to grade 1; see collection by Kennedy and Tunnicliffe, 2022), but is also occurring at later years in K-12 education (Johnson and Sondergeld, 2023; Tytler et al., 2023) and in some teacher education programs (see collection by Al-Balushi et al., 2023). To the extent that there is an increase in STEM education in teacher education programs, it is likely because of research which demonstrates that a greater involvement in STEM education at the K-12 level leads to an increase in interest in STEM-related programs in post-secondary schooling (Franz-Odendall et al., 2016). Krug and Shaw (2016) argued that there are 3 ways of reconceptualizing the teaching of STEM – Critical inquiry within STEM subjects and about STEM; Discourses within and about STEM; and Positionality with respect to understanding different points of view about STEM. However, even within their country jurisdiction there is only evidence of a small number of Faculties of Education taking up STEM teaching in any fashion (Bowen et al., 2023b), not to mention the more robust perspectives on STEM that Krug and Shaw (2016) suggest should be adopted, despite universities having a role in promoting STEM education (DeCoito, 2016; Vennix et al., 2018). This might relate to a number of identified challenges to achieving that subject integration (Ryu et al., 2019).

The sociopolitical and economic focus on STEM and its influence on science education is of concern to some academics from a variety of perspectives (Bencze et al., 2016; Carter, 2016; Shanahan et al., 2016; Sharma, 2016; Weinstein et al., 2016; Zhao, 2019), including the concern that there is "some 'muddling' in STEM education projects of epistemological and ontological differences among the four STEM fields" (Bencze et al., 2016, p. 70). In part, these concerns arise from the complex and uncertain definitions which multiple researchers bring to the term STEM (see Bybee, 2013; Shanahan et al., 2016), which then leads to the well-asked question:

> Is STEM a multidisciplinary endeavor where science, engineering, and mathematics are seen to work together yet retain their distinct epistemological commitments or is STEM an interdisciplinary or even transdisciplinary space that is neither science nor mathematics but something that emerges in between or beyond disciplinary commitments? (Shanahan et al., 2016, pp. 130-131)

The current lack of clarity in the definition of the term is problematic from the perspective of making recommendations for policy or practice, as any comparisons of findings across and between studies about STEM is difficult. As Wong et al. (2016, p. 2346) conclude, there is a "need for greater clarity about what [STEM] represents in educational terms and a wider debate about its compatibility with the aims of science education for all." At this point, until these types of definitional questions are resolved and broadly accepted within the relevant communities of research and educational practice, it falls on individual researchers in each study to make clear the definitions and decisions they have made for their individual work so that readers best understand the context of the STEM research they are writing about.

While some educators and policymakers advocate for STEM to replace traditional monodisciplinary subjects like Physics and Chemistry, others believe that STEM should be an additional subject with a focus on multidisciplinary projects (Bybee, 2013). We argue that STEM should be an additional subject, complementing traditional disciplines. This would allow students to retain a strong foundation in core scientific principles while also engaging in multidisciplinary projects that foster creativity, critical thinking, and problem-solving skills.

METHODS

Research Task

In this study, we explore the current state of STEM education in Kazakhstan as presented through STEM research concerning the examined context. This study reviews publications in STEM education to identify the principal interests or subjects guiding STEM research in Kazakhstan, and the issues or areas of concern raised by this research.

Literature Search

As STEM education is new in Kazakhstan, we didn't impose any restrictions on the publication date and type. We utilized the following databases: Google Scholar, ERIC, Web of Science, and Scopus. The keywords used were STEM, STEM education, STEAM, Science- technology- engineering- and mathematics, and STEM learning. "Kazakhstan" was used along with each of these keywords. Initially, the selection of studies was conducted by evaluating their titles and abstracts. After a thorough review of these studies, we incorporated 24 papers into this analysis. Papers were excluded due to reasons such as weakly structured research, deviation from the previously established definition of STEM education, and absence of sufficient data. To determine the quality of the studies each author rated the studies between 1 and 10. The assessment criteria are presented in **Appendix A**. Papers receiving an average score above 5 were included in this review.

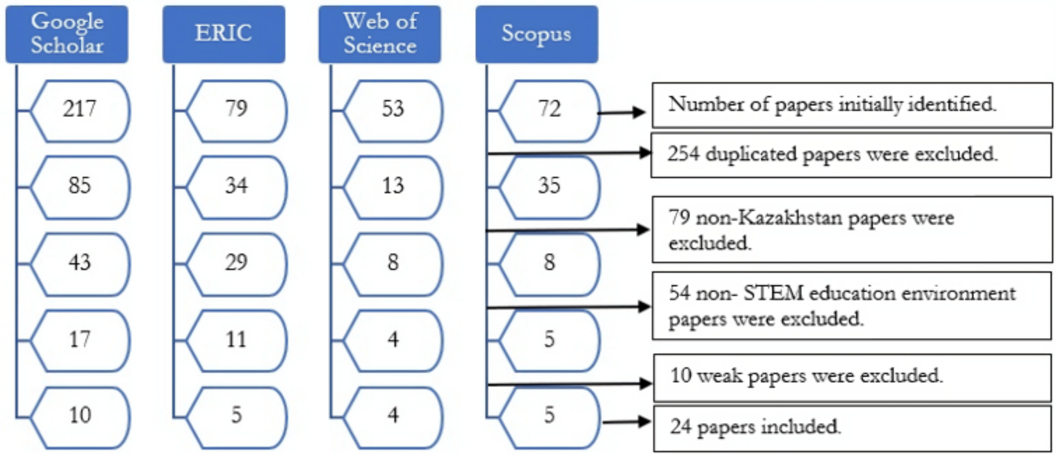

Figure 1. Database search results

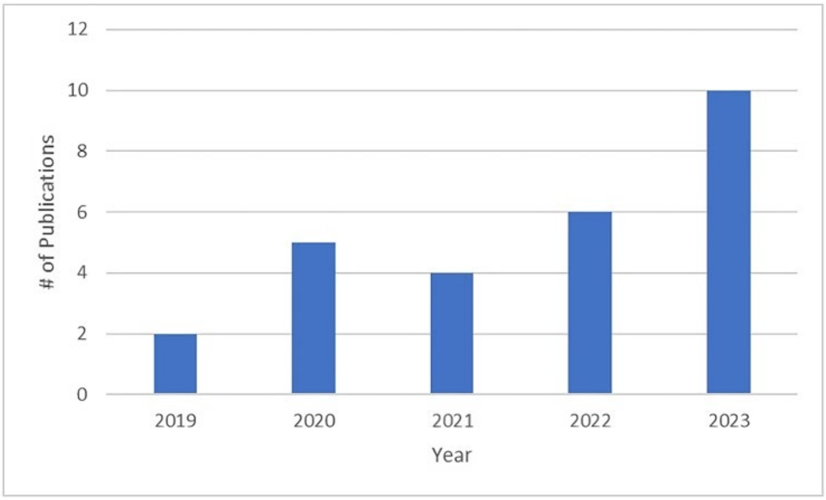

Figure 2. The distribution of publications related to STEM education across the years

Criteria for Inclusion

We established a set of criteria to determine which studies would be included in our review. First, the study should be conducted in Kazakhstan. Second, the study should be conducted in a STEM education environment that is characterized by: (a) an interdisciplinary approach, (b) real-world relevance, (c) hands-on learning, and (d) critical thinking. We did not limit our selection to journal articles, and we encompassed studies that employed diverse methodologies. Only studies published in English (or those with extended abstracts in English) were considered for inclusion in the current study. A total of 24 research papers meeting the aforementioned criteria were selected for comprehensive analysis in the current study. The search process and outcomes are illustrated in **Figure 1**.

Coding Study Characteristics

Aligned with our research questions, we devised a coding framework to effectively categorize and synopsize all the studies that met our criteria. We examined the selected research papers for the following details: title, authors, journal, type of publication, year of publication, aim, construct measured, study design, instrument, participants, school level, and main findings. This coding process was a collaborative effort involving four authors Nurman Zhumabay, Nuri Balta, Alma Abylkassymova, and Tannur Bakytkazy. Any disparities in coding were resolved through constructive iterative discussions.

Descriptive Characteristics of the Reviewed Studies

Figure 2 illustrates the annual publication count. As depicted in **Figure 2**, except for 2021, there is a consistent rise in the number of publications each year starting from 2019. These findings indicate substantial growth in STEM education research since 2019, with a notable jump from 2022 to 2023. The recent surge in STEM education publications further suggests that this field has gained momentum as a prominent and crucial area of focus in Kazakhstan.

Table 1. Main characteristics of the selected studies

First author	Year	Type	Construct	Study design	School level	Participants
Japashov, N.	2022	Article	STEM career interests	Quantitative	High school	398 students
Almukhambetova, A.	2020	Article	Experiences	Qualitative	University	29 female students
Balta, N.	2023	Article	STEM carries interest	Quantitative	High school	522 female students
Ibrayeva, E. S.	2022	Article (preprint)	Achievement	Mixed methods	Primary school	110 students, and 40 parents
CohenMiller, A.	2022	Book chapter	NA	Quantitative	University	NA
Shurygina, V.	2023	Article	Academic performance & motivation	Quantitative	High school	72 students
Almukhambetova, A.	2021	Article	Experiences	Qualitative	University	14 female students
Kuzhabekova, A.	2021	Conference proceedings	Employment	Quantitative	NA	NA
Ibraeva, E. S.	2022	Article	Research skills & awareness	Quantitative	Primary school	110 students
Dyussembekova, A.	2022	Article	Writing skills	Qualitative	University	5 students
Almukhambetova, A.	2021	Article	NA	Qualitative	University	14 female students
Tsakalerou, M.	2022	Conference paper	NA	Qualitative	University	6 female students
Syzdykbayeva, R.	2020	Book chapter	NA	Mixed methods	University	212 students
Kairollovna, D. S.	2021	Article	Interest	Mixed methods	Primary school	250 students
Serkova, Y.	2020	Master's thesis	NA	Mixed methods	University	935 STEM graduates and 40 employers
Kussaiynkyzy , A.	2020	Article	NA	Qualitative	University	109 female students
Dauletiyarova, A.	2020	Master's thesis	Engagement	Qualitative	High school	12 students
Kurmankulov, S.	2023	Conference paper	NA	Qualitative	University	18 female students
Ergobek, E.	2023	Review	NA	Qualitative	NA	NA
Almukhambetova, A.	2023	Article	NA	Qualitative	University	29 female students
Shynarbek, N.	2023	Conference proceedings	NA	Quantitative	High school	207 female students
Seitenova, S.	2023	Article	Speaking skills & attitude	Quantitative	Secondary school	60 students
Temirton, G.	2023	Article	Success, attitudes, & interests	Quantitative	Secondary school	60 students
Yilmaz, H. S.	2022	Article	NA	Mixed methods	University	14 STEM teachers

Table 1 provides an overview of the 24 studies. As can be seen in **Table 1**, studies published on STEM education in Kazakhstan cover a short range, that is, the years between 2019 and 2023. Fifteen studies were journal articles, four were conference proceedings, two were book chapters, two were theses, and one was a review article. Of the 15 journal articles, three were published in International Journal of Science and Mathematics Education, two were published in International Journal of Science Education, and the rest were published in different journals. Different constructs such as interest, perceptions, and engagement were measured. Nine of the studies were quantitative (five were experimental), ten were qualitative, and five were mixed method studies. Five of them used surveys; ten studies used surveys and questionnaires; four studies used achievement tests; ten studies used interviews; four studies used document, discussion, and conversation analysis; two studies used ready data from institutional sources; and one review study did not use any data collection tool. All these may not sum up to 24 because many studies employed several data collection tools. For example, Kairollovna et al. (2021) used a questionnaire and semi-structured interviews to examine students' interest in STEM education. Twelve studies were conducted with university students while ten were conducted with K-12 students. Moreover, one review study and one study about STEM graduate employment did not have a school level variable. Finally, it emerged that nine studies exclusively involved female students as participants. The combined participant count across all included studies amounted to 3282 individuals, with an average sample size of 156 and a standard deviation of 227. Notably, Dyussembekova and Wu's (2022) study engaged five interviewees, whereas Serkova's (2020) research on the perceptions of STEM skills among employers and graduates incorporated 975 participants, comprising 935 STEM graduates and 40 employers.

Figure 3. Frequency of measurements and impact per construct (filled circles indicate positive effects and empty circles indicate ineffective situations)

In the cases in which requested information was not identified, it was coded "NA". The data extracted from every article was transferred to Microsoft Excel 2019 and categorized following the predefined protocol instructions (see **Table 1** and **Figure 3**). The title, aims, and main findings of the selected studies were used to identify shared themes.

FINDINGS

Constructs Measured in STEM Educational Research in Kazakhstan

To determine the effect of STEM education interventions, researchers measured several constructs: students' STEM career interests, experiences, motivation, academic performance, employment, interest, perceptions, engagement, speaking skills, writing skills, research skills, awareness, and attitude. Among these, interests, academic performance and attitude were the three most commonly measured constructs. In three of the studies, no constructs were measured because they were program development (Yilmaz, 2022), case study (CohenMiller et al., 2022), and review (Ergobek, 2023) articles.

In some studies, several constructs were measured together. For instance, Temirton et al. (2023) measured success, attitudes, and interests in their study. These constructs were examined utilizing questionnaires, achievement tests, observations, interviews, surveys, and content analysis techniques. **Figure 3** provides a depiction of the frequency of measurements for each construct, along with the corresponding impact (positive or neutral) of STEM education. No negative effects were observed.

Student's STEM career interests were measured in two studies (Japashov et al., 2022; Balta et al., 2023), and in both of them the effects were positive. Similarly, academic performance was measured in three studies (Ibrayeva and Shaushekova, 2022; Shurygin et al., 2023; Temirton et al., 2023), and the effects were positive. Writing skills were measured in one study, and the effect was neutral; Dyussembekova and Wu (2022) investigated STEM students' perceptions regarding their writing practices through interviews and observations of written papers. They found that students' perspectives on writing are not entirely pessimistic. To some degree, they grasp the significance of writing in their lives and recognize how it can contribute to their personal and professional development.

The Current Status of STEM Educational Research in Kazakhstan

Based on the primary objectives of the examined studies, the reviewed studies can be classified into three distinct groups. Firstly, there are studies focusing on gauging psychological variables like academic achievement. Secondly, there are studies centered around pinpointing factors that influence outcomes, such as participant retention and achievement in STEM education. Lastly, there are studies like "program development" that don't fall within the scope of the prior two categories. These categories contained 12, 9, and 3 studies, respectively. The three studies in the final category were Yilmaz's (2022) article on establishing benchmarks in the process of creating a novel Integrated STEM Leader Preparation Program, Serkova's (2020) thesis on comparing employers' and graduates' views on essential and attained STEM skills in Kazakhstan, and Ergobek's (2023) review on theoretical dimensions related to fostering students' critical thinking through STEM education. Ibrayeva and Shaushekova's (2022) study was the only article which was published in Russian with an extended abstract in English.

Based on the provided findings from the 24 studies, we identified three challenging areas for STEM education in Kazakhstan. Overall, the thematically organized findings from the selected research underscored the multifaceted nature of factors influencing young women's interest and engagement in STEM fields. Gender stereotypes, self-efficacy, family influence, school environments, and cultural norms all play significant roles in shaping girls' decisions to pursue STEM disciplines. While challenges related to societal expectations, lack of role models, and perceptions of STEM subjects persist, strategies such as innovative education approaches, mentorship, early exposure, and inclusive environments hold the potential to inspire and empower young women to pursue STEM careers. Addressing the gender gap in STEM requires concerted efforts across educational institutions, workplaces, communities, and policy-making bodies to create a supportive, equitable, and diverse ecosystem that fosters the aspirations of young women in STEM fields. The following subsections present the identified areas of concern in more detail.

Students' perceptions about STEM subjects and careers

Although students' interest in STEM careers varies across school levels and types, it is generally positive, and both genders display similar enthusiasm in Kazakhstan. Many students perceive STEM fields as offering better career opportunities, job security, and higher earning potential compared to other fields. This perception has led to an increased enrollment in STEM-related programs at universities and technical colleges. However, a pervasive and impactful challenge is the negative perception of STEM subjects as being difficult, unappealing, or unrelated to personal interests. This perception often deters students, particularly young women, from exploring STEM disciplines, as they may believe that they lack the inherent skills or aptitude required for success (Almukhambetova and Kuzhabekova, 2020; Dyussembekova and Wu, 2022; Japashov et al., 2022; Kairollovna et al., 2021). Moreover, by providing opportunities for active participation and exploration, educators can dispel misconceptions about the difficulty of STEM subjects and demonstrate their relevance to real-world problems (Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021).

In addition to students' interest in STEM, students' self-efficacy, i.e., an individual's belief in their capacity to succeed in a particular domain (Bandura, 1997), emerged as a central and nuanced factor, particularly impacting female students' interest in STEM fields in Kazakhstan. A recurrent finding across multiple studies is the hesitancy among female participants to exhibit self-confidence in STEM subjects, even when they possess the necessary skills. This lack of self-assuredness translates into the need to consistently prove their competence in STEM-related pursuits, as they often encounter skepticism and bias from peers and educators (Almukhambetova and Kuzhabekova, 2020). As a result, girls face challenges in fully embracing STEM subjects and feeling confident in their potential to excel, despite showing interest in specific STEM subjects (Balta et al., 2023; Dauletiyarova, 2020; Japashov et al., 2022). Connected to this was the absence of visible female role models in STEM fields, reported as a recurrent and critical barrier in the selected studies. The dearth of relatable role models hinders the pathway for girls aspiring to venture into STEM careers. Female role models play a crucial role in illustrating that success in STEM is attainable for women and dispelling the notion that STEM is exclusively a male domain. Young women who lack role models to emulate may struggle to envision themselves succeeding in STEM fields, further contributing to the gender gap in STEM education and professions (Kussaiynkyzy and Doskeyeva, 2020).

School environment and educational culture

The reviewed studies underscored the importance of school environment and educational culture in developing students' skills, engagement, and positive attitudes towards STEM subjects. Some of the selected studies highlighted the significance of a positive school culture that fosters curiosity, exploration, and hands-on experiences. Participating in STEM competitions, hands-on projects, and interactive workshops not only ignites curiosity, enhances learning motivation, and supports performance (Seitenova et al., 2023; Shurygin et al., 2023), but also reinforces the idea that STEM is accessible to everyone, regardless of gender (Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021). Several of the reviewed studies further suggested that an integrational approach to STEM education may enhance students' success, attitudes, and interests in lessons leading to more positive outcomes (Temirton et al., 2023). Technology integration is recognized as crucial in effective STEM education. Implementing STEM technology enhances scientific literacy and aligns education with real-world industry demands, bridging the gap between theoretical learning and practical application (Ergobek, 2023; Shurygin et al., 2023). A curriculum that allows students to engage with real-world problems fosters a deeper connection to STEM subjects and demonstrates their applicability to various aspects of life (Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021).

While school environment and educational culture are important to all students, they are particularly influential on female students' interest in and identification with STEM fields. Schools that provide access to interactive STEM-related activities and inclusive classroom environments may nurture and sustain interest in STEM among young women (Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021). Moreover, integrating STEM activities that encourage critical thinking, problem-solving, and collaboration can enhance young women's engagement and confidence in their STEM abilities (Ibrayeva and Shaushekova, 2022). This outcome could be enhanced by connecting classroom learning to real-world applications and showcasing the impact of STEM fields on society, which may inspire young women to envision meaningful careers in these domains (Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021), and influence their decision to pursue STEM disciplines in Kazakhstan (Almukhambetova and Kuzhabekova, 2020; Kairollovna et al., 2021). Teachers and educators play a critical role in shaping students' perceptions and attitudes towards STEM subjects, and their support can significantly impact young women's decisions to pursue STEM careers (Kairollovna et al., 2021).

To address identified challenges in STEM education in Kazakhstan pertaining to female students' interest, participation, and aspirations, some of the reviewed studies argued in favor of early exposure to STEM learning experiences. For example, hands-on workshops, interactive science exhibits, and STEM-related competitions serve as entry points that captivate curiosity and stimulate exploration. Meanwhile, cultivating interest at a young age can help challenge gender stereotypes and instill a sense of excitement and confidence in STEM pursuits. In addition to early exposure, the reviewed studies advocated mentorship as a vital and transformative strategy in attracting and retaining female students in STEM fields (Almukhambetova and Kuzhabekova, 2020; Almukhambetova et al., 2021; Kussaiynkyzy and Doskeyeva, 2020). Female students who receive guidance, encouragement, and advice from mentors—especially women who have succeeded in STEM careers—tended to exhibit higher levels of confidence and motivation. Mentorship provided a personalized support system that helps young women navigate challenges, make informed decisions, and envision a future in STEM. Establishing mentorship programs within educational institutions and professional settings can offer a sense of belonging, foster self-efficacy, and counteract feelings of isolation (Almukhambetova and Kuzhabekova, 2020; Almukhambetova et al., 2021; Kussaiynkyzy and Doskeyeva, 2020).

The reviewed studies also noted the need for instructional approaches and culture to address the imbalance STEM graduates face between their supply and labor market demand. Non-STEM-oriented trajectories after graduation raise concerns about the alignment of higher education with real labor needs (Kuzhabekova et al., 2021). In addition, gender stereotypes encourage biases against STEM that extend to the labor market, affecting career progression. Initiatives promoting gender equality aim to counter these biases and encourage female participation (Kurmankulov et al., 2023; Syzdykbayeva, 2020). The development of benchmarks and frameworks, such as Integrated STEM Leader Preparation Programs, aims to enhance STEM education quality and relevance. These frameworks establish standards for educational leadership, interdisciplinary integration, and research-oriented instruction (Yilmaz, 2022).

Societal and gendered expectations

The influence of gender stereotypes on young women's perceptions of STEM fields and their own abilities is a prevailing and pervasive theme that emerged across several of the selected studies. In a variety of cultural and regional contexts, gender norms tend to frame certain STEM disciplines as more suitable and appealing to males, leading to the internalization of self-doubt and diminished self-perceptions among females. These gendered perceptions contribute to the underrepresentation of women in STEM fields in Kazakhstan, as they often question their competence and belonging (Serkova, 2020). The studies highlighted how deeply ingrained societal norms and cultural expectations significantly shape perceptions of gender roles and suitable career paths. In societies like Kazakhstan, where traditional gender norms prevail, women often experience conflicting expectations, i.e., to excel in professional careers while adhering to traditional roles (e.g., CohenMiller et al., 2022). These conflicting expectations create internal conflict for young women, who feel the pressure to fulfill societal roles and responsibilities while pursuing STEM aspirations. The struggle to balance these expectations can deter young women from fully embracing STEM disciplines and pursuing careers in STEM fields (CohenMiller et al., 2022).

Additional barriers hindering women's engagement in STEM include disrupted work-life balance, cultural stereotypes, and gender-based discrimination. Cultural gender expectations feed the conflicting discourses and introduce challenges as female students navigate the expectations of both traditional societies and international academic settings. This clash can result in ambiguity about future careers (Almukhambetova and Kuzhabekova, 2020; Kurmankulov et al., 2023; Tsakalerou et al., 2022). The scarcity of female role models in Kazakshtan and the prevalence of traditional gender norms exacerbate these challenges, influencing girls' self-perceptions and professional experiences (Almukhambetova et al., 2021; Kurmankulov et al., 2023; Syzdykbayeva, 2020; Tsakalerou et al., 2022). For example, some female participants expressed confidence in their STEM abilities but grappled with discouragement from societal opinions and perceived workplace discrimination. Intrinsic abilities, supportive educators, and encouragement from family positively influence their pursuit of STEM careers (Kurmankulov et al., 2023; Shynarbek and Orynbassar, 2023).

The role of family dynamics in shaping females' interest in STEM disciplines is multifaceted and a prominent research focus (Almukhambetova and Kuzhabekova, 2020; Kussaiynkyzy and Doskeyeva, 2020). Students' interest was ignited by a family member's STEM career, suggesting that familial influence serves as a pivotal catalyst for STEM curiosity (Almukhambetova and Kuzhabekova, 2020). Participants with family members employed in STEM industries were more likely to express curiosity and interest in these areas, highlighting the significance of familial exposure. Positive familial support and encouragement emerged as influential factors that catalyzed interest in STEM disciplines, as participants who received support were more likely to explore STEM opportunities in Kazakhstan. Conversely, the absence of supportive role models within families was found to hinder interest and aspirations, particularly when girls lacked the exposure to STEM-related activities and conversations (Kussaiynkyzy and Doskeyeva, 2020).

DISCUSSION

This mapping review examined the current state of STEM education in Kazakhstan across levels of education. This study found that STEM research has been steadily developing, with a recent surge in publications, suggesting the sustained interest but also importance of STEM fields in Kazakhstani education. Additionally, this study made visible the challenges pupils and university students encounter in STEM education, important educational barriers and resources for students, and the societal influences framing and informing STEM education in the examined context. This study contributes to wider STEM research by identifying and synthesizing studies from a cultural and educational context that has been under-represented in international STEM discourse, and by further highlighting the gender inequality regarding participation in STEM-related instructional and professional endeavours.

Several of the studies included in this review suggested notable hurdles in female participants' STEM education either directly by addressing issues of gender differences, equality, and equity, or indirectly by examining skills and interest regarding STEM education and careers. This suggests an awareness of the difficulty female students face in access and participation to STEM education, and an interest to overcome perceived barriers. Moreover, the observed phenomenon of women falling behind in STEM education in the examined context underlines the need to discuss the gender divide noted in STEM research, which mostly represents a straight white male population (Bonardi et al., 2023), and in STEM education, where the gender divide persists regardless of a country's socioeconomic circumstances (Kenneth, 2021; OECD, 2019). The gender gap reported and discussed in the reviewed studies was perpetuated by parental and social expectations. This finding is consistent with several studies in the United States reporting girls' different socialization, which is largely based preconceived gender roles, and the enduring gender stereotypes connected to STEM careers that contribute to the marginalization of women in STEM fields (Reinking and Martin, 2018).

The reviewed studies also indicated that Kazakhstani researchers are concerned with the improvement of the culture of STEM education. The reviewed studies suggested this would be achieved through early exposure, explorative and experiential learning, role models for girls, and educators' supportive role in shaping students' positive attitudes towards STEM. These suggestions are in line with international literature. For instance, exposure to STEM as early as kindergarten has been previously advocated (see Kennedy and Tunnicliffe, 2022). STEM learning at an early age may involve more hands-on activities and learner interaction with instructional material, consequently stimulating children's intrinsic motives and interest for learning (Wan et al., 2021). Exposure to STEM through experiential learning is also influential on secondary school students (e.g., Johnson and Sondergeld, 2023; Konowitz et al., 2022; Tytler et al., 2023). STEM activities incorporating creativity, design, and real-world problem-solving skills have been found to positively predict female high school students' interest in STEM subjects, which is particularly important given the steady decrease of girls' interest, confidence, and positive attitudes regarding STEM subjects from early academic experiences onwards (Cooper and Heaverlo, 2013). It is worth noting that including authentic real-world problems, developing students' 21st century skills, and promoting STEM careers are some of the well-defined characteristics of STEM education, yet a distinct lack of consensus on the conceptualization of STEM education renders achieving these instructional goals challenging for STEM educators (Bencze et al., 2016; Bybee, 2013; Dare et al., 2021; Ryu et al., 2019; Shanahan et al., 2016; Wong et al., 2016).

Although early introduction to STEM education may have a positive impact on student interest in STEM subject areas, early introduction alone would not be enough to counter the underrepresentation of women in STEM fields. A change would also be needed in the institutional or disciplinary culture of STEM education. For example, university-level science pedagogy in STEM often fosters a competitive classroom climate with little collaborative learning, or fewer practical and active teaching strategies, which women might not find meaningful to their learning processes, and which might discourage women from pursuing and completing a STEM degree (Shapiro and Sax, 2011). The academic climate students experience in STEM education has social, psychological, and structural dimensions informing students' feelings of belonging and connection of personal and learner identities to STEM fields, with implications for their performance, engagement, and persistence in STEM (Dasgupta and Stout, 2014; Malcom and Feder, 2016). Research suggests that female students are often drawn to STEM activities that have a clear social impact or that address real-world issues related to health, environment, or community well-being (Baker, 2013). For instance, projects that involve solving local environmental challenges, such as designing sustainable waste management systems or developing strategies to reduce pollution, can be particularly appealing. Similarly, healthcare-related projects, such as creating affordable medical devices or developing apps to improve public health awareness may resonate with female students.

In addition to creating learning environments conducive to explorative learning, STEM educators bear the responsibility of providing role models to students. Role models, especially gender-matched ones, are invaluable in students' career selection, and meaningful interactions with women scientists can have a formative influence on female students' identification of science role models and consideration of nontraditional careers for women (Buck et al., 2007). Particularly in STEM, female role models have been found to have a positive effect on girls' preferences for STEM studies and on their expectations of success in STEM choices, and a negative effect on gender stereotypes (González-Pérez et al., 2020). As Reinking and Martin (2018) argued, the gender gap would close more quickly were women to combat gender-based stereotypes and developed a mindset of confidence. Educational culture in STEM, shaped by educators, peers, and parents, may play a pivotal role in realizing this.

The reviewed studies also highlighted the issue of students' perceptions and attitudes concerning STEM subjects and careers. The examined student population regarded STEM careers as safe and promising, but reportedly found STEM subjects challenging and even unappealing. This is an understandable concern in the examined context; students' high engagement in STEM activities and understanding of math requirements strongly influence students' choice of a STEM career (Franz-Odendaal et al., 2016). Affording students more pathways to STEM education, convincing students of their receiving support to succeed, and communicating an inclusive message of support for students regardless of gender, race, and privilege have been proposed as incentives for students to pursue a STEM career, adjunctive to an early introduction to STEM and the development of a strong belief in mathematical ability (Blackburn, 2017). Additional incentive may be offered by STEM-based activities in a workshop format or out-of-school connections between work contexts and school-science, as these have been found to increase students' self-reported motivation and positive attitudes towards STEM and related careers (Vennix et al., 2018). The reviewed studies also showed that female students lacked self-confidence in STEM subjects, despite being competent, and often encountered peers' and educators' biases. The presence of such biases has been well documented, and it is understood that interactions with educators and peers shape women's interest and commitment to STEM (Shapiro and Sax, 2011). Gender biases emerging in peer-to-peer interactions, whereby women are deemed less able and talented in STEM subjects, even when outperforming male counterparts, has also been observed in other education contexts (Bloodhart et al., 2020). Moreover, gender biases concerning perceived ability, attitudes, and expectations in math-intensive subjects and careers have been observed as early as kindergarten, negatively affecting female students' choice of STEM majors (Ceci et al., 2014). Especially considering the importance of mathematics in STEM fields (Yore et al., 2013), it is therefore highly relevant to STEM education to not only attract students' interest but also address the early onset of perceived discrepancy in skills for girls in order to provide adequate and equal preparation on STEM-related skills.

CONCLUSION

The body of the reviewed literature showed there are several challenges to STEM education in Kazakstan, stressing the importance of creating inclusive environments. Promoting inclusive environments within educational institutions and workplaces is crucial to fostering a sense of belonging and empowerment in STEM, particularly among young women. Educational institutions and organizations should actively address biases, dismantle gender stereotypes, and challenge traditional norms that hinder young women's participation in STEM disciplines (Almukhambetova and Kuzhabekova, 2020; Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021; Serkova, 2020). Implementing policies and practices that ensure equal opportunities for all students, regardless of gender, can create environments where young women thrive and succeed in STEM fields (Almukhambetova and Kuzhabekova, 2020; Ibrayeva and Shaushekova, 2022; Kairollovna et al., 2021; Serkova, 2020). Facilitating safe spaces for open dialogue, where challenges related to gender bias and discrimination are discussed, can empower young women to voice their concerns and seek support.

Our review of 24 studies in the field of STEM education in Kazakhstan is a valuable resource for the current terrain of STEM learning. In our study design, we intentionally adopted an inclusive approach, considering a diverse range of research methodologies. As STEM education is relatively new in Kazakhstan, we deliberately refrained from imposing restrictions on publication dates and types. This approach allowed us to capture the evolving nature of STEM initiatives in the region, providing a comprehensive overview that extends beyond temporal boundaries. The diversity within the selected studies mirrors the evolving nature of STEM education in Kazakhstan and emphasizes the need for a nuanced and adaptive approach to curriculum development. We also note that the quality assessment of the studies was a collaborative effort among the authors, involving a rating system that considered various aspects of each paper. This process ensured a rigorous evaluation and contributed to the robustness of our analysis.

One notable constraint of our study is the geographical scope, as our focus was exclusively on Kazakhstan. This narrow geographic concentration might limit the generalizability of our findings to other regions with different educational contexts and practices. Additionally, our reliance on English-language publications may introduce a language bias, potentially excluding relevant studies published in Russian. Despite these limitations, our study notably contributes to the understanding of STEM education in Kazakhstan, which is a source for future cross-country comparisons. It reveals significant comprehension of the current terrain and emphasizes the need for flexibility and adaptability in designing and evaluating STEM initiatives in this evolving educational context.

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REFERENCES

Al-Balushi, S. M., Martin-Hansen, L. and Song, Y. (2023). *Reforming Science Teacher Education Programs in the STEM Era: International Practices*. London (UK): Palgrave Macmillan. https://doi.org/10.1007/978-3-031-27334-6

Almukhambetova, A. and Kuzhabekova, A. (2020). Factors affecting the decision of female students to enrol in undergraduate science, technology, engineering and mathematics majors in Kazakhstan. *International Journal of Science Education*, 42(6), 934–954. https://doi.org/10.1080/09500693.2020.1742948

Almukhambetova, A., Torrano, D. H. and Nam, A. (2021). Fixing the leaky pipeline for talented women in STEM. *International Journal of Science and Mathematics Education*, 21, 305–324. https://doi.org/10.1007/s10763-021-10239-1

Archer, L., DeWitt, J., Godec, S., Henderson, M., Holmegaard, H., Liu, Q., MacLeod, E., Mendick, H., Moote, J. and Watson E. (2023). ASPIRES3 Main Report: Young People's STEM Trajectories, Age 10-22, *UCL Institute of Education*. Available at: https://discovery.ucl.ac.uk/id/eprint/10181968/1/ASPIRES3%20Main%20Report.pdf.

Astana Times. (2022). University of Calgary Among Four Foreign Universities Set to Open Branches in Kazakhstan, *Astana Times*. Available at: https://astanatimes.com/2022/11/university-of-calgary-among-four-foreign-universities-set-to-open-branches-in-kazakhstan/.

Baker, D. (2013). What works: Using curriculum and pedagogy to increase girls' interest and participation in STEM. *Theory Into Practice*, 52(1), 14–20. https://doi.org/10.1080/07351690.2013.743760

Balta, N., Japashov, N., Karimova, A., Agaidarova, S., Abisheva, S. and Potvin, P. (2023). Middle and high school girls' attitude to science, technology, engineering, and mathematics career interest across grade levels and school types. *Frontiers in Education*, 8, 1158041. https://doi.org/10.3389/feduc.2023.1158041

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York: W. H. Freeman and Company.

Basham, J. D. and Marino, M. T. (2010). Introduction to the topical issue: Shaping STEM education for all students. *Journal of Special Education Technology*, 25(3), 1–2. https://doi.org/10.1177/016264341002500301

Bencze, L., Reiss, M., Sharma, A. and Weinstein, M. (2018). STEM education as 'Trojan horse': Deconstructed and reinvented for all. In L. Bryan and K. Tobin (eds), *13 Questions: Reframing Education's Conversation: Science* (pp. 69–87). New York City (NY): Peter Lang.

Blackburn, H. (2017). The status of women in STEM in higher education: A review of the literature 2007-2017. *Science & Technology Libraries*, 36(3), 235–273. https://doi.org/10.1080/0194262X.2017.1371658

Bloodhart, B., Balgopal, M. M., Casper, A. M. A., Sample McMeeking, L. B. and Fischer, E. V. (2020). Outperforming yet undervalued: Undergraduate women in STEM. *PLoS ONE*, 15(6), Article e0234685. https://doi.org/10.1371/journal.pone.0234685

Blustein, D. L., Barnett, M., Mark, S., Depot, M., Lovering, M., Lee, Y., Hu, Q., Kim, J., Backus, F., Dillon-Lieberman, K. and DeBay, D. (2013). Examining urban students' constructions of a STEM/career development intervention over time. *Journal of Career Development*, 40(1), 40–67. https://doi.org/10.1177/0894845312441680

Bonardi, O., Burchell, D., Franz-Odendaal, T. A. and Joy, P. (2023). "My discipline is never going to survive if it continues being the discipline of straight white men": Experiences of LGBQ+ science postdoctoral scholars in Canada. *Canadian Journal of Science, Mathematics and Technology Education*, 32, 282–302. https://doi.org/10.1007/s42330-023-00275-0

Bowen, G. M., Knoll, E. and Willison, A. M. (2023a). Using Bee-Bots in early learning STEM: An analysis of resources. In C. Tippett and T. Milford (eds), *Exploring Elementary Science Teaching and Learning in Canada* (pp. 147–165). New York City (NY): Springer. https://doi.org/10.1007/978-3-031-23936-6_9

Bowen, G. M., Wiseman, D., Shanahan, M.-C., Khan, S., Gonsalves, A., Sengupta, P., Simms, W., Knoll, E. and Carter, A. (2023b). STEM education in Canadian faculties of education: An overview. In S. M. Al-Balushi, L. Martin-Hansen and Y. Song (eds), *Reforming Science Teacher Education Programs in the STEM Era: International Practices*. London (UK): Palgrave Macmillan. https://doi.org/10.1007/978-3-031-27334-6_4

Bridges, D. (ed). (2014). *Education Reform and Internationalisation: The Case of School Reform in Kazakhstan*. Cambridge (UK): Cambridge University Press.

Buck, G. A., Plano Clark, V. L., Leslie-Pelecky, D., Lu, Y. and Cerda-Lizarraga, P. (2007). Examining the cognitive processes used by adolescent girls and women scientists in identifying science role models: A feminist approach. *Science Education*, 92(4), 688–707. https://doi.org/10.1002/sce.20257

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. Richmond (VA): NSTA Press.

Carter, L. (2016). Neoliberalism and STEM education. *Journal for Activist Science and Technology Education*, 9(1), 31–41.

Ceci, S. J., Ginther, D. K., Kahn, S. and Williams, W. M. (2014). Women in academic science: A changing landscape. *Psychological Science in the Public Interest*, 15(3), 75–141. https://doi.org/10.1177/1529100614541236

Clark, J. V. (ed). (2013). *Closing the Achievement Gap from an International Perspective: Transforming STEM for Effective Education*. New York City (NY): Springer. https://doi.org/10.1007/978-94-007-4357-1

CohenMiller, A., Saniyazova, A., Sandygulova, A. and Izekenova, Z. (2022). Gender equity in STEM higher education in Kazakhstan. In H. Kyoung Ro, F. Fernandez and E. Ramon (eds), *Gender Equity in STEM in Higher Education* (pp. 140–157). Routledge.

Compeau, S. (2023). Organizational features of university-based STEM outreach units in Canada. *Canadian Journal of Science, Mathematics & Technology Education*, 23(3), 422–440. https://doi.org/10.1007/s42330-023-00289-8

Cooper, R. and Heaverlo, C. (2013). Problem solving and creativity and design: What influence do they have on girls' interest in STEM subject areas? *American Journal of Engineering Education*, 4(1), 27–38. https://doi.org/10.19030/ajee.v4i1.7856

Corrigan, E., Williams, M. and Wells, M. A. (2023). High school enrolment choices–Understanding the STEM gender gap. *Canadian Journal of Science, Mathematics and Technology Education*, 23, 403–421. https://doi.org/10.1007/s42330-023-00285-y

Dare, E. A., Keratithamkul, K., Hiwatig, B. M. and Li, F. (2021). Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education. *Education Sciences*, 11(11), Article 737. https://doi.org/10.3390/educsci11110737

Dasgupta, N. and Stout, J. G. (2014). Girls and women in science, technology, engineering, and mathematics: STEMing the tide and broadening participation in STEM careers. *Policy Insights from the Behavioral and Brain Sciences*, 1(1), 21–29. https://doi.org/10.1177/2372732214549471

Dauletiyarova, A. (2020). *Gender Differences in Grade 12 Students' Engagement in STEM Subjects: A Case Study of One Specialized School in South Kazakhstan* [Master's thesis, Nazarbayev University]. Nazarbayev University Repository. https://nur.nu.edu.kz/items/c4002ce0-21f8-4b3c-b373-814622199f74

DeCoito, I. (2016). STEM education in Canada: A knowledge synthesis. *Canadian Journal of Science, Mathematics and Technology Education*, 16(2), 114–128. https://doi.org/10.1080/14926156.2016.1166297

Dodge, D. (2015). *Executive Summary: Some Assembly Required: STEM Skills and Canada's Economic Productivity*. Ottawa (ON): Council of Canadian Academies.

Dubrovskiy, A. V., Broadway, S., Weber, R., Mason, D., Jang, B., Mamiya, B., Powell, C. B., Shelton, G. R., Walker, D. R., Williamson, V. M. and Villalta-Cerdas, A. (2022). Is the STEM gender gap closing? *Journal of Research in Science, Mathematics and Technology Education*, 5(1), 47–68. https://doi.org/10.31756/jrsmte.512

Dyussembekova, A. and Wu, T. (2022). What are the perceptions of STEM students regarding writing practices in a university in Kazakhstan?. *Journal of Student Research*, 11(1). https://doi.org/10.47611/jsr.v11i1.1569

Ergobek, E. (2023). Theoretical aspects of the problem of developing students' critical thinking based on STEM learning. *Nauchnyy zhurnal «Vestnik NAN RK»*, 403(3), 83–91.

Franz-Odendaal, T. A., Blotnicky, K., French, F. and Joy, P. (2016). Experiences and perceptions of STEM subjects, careers, and engagement in STEM activities among middle school students in the maritime provinces. *Canadian Journal of Science, Mathematics and Technology Education*, 16(2), 153–168. https://doi.org/10.1080/14926156.2016.1166291

González-Pérez, S., Mateos de Cabo, R. and Sáinz, M. (2020). Girls in STEM: Is it a female role-model thing? *Frontiers in Psychology*, 11. https://doi.org/10.3389/fpsyg.2020.02204

Hira, R. (2019). Outsourcing STEM jobs: What STEM educators should know. *Journal of Science Education and Technology*, 28(1), 41–51. https://doi.org/10.1007/s10956-018-9747-z

Ibrayeva, E. S. and Shaushekova, B. K. (2022). Raising awareness for the lack of interest in STEM of primary school learners in Kazakhstan: Experiences and perspectives. *Research Square*, 1–23. https://doi.org/10.21203/rs.3.rs-1963121/v1

Japashov, N., Naushabekov, Z., Ongarbayev, S., Postiglione, A. and Balta, N. (2022). STEM career interest of Kazakhstani middle and high school students. *Education Sciences*, 12(6), 397. https://doi.org/10.3390/educsci12060397

Johnson, C. C. and Sondergeld, T. A. (2023). Outcomes of an integrated STEM high school: Enabling access and achievement for all students. *Urban Education*, 58(8), 1772–1798. https://doi.org/10.1177/0042085920914368

Kairollovna, D. S., Nurkenivna, N. N., Nurlybekovna, D. S., Sultanseitovna, K. A., Bolatovna, F. I. and Alkeshovna, S. A. (2021). STEM education of students at children's university. *Ilkogretim Online*, 20(4), 264–271.

Kennedy, T. J. and Tunnicliffe, S. D. (2022). Introduction: The role of play and STEM in the early years. In S. D. Tunnicliffe and T. J. Kennedy (eds), *Play and STEM Education in the Early Years: International Policy and Practices* (pp. 3–37). New York City (NY): Springer. https://doi.org/10.1007/978-3-030-99830-1_1

Kenneth, A. (2021). Gender gap in engineering and medical colleges in India. *Journal of Research in Science Mathematics and Technology Education*, 4(3), 225–237. https://doi.org/10.31756/jrmste.434

Konowitz, L., Lund, T., Lincoln, B., Reed, M., Liang, B., Barnett, M. and Blustein, D. (2022). Changemakers: Influences on engagement in STEM curricula among underrepresented youth. *European Journal of Psychology and Educational Research*, 5(2), 103–113. https://doi.org/10.12973/ejper.5.2.103

Krug, D. and Shaw, A. (2016). Reconceptualizing ST®E(A)M(S) education for teacher education. *Canadian Journal of Science, Mathematics and Technology Education*, 16(2), 183–200. https://doi.org/10.1080/14926156.2016.1166295

Kurmankulov, S., Dikhanbayeva, D., Perveen, A. and Tsakalerou, M. (2023, June). Female engineers in a transitional economy: Perceptual facilitators for and barriers to studying in STEM fields, in *2023 ASEE Annual Conference & Exposition*.

Kussaiynkyzy, A. and Doskeyeva, G. Z. (2020). Gender gap in STEM studies and ways to overcome them: A Kazakhstan case. *Central Asian Economic Review*, 3, 91–105.

Kuzhabekova, A., Dmitrienko, A. and Daurbay, Z. (2021). Employment of STEM graduates in Kazakhstan: Current situation, in *New Perspectives in Science Education* (pp. 1–6). Pixel International Conferences.

Latour B. and Woolgar S. (1979). *Laboratory Life: The Social Construction of Scientific Facts*. Los Angeles (CA): SAGE.

Mahon, D. and Murphy, D. (2019). Do students develop the way universities say they do? Staff perceptions of student development of graduate attributes in the context of a transnational partnership in Kazakhstan. *The European Educational Researcher*, 2(2), 145–164. https://doi.org/10.31757/euer.225

Malcom, S. & Feder, M. (eds). (2016). *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways*. Washington, D.C.: National Academies Press. https://doi.org/10.17226/21739

Massyrova, R., Tautenbaeva, A., Tussupova, A., Zhalalova, A. and Bissenbayeva, Z. (2015). Changes in the higher education system of Kazakhstan. *Procedia-Social and Behavioral Sciences*, 185, 49–53. https://doi.org/10.1016/j.sbspro.2015.03.458

McLaughlin, C., Winter, L. and Yakavets, N. (eds). (2023). *Mapping Educational Change in Kazakhstan*. Cambridge (UK): Cambridge University Press. https://doi.org/10.1017/9781009070515

Milford, T. M. and Tippett, C. D. (2016). The design and validation of an early childhood STEM classroom observational protocol. *International Research in Early Childhood Education*, 6(1), 24–37. https://doi.org/10.4225/03/5817cdcd6b1e8

Moomaw, S. (2013). *Teaching STEM in the Early Years: Activities for Integrating Science, Technology, Engineering, and Mathematics*. St Paul (MN): Redleaf Press.

Morgan, R. and Kirby, C. (2016). *The UK STEM Education Landscape: A Report for the Lloyd's Register Foundation from the Royal Academy of Engineering Education and Skills Committee*. London (UK): Royal Academy of Engineering.

Nazarbayev University Graduate School of Education. (2014). *Development of Strategic Directions for Education Reforms in Kazakhstan for 2015-2020, Diagnostic Report*. Astana (Kazakhstan): Indigo Print.

Nuriyev, M., Sovetkanova, D. and Seysenbayeva, Z. (2018). Achievements and new challenges in the area of education of independent Kazakhstan. *Opción*, 34(85–2), 337–352.

Nutch, F. (1996). Gadgets, gizmos, and instruments: Science for the tinkering. *Science, Technology and Human Values*, 21(2), 214–228. https://doi.org/10.1177/016224399602100205

OECD. (2019). *PISA 2018 Results (Volume I): What Students Know and Can Do*. Paris (France): OECD Publishing. https://doi.org/10.1787/5f07c754-en

Penprase, B. E. (2020). *STEM Education for the 21st Century*. New York City (NY): Springer. https://doi.org/10.1007/978-3-030-41633-1

Piatek-Jimenez, K., Cribbs, J. and Gill, N. (2018). College students' perceptions of gender stereotypes: Making connections to the underrepresentation of women in STEM fields. *International Journal of Science Education*, 40(12), 1432–1454. https://doi.org/10.1080/09500693.2018.1482027

Reinking, A. and Martin, B. (2018). The gender gap in STEM fields: Theories, movements, and ideas to engage girls in STEM. *Journal of New Approaches in Educational Research*, 7(2), 148–153. https://doi.org/10.7821/naer.2018.7.271
Roth, W.-M. and Bowen, G. M. (1999). Digitising lizards or the topology of vision in ecological fieldwork. *Social Studies of Science*, 29(5), 627–654. https://doi.org/10.1177/030631299029005003
Roth, W.-M. and Bowen, G. M. (2001). 'Creative solutions' and 'fibbing results': Enculturation in field ecology. *Social Studies of Science*, 31, 533–556. https://doi.org/10.1177/030631201031004003
Ryu, M., Mentzer, N. and Knobloch, N. (2019). Preservice teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation. *International Journal of Technology and Design Education*, 29, 493–512. https://doi.org/10.1007/s10798-018-9440-9
Salzman, H. and Lieff Benderly, B. (2019). STEM performance and supply: Assessing the evidence for education policy. *Journal of Science Education and Technology*, 28(1), 9–25. https://doi.org/10.1007/s10956-018-9758-9
Science, Technology and Innovation Council. (2015). *State of the Nation 2014. Canada's Innovation Challenges and Opportunities*. Ottawa (ON): Science, Technology and Innovation Council.
Seitenova, S., Khassanova, I., Khabiyeva, D., Kazetova, A., Madenova, L. and Yerbolat, B. (2023). The effect of STEM practices on teaching speaking skills in language lessons. *International Journal of Education in Mathematics, Science and Technology*, 11(2), 388–406.
Serkova, Y. (2020). *Required and acquired skills in STEM: Comparing employers and graduates' perceptions in Kazakhstan* [Master's thesis, Nazarbayev University]. Nazarbayev University Repository. Available at: https://nur.nu.edu.kz/items/e835e526-7f0f-41f8-91ad-6e722d08cda1.
Shanahan, M. C., Burke, L. E. C.-A. and Francis, K. (2016). Using a boundary object perspective to reconsider the meaning of STEM in a Canadian context. *Canadian Journal of Science, Mathematics and Technology Education*, 16(2), 129–139. https://doi.org/10.1080/14926156.2016.1166296
Shapiro, C. A. and Sax, L. J. (2011). Major selection and persistence for women in STEM. *New Directions for Institutional Research*, 2011(152), 5–18. https://doi.org/10.1002/ir.404
Sharma, A. (2016). STEM-ification of education: The Zombie Reform Strikes Again. *Journal for Activist Science and Technology Education*, 7(1), 42–51.
Shurygin, V., Anisimova, T., Orazbekova, R. and Pronkin, N. (2023). Modern approaches to teaching future teachers of mathematics: The use of mobile applications and their impact on students' motivation and academic success in the context of STEM education. *Interactive Learning Environments*, 32(6), 2884–2898. https://doi.org/10.1080/10494820.2022.2162548
Shynarbek, N. and Orynbassar, A. (2023). Investigating the factors that influence Kazakh female students' interest in STEM careers using machine learning techniques, in *2023 IEEE 17th International Conference on Electronics Computer and Computation (ICECCO)* (pp. 1–6). https://doi.org/10.1109/ICECCO58239.2023.10147134
Smith, E. and White, P. (2019). Where do all the STEM graduates go? Higher education, the labour market and career trajectories in the UK. *Journal of Science Education and Technology*, 28(1), 26–40. https://doi.org/10.1007/s10956-018-9741-5
Syzdykbayeva, R. (2020). Exploring gender equality in STEM education and careers in Kazakhstan, in *STEM Education for Girls and Women STEM Education for Girls and Women: Breaking barriers and exploring gender inequality in Asia* (pp. 189–225). UNESCO Office Bangkok and Regional Bureau for Education in Asia and the Pacific.
Temirton, G., Kharipova, R. E. and Kistaubayeva, A. K. (2023). The effect of STEM application on learning history and culture based on photo-documents in museums. *International Journal of Education in Mathematics, Science and Technology*, 11(1), 17–36. https://doi.org/10.46328/ijemst.2824
Traweek, S. (1988). *Beamtimes and Lifetimes. The World of High Energy Physicists*. London (UK): Harvard University Press. https://doi.org/10.4159/9780674044449
Tsakalerou, M., Perveen, A., Ayapbergenov, A., Rysbekova, A. and Bakytzhanuly, A. (2022). Understanding the factors influencing women's career trajectories in STEM education in Kazakhstan, in E. Pereira, C. Costa and Z. Breda (eds), *ICGR 2022 5th International Conference on Gender Research* (pp. 230–239).
Tytler, R., Anderson, J. and Williams, G. (2023). Exploring a framework for integrated STEM: Challenges and benefits for promoting engagement in learning mathematics. *ZDM Mathematics Education*, 55, 1299–1313. https://doi.org/10.1007/s11858-023-01519-x
Vennix, J., den Brok, P. and Taconis, R. (2018). Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM?. *International Journal of Science Education*, 40(11), 1263–1283. https://doi.org/10.1080/09500693.2018.1473659
Wan, Z. H., Jiang, Y. and Zhan, Y. (2021). STEM education in early childhood: A review of empirical studies. *Early Education and Development*, 32(7), 940–962. https://doi.org/10.1080/10409289.2020.1814986

Weinstein, M., Blades, D. and Gleason, S.C. (2016). Questioning power: Deframing the STEM discourse. *Canadian Journal of Science, Mathematics and Technology Education*, 16(2), 201–212. https://doi.org/10.1080/14926156.2016.1166294

Wong, V., Dillon, J. and King, H. (2016). STEM in England: Meanings and motivations in the policy arena. *International Journal of Science Education*, 38(15), 2346–2366. https://doi.org/10.1080/09500693.2016.1242818

Yilmaz, H. S. (2022). A study of determination of benchmarks during the new formation of integrated STEM leader preparation program. *European Journal of STEM Education*, 7(1), 10. https://doi.org/10.20897/ejsteme/12634

Yore, L. D., Pelton, L. F., Neill, B. W., Pelton, T. W., Anderson, J. O. and Milford, T. M. (2013). Closing the science, mathematics, and reading gaps from a Canadian perspective: Implications for STEM mainstream and pipeline literacy. In J. V. Clark (ed), *Closing the Achievement Gap from an International Perspective: Transforming STEM for Effective Education* (pp. 73–74). New York City (NY): Springer. https://doi.org/10.1007/978-94-007-4357-1_5

Zhao, Y. (2019). The rise of the useless: The case for talent diversity. *Journal of Science Education and Technology*, 28(1), 62–68. https://doi.org/10.1007/s10956-018-9743-3

APPENDIX A

Table A1. Assessment criteria for quality of articles

Section	Score	Criteria
Research Problem and Objectives	1	Is the research problem clearly stated and well-defined? Are the research objectives or questions clearly formulated?
Significance and Contribution	1	Does the article address an important issue or gap in the existing literature? Does the research offer new insights, knowledge, or solutions to the field?
Literature Review	1	Is there a comprehensive and up-to-date review of related literature? Does the article place the research within the context of existing research and theories?
Theoretical Framework	1	Is the theoretical framework, if applicable, well-developed and relevant to the research? Are theoretical concepts appropriately integrated into the analysis and discussion?
Methodology	1	Is the research methodology well-designed and suitable for the research questions? Are the data collection methods clearly described and justified? Are the research procedures replicable by other researchers?
Data Analysis and Interpretation	1	Are the data analysis methods appropriate for the research design and data collected? Are the results presented clearly and accurately? Are the findings interpreted in the context of the research objectives?
Citation and Referencing	1	Are sources properly cited and referenced according to the appropriate style (e.g., APA, MLA)? Does the article give credit to relevant prior research and ideas?
Discussion and Conclusion	1	Are the implications of the research findings discussed in detail? Do the conclusions drawn from the research align with the evidence presented?
Limitations and Future Research	1	Are the limitations of the study acknowledged and discussed? Are potential avenues for future research suggested?
Overall Quality	1	Does the research article demonstrate rigor, depth, and originality? Is the research presented in a manner that is engaging and valuable to the intended audience?