Contemporary Educational Technology, 2026, **18**(2), ep661
ISSN: 1309-517X (Online)

OPEN ACCESS

Review Article

Transformation in STEM education through ICT: A systematic review of life skills development and gender-related outcomes

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Citation: De Lorenzo, A., Musso, M., Bono, V., Martin, B., & Rabaglietti, E. (2026). Transformation in STEM education through ICT: A systematic review of life skills development and gender-related outcomes. *Contemporary Educational Technology, 18*(2), Article ep661. https://doi.org/10.30935/cedtech/18601

ARTICLE INFO

Received: 22 Dec 2025

Accepted: 22 Apr 2026

ABSTRACT

This systematic review examines the integration of information and communication technologies (ICT) and digital tools into science, technology, engineering, and mathematics (STEM) education within secondary schools with a particular focus on gender-related outcomes and life skills development. The results come from 12 studies published between 2010 and 2023 and analyzed according to PRISMA guidelines. The findings indicate that digital tools, including block-based programming, game-based learning, STEM-specific applications, and robotics, can enhance engagement, critical thinking and creativity. While the pandemic increased the visibility and urgency of ICT adoption, the limited number of post-pandemic studies does not allow systematic temporal comparisons. Given the limited number of studies, especially post-pandemic, the results are indicative rather than conclusive. Although ICT-based environments show potential for supporting female students' self-efficacy in STEM, the available evidence is limited and largely descriptive and therefore should be interpreted with caution. Digital tools contribute significantly to the development of problem-solving, self-regulation and interpersonal communication skills, which are essential for STEM skills and overall academic success. The review highlights the transformative potential of ICT in STEM education while emphasizing the need for future research to include larger, longitudinal studies, strategies for equitable access, and targeted teacher training to maximize effectiveness in diverse secondary school contexts.

Keywords: STEM, secondary education, ICT, digital tools, gender gap, life skills

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education is currently a major focus in educational research, not only for developing specific disciplinary skills but also for its potential to promote transversal skills, equitable participation, and prepare students for the social and professional challenges of the 21st century. In this perspective, recent discussions emphasize a broader transformation of science education, driven by the integration of emerging technologies and innovative pedagogical approaches, which reshape both teaching practices and learning environments (Usak, 2025). In the literature, the concept of STEM has various interpretations: it may refer to the joint teaching of the four disciplines or to teaching methods that integrate practices, concepts, and processes from different domains (Reynante et al., 2020). This review adopts the perspective of integrated STEM, defined as an intentional approach that connects ideas and practices across multiple disciplines to develop problem-solving, creativity, and critical thinking (Thibaut et al., 2017).

Despite increasing attention to more integrated teaching, STEM remains a conceptually unstable construct. Disciplinary boundaries persist, shaping curricula, methodological choices, and research directions (Maass et al., 2019; Roehrig et al., 2021). Within these dynamics, mathematics often plays a subordinate role, viewed more as a tool for data processing or calculation than as a discipline defined by its own practices, such as abstraction, formal reasoning, and proof (Goos et al., 2023). Furthermore, in secondary schools, mathematics and science are the most institutionalized subjects in the curriculum, while technology and engineering are less systematically included or entirely absent, limiting opportunities for full STEM integration (Cetin & Balta, 2017). In light of these issues, this review, focused on secondary school contexts, examines how STEM is conceptualized and implemented in educational research, with particular attention to the role of mathematics as a central component of interdisciplinary practices and as the main area through which integration with digital technologies occurs.

In addition to epistemological issues, STEM education is traditionally associated with two important topics: the gender gap and the development of life skills. Regarding gender inequality, several studies document that differences in perceived competence, mathematics anxiety, and attitudes toward technical and scientific disciplines already emerge in secondary school. For example, Sáinz et al. (2020) show that female students tend to underestimate their abilities in STEM subjects, while male students tend to overestimate theirs. John et al. (2022) highlights that strong identification with traditional gender roles is associated with higher levels of math anxiety in girls and lower levels in boys. Similarly, although international data from standardized tests such as PISA indicate slightly better performance by boys, girls more frequently achieve high school grades in all subjects, including mathematics and science (Levine & Pantoja, 2021; Voyer & Voyer, 2014). These findings suggest that school assessment dynamics may provide a relatively more favorable context for girls than standardized tests, while perceptions of self-efficacy and internalized social roles significantly influence engagement in STEM subjects. Beyond psychological aspects, the social context also plays a decisive role. A sense of belonging to the school and to scientific disciplines is an important predictor of long-term interest and participation (Tellhed et al., 2016). Parental support and family expectations also significantly influence students' beliefs about self-efficacy and their inclination toward STEM disciplines (Fernández García et al., 2019). In summary, the gender gap in STEM learning appears to result from a combination of emotional (anxiety and confidence), social (stereotypes and belonging), contextual, and family factors. This underscores the need to develop educational strategies and learning environments that reduce these inequalities, offering balanced learning opportunities for all genders.

A second line of research connects STEM to the development of life skills, a set of cross-cutting abilities essential for tackling complex tasks and adapting to rapidly changing contexts. Among these, self-efficacy holds a central position: students with greater confidence in their abilities are more likely to engage in scientific disciplines and consider careers in these fields (John et al., 2023). Research shows that interventions aimed at enhancing self-efficacy are particularly effective in promoting girls' interest in STEM (Fernández García et al., 2019; Tellhed et al., 2016). Social affiliation and a sense of community are also crucial. Students who perceive a supportive and inclusive school climate demonstrate higher participation and are less vulnerable to negative stereotypes (Sáinz et al., 2020). Peer support is especially important in reducing anxiety about math and science and in sustaining perseverance in complex tasks (John et al., 2022; Kim et al., 2020).

Resilience, the ability to cope with difficulties and adjust strategies when faced with obstacles, is another key life skill. Recent studies indicate that resilience is vital for academic success and persistence in STEM careers (Geary et al., 2023; Levine & Pantoja, 2021). Promoting a growth mindset strengthens resilience by encouraging students to view mistakes as part of the learning process (Eckstein, 2023). Intrinsic motivation, linked to curiosity, enjoyment of learning, and the pursuit of original solutions, is another predictor of success in STEM disciplines (Ayuso et al., 2022; Humble, 2023). Activities that stimulate creativity, authentic problem-solving, or the use of innovative materials foster greater cognitive and emotional engagement. The literature shows that integrating practical methodologies and digital tools increases motivation and participation, making learning more meaningful (Weinhandl et al., 2021). In order to synthesize the heterogeneous constructs reported in this literature, the present review refers to the life skills framework proposed by the World Health Organization (1994), which groups psychosocial competences into cognitive, emotional, and interpersonal domains.

A third set of studies examines the relationship between STEM education and technological innovation. The inclusion of information and communication technologies (ICT), artificial intelligence (AI), digital environments, and game-based learning is increasingly central to renewing teaching practices. Digital technologies enable interactive learning paths, dynamic visualizations, and immediate feedback systems, with positive effects on conceptual understanding and student motivation (Hoffman et al., 2020; Kim et al., 2019). The digitization of teaching also allows for the integration of innovative tools–such as simulations, virtual laboratories, cloud platforms, and three-dimensional modeling–which expand opportunities for exploration and experimentation in STEM disciplines (Hawes et al., 2022). AI-based technologies further support personalized learning through adaptive systems that respond to students' specific needs, offering individualized support (John et al., 2022). Alongside these developments, digital game-based learning has gained increasing relevance in STEM education: educational video games incorporate elements of challenge, storytelling, and immediate feedback that promote learning, engagement, and self-regulation (All et al., 2014; Boyle et al., 2016).

Overall, the use of digital technologies in STEM contexts is promising not only for improving academic performance, but also for broadening participation, strengthening self-efficacy, and developing cross-cutting skills fundamental for lifelong learning and entry into the workforce. However, further investigation is needed, particularly regarding the role of digital technologies in reducing the gender gap and promoting life skills such as resilience, critical thinking, creativity, and autonomy. Understanding how these tools can be integrated in a coherent, equitable, and pedagogically sound manner remains a central goal of current educational research.

Objectives

Considering the existing literature, this systematic review examines the use of ICT and digital technologies in the teaching and learning of STEM subjects in secondary schools, taking into account the contextual role of COVID-19. In this review, COVID-19 is treated as contextual background rather than as a comparative axis, given the limited number of post-pandemic studies. Particular attention is given to studies that discuss the gender gap and focus on life skills related to STEM education using digital technologies.

In line with recent conceptualizations (Reynante et al., 2020; Thibaut et al., 2017), this review adopts an integrated perspective of STEM education, in which science, technology, engineering, and mathematics are interconnected through interdisciplinary learning processes often mediated by digital tools. Within this framework, mathematics plays a pivotal and non-negotiable role, serving as both a disciplinary foundation and a unifying language that enables integration across the other STEM domains. Although the acronym STEM may sometimes refer to the collective teaching of these four areas, our operational definition specifically emphasizes studies that involve mathematics in connection with at least one other STEM discipline through the use of ICT or digital technologies, thereby reflecting the integrated and mathematically grounded nature of STEM learning environments. This perspective guided both the formulation of the research questions (RQs) and the inclusion criteria used in the systematic search.

The RQs that guided this review are the following:

1. **RQ1.** Which ICT, digital tools or other digital technologies are used in integrated STEM learning, with a specific emphasis on mathematics as a core component, in secondary education?
2. **RQ2.** How do ICT or digital technologies influence gender-related differences in STEM learning and participation?
3. **RQ3.** Which are the life skills outcomes associated with STEM learning through ICT?

Table 1. Eligibility criteria for inclusion in the systematic review

Variable	Criteria
Population	- Secondary school students: age: 10-17 who were taught STEM through ICT - Teachers experienced in the use of digital tools in mathematics or technology classes
Type of interventions	- Study and development of learning ICTs and digital methodologies
Comparison	- Traditional teaching without the use of digital tools
Outcome	- Applied technologies in STEM before and after COVID-19 - Gender gap in the use of ICT in the STEM learning/teaching - Associations between the use of ICT in STEM and life skills
Design	- Qualitative studies - Quantitative studies
Year of publication	- 2010-2023
Language	- English
Type of publication	Excluded: - Clinical trials - Clinical cases - Posters - Systematic reviews - Meta-analyses - Conference papers - Editorials

SEARCH STRATEGY AND DESIGN

To ensure a detailed and accurate report, this research was written following the specific methodology for systematic reviews PRISMA 2020 statement (Page et al., 2021). The initial research hypothesis guided the survey towards the following ones, and the relative database search parameters.

To adequately identify the RQs, the PICO model was used (Counsell, 1997) through which the main characteristics of the studies to be included in the review were specified in **Table 1**. PICO is often used when the study focuses on the evaluation of interventions, particularly in the context of evidence-based medicine. However, the PICO format is not limited to the clinical domain, but can also be applied in other areas, such as studying the effects of psychological interventions on school-age children (Foster & Jewell, 2022).

In accordance with our operational definition of STEM, the search strategy targeted studies addressing the integrated use of ICT or digital technologies across two or more STEM disciplines, with particular emphasis on mathematics and science, given their predominant representation in the literature. Studies limited to single-discipline analyses were included only when they explicitly connected digital technology use to broader STEM-related competences or learning outcomes.

Inclusion and Exclusion Criteria

The inclusion criteria were articles published in English, population secondary school students aged 10 to 17 or secondary school teachers and educators trained in STEM, studies published between 2010 and 2023, research concerning mathematical and STEM oriented digital tools and interventions focused on the development of life skills and academic performance. The year 2010 was chosen because it is a critical year for the integration of ICT in STEM education, as education policy promotes the use of digital technologies and methods, but also the rapid spread of advanced technological tools such as e-learning platforms and apps for science simulations, as well as the introduction of coding and robotics in schools (Bybee, 2010; McPherson, 2010). The main criteria for exclusion were psychiatric populations or students with learning disabilities.

Study Identification

Regarding the sources that form the bibliography, the research focused on databases with vast psychological article collections like Web of Science, PsycInfo, and Scopus.

The query string used was as follows: *(life skills OR soft skills OR socioemotional learning) AND (Performance OR grades OR academic OR achievement OR school outcomes) AND (math OR mathematics OR arithmetic OR algebra OR STEM OR Science) AND (Digital OR online OR internet OR media OR technology) NOT (psychopathology OR disabilities OR disorders OR mental illness OR psychiatry).*

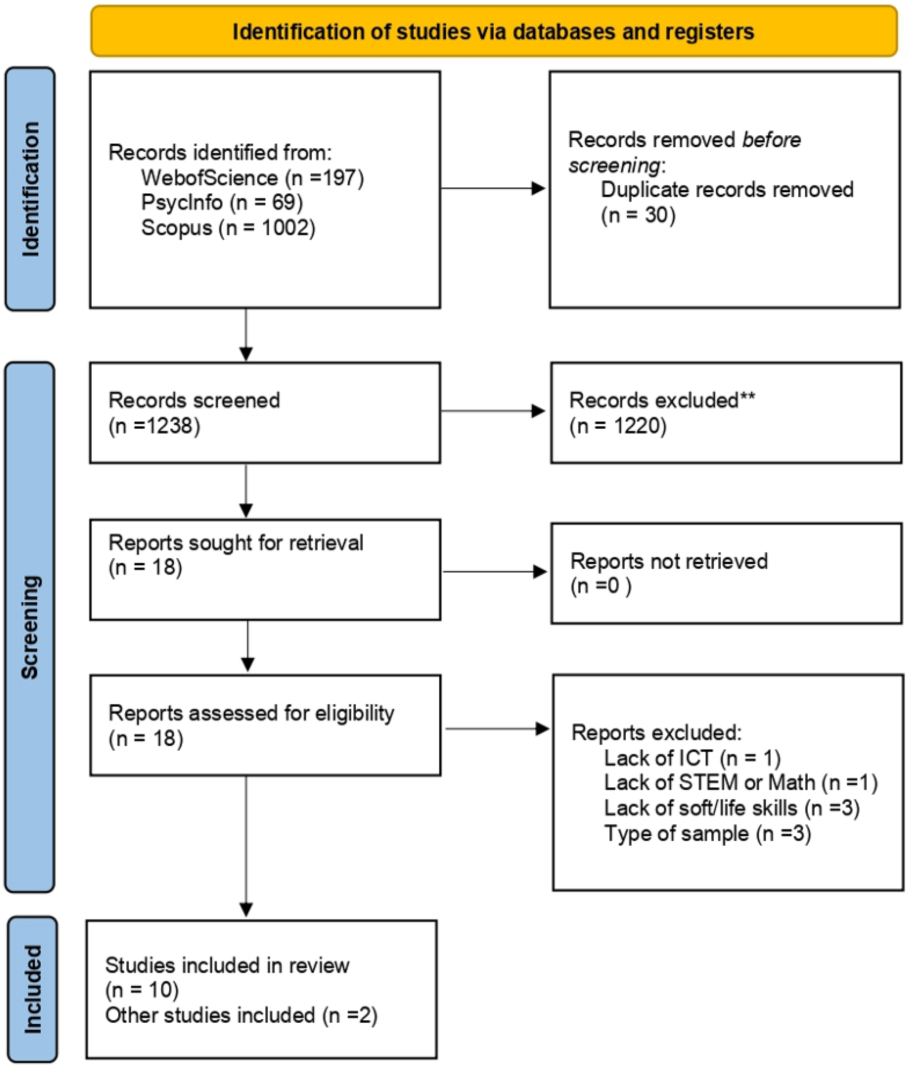

Figure 1. Flow diagram of the selection process (adapted from Page et al., 2021)

We acknowledge that our search string may have excluded studies referring to broader constructs (e.g., motivation, engagement, and 21st century skills) that overlap with life skills but are not explicitly labelled as such. After the exclusion of unrelated studies and documents, a total of 1268 studies were selected. The following examination revealed 30 duplicates among the studies; after their removal, the final number of studies included in the screening process was 1238.

Data Collection and Study Selection

The screening process began in November 2023 when the final collection of studies was uploaded to the online program Rayyan (Ouzzani et al., 2016). With the organizational aid of Rayyan, the 3 selected databases were examined by the 2 reviewers who worked autonomously utilizing Rayyan's blind mode. From November 2023 to December 2023 the reviewers surveyed the studies based on titles, abstracts, authors, date, and type of publication, choosing whether to include or reject the articles independently and marking those for which inclusion was uncertain. A second phase subsequently began when Blind mode was removed, and the reviewers could compare their results and discuss the outcome removing the risk of bias. Of the 1238 records screened by title and abstract, 1188 were excluded because they did not meet the PICO criteria (wrong population, non-STEM focus, no ICT component, no life skills outcomes). This resulted in 50 papers marked as 'uncertain'. After discussion, 18 were retained for full-text analysis. Following the PRISMA 2020 statement's guidelines, a flow diagram was created to recount the selection process of the chosen studies (**Figure 1**). Using the research methodology we described, the screening and study selection process ended resulting in 12 articles suitable for this review.

Synthesis Approach

In addition to study identification and selection procedures, particular attention was given to the choice of synthesis strategy. Given the heterogeneity of study designs, interventions, digital tools, and outcome measures, a quantitative meta-analysis was not considered methodologically appropriate. The included studies varied substantially in terms of:

(a) types of ICT interventions (e.g., robotics, block-based programming, game-based learning, and learning management systems [LMS]),

(b) research designs,

(c) duration of interventions, and

(d) operationalization of life skills and academic outcomes.

Furthermore, several studies did not report standardized effect sizes or sufficient statistical information to enable reliable comparisons. For these reasons, the review adopted a systematic narrative synthesis aimed at identifying patterns, thematic convergences, and conceptual relationships rather than statistical aggregation.

RESULTS

General Study Characteristics

A detailed description of the 12 included studies, their basic characteristics, ICT and digital tools, and key findings are summarized in **Table 2**.

Table 2. Overview of the research on the impact of ICT on STEM teaching/learning in secondary education

Study	Title	Age range (size)	Gender difference	STEM	Life skills	ICT and digital tools	Key findings
Tsai (2017)	An investigation of gender differences in a game-based learning environment with different game modes	14-15 (n = 74)	Yes	Technology	Interpersonal skills	TRIS-Q game and online learning system	Female students improved their STEM learning outcomes through game-based learning, especially using ICT tools like the TRIS-Q game, which enhanced engagement and knowledge retention.
Mavridis et al. (2017)	Impact of online flexible games on students' attitude towards mathematics	12-14 (n = 79)	Yes	Math	Emotional skills	Online flexible educational game	The use of an online flexible educational game improved students' attitudes towards mathematics compared to traditional methods; gender did not influence the effects of the game on students' attitudes and performance.
Owens and Hite (2022)	Enhancing student communication competencies in STEM using virtual global collaboration project based learning	10-11 (n = 64)	Not	Science	Interpersonal skills	Global PBL and LMS Canvas	Global project-based learning using ICT enhances students' communication skills in STEM by promoting collaboration and cross-cultural understanding.
Hoffman et al. (2020)	Motivation outcomes in math-related videogames	11 (n = 30)	Not	Math	Emotional skills	Educational videogame and game performance metrics	Domain-specific and game-specific motivations significantly influence their engagement and performance in educational video games related to STEM, particularly mathematics. Participants with lower math motivation experienced a decline in their self-perceived competence.
Abdullah et al. (2020)	The effects of an inductive reasoning learning strategy	15-16 (n = 94)	Not	Math	Emotional skills	Worksheets and	Inductive reasoning learning strategy assisted by

Table 2 (Continued).

Study	Title	Age range (size)	Gender difference	STEM	Life skills	ICT and digital tools	Key findings
	assisted by the GeoGebra software on students' motivation for the functional graph II topic					GeoGebra	GeoGebra significantly enhances students' motivation in STEM, particularly in understanding functional graphs and it improves students' attention, relevance, and confidence.
Hossein-Mohand et al. (2021)	Uses and resources of technologies by mathematics students prior to COVID-19	12-17 (n = 2,018)	Yes	Math	Cognitive and emotional skills	Not applicable	ICT plays a crucial role in enhancing mathematics students' academic performance, largely influenced by their perception of its usefulness. A significant portion of students do not utilize ICT, pointing to issues in digital literacy and access.
Negara et al. (2022)	Improving students' mathematical reasoning abilities through social cognitive learning using GeoGebra	16-17 (n = 70)	Not	Math	Cognitive and emotional skills	GeoGebra, online learning platforms and computer-assisted learning	Using GeoGebra in social cognitive learning enhances students' mathematical reasoning compared to traditional approaches; ICT tools in STEM education boost engagement and comprehension.
Plangg and Fuchs (2022)	A gender-related analysis of a robots' math class	11-12 (n = 24)	Yes	Math	Cognitive skills	TI-innovator rover, programming languages, digital simulations	Using educational robotics promotes better understanding of mathematical concepts and enhances student engagement, particularly among female students; ICT tools support collaborative and problem-oriented learning in mathematics.
Weng et al. (2022)	Applying relatedness to explain learning outcomes of STEM maker activities	13-15 (n = 95)	Not	Science, technology, math, and physics	Cognitive skills	Arduino I/0 circuit board, digital learning platforms, computer programming interface	Incorporating ICT through real-world problems and mentoring in STEM education significantly boosts students' critical thinking skills and their sense of identity in STEM fields.
Del Olmo-Muñoz et al. (2022)	Using intra-task flexibility on an intelligent tutoring system to promote arithmetic problem-solving proficiency	10-12 (n = 110)	Yes	Math	Cognitive skills	Hypergraph intelligent tutoring system and digital problem-solving environment	Using an intelligent tutoring system to promote intra-task flexibility significantly enhances students' problem-solving proficiency in arithmetic, particularly benefiting girls and helping to reduce gender gaps in STEM.
Weng et al. (2023)	Creativity development with problem-based digital making and block-based programming for science, technology, engineering, arts, and mathematics learning in middle school contexts	10-14 (n = 54)	Not	STEAM	Cognitive skills	Scratch, Desmos custom activities, video conferencing software	The integration of ICT in STEM education through problem-based digital making using Scratch fosters student's creativity, enhancing their skills in novelty, utility, aesthetics, and authenticity; it encourages students to engage deeply with real-world problems, promoting critical thinking and collaborative skills.

Table 2 (Continued).

Study	Title	Age range (size)	Gender difference	STEM	Life skills	ICT and digital tools	Key findings
Ruiz-Palmero et al. (2023)	Effectiveness of the flipped classroom in the teaching of mathematics in an online environment: Identification of factors affecting the learning process	14-16 (n = 113)	Yes	Math/ geometry	Problem-solving, motivation, self-regulation and collaboration	Flipped classroom methodology, videoconference platforms, digital resources and applications	Flipped classroom methodology improves academic performance fostering engagement and understanding in mathematics, particularly geometry, when integrated with ICT resources.

Table 3. Systematic review sources

Variables		Frequencies
Year	2017	2
	2020	3
	2021	1
	2022	5
	2023	1
Journal	Eurasia Journal of Mathematics Science and Technology Education	1
	Educational Technology Research and Development	1
	Technology, Knowledge and Learning	1
	Research in Science & Technological Education	1
	IEEE Access	1
	Sustainability	1
	International Journal of Technology in Mathematics Education	1
	Frontiers in Psychology	1
	International Journal of Emerging Technologies in Learning	1
	British Journal of Educational Technology	1
	Journal of Educational Computing Research	1
	Online Learning Journal	1
Country	Taiwan	1
	Greece	1
	United States	2
	Malaysia	1
	Spain	3
	Indonesia	1
	Austria	1
	China	2

Furthermore, general characteristics of the systematic review sources (year, journal, and country) that can help to understand the content of the selected articles are described in **Table 3**.

These 12 articles were published in 12 different journals, which are all indexed in SJR. Five articles refer to pre-pandemic studies published between 2017 and 2020, while seven articles refer to studies published after the onset of the COVID-19 pandemic, i.e., between 2021 and 2023. However, only one of the studies explicitly refers to COVID-19 period. Five of the articles refer to European studies (42%), specifically 3 Spanish, 1 Austrian and 1 Greek; only two articles are from the United States (16%), and the remaining five articles are from Asia (42%), specifically 1 from Taiwan, 1 from Indonesia, 1 from Malaysia and 2 from China. Of the 12 studies included in this review, only 6 (50%) explicitly address the gender gap or gender differences related to the impact of ICT on STEM learning. Various types of ICT and digital tools were used in the studies: block-based programming tools (n = 3), game-based learning and educational video games (n = 3), LMS and online learning platforms (n = 3), STEM-specific tools (e.g. GeoGebra) (n = 4), project-based learning (PBL) and collaborative learning (n = 2), robotics (n = 1), and intelligent computer assisted instruction (n = 1). In some studies, several digital tools were used, while only one study did not use any digital tools outside of the survey due to its exploratory nature. Of the items selected for review, 2 relate to interpersonal skills, 5 to emotional skills and 6 items to cognitive skills.

Methodological Characteristics of Included Studies

Beyond descriptive publication data, examining the methodological profiles of the included studies provides essential interpretative context. The methodological designs of the studies were heterogeneous. Most investigations adopted quasi-experimental, exploratory, or mixed-method approaches. Sample sizes were frequently limited, often involving single-classroom or small institutional cohorts. Intervention durations varied considerably, with many studies implementing short-term instructional activities rather than longitudinal programs. Only a small subset of studies incorporated control group comparisons or extended follow-up measures. Outcome measures also differed across studies. While some employed performance-based assessments, many relied on self-reported instruments evaluating constructs such as motivation, engagement, self-efficacy, or attitudes toward STEM. Additionally, the operationalization of "life skills" was not uniform, reflecting variability in theoretical frameworks and measurement tools used by primary researchers.

This methodological diversity, while indicative of the field's richness, limits direct comparability and constrains the generalizability of conclusions.

Risk of Bias Considerations

Potential sources of bias were considered at both the review level and the primary study level.

At the review level, selection bias was mitigated through independent blind screening conducted by two reviewers using Rayyan software. Discrepancies were resolved through structured discussion, ensuring consensus-based inclusion decisions.

At the primary study level, several recurrent limitations were identified: small or convenience-based samples, short intervention durations, limited use of randomized designs, absence of long-term follow-up, reliance on self-reported measures, inconsistent reporting of statistical indicators, and limited availability of standardized effect sizes.

These characteristics suggest that findings across studies should be interpreted cautiously, particularly regarding causal inferences and the magnitude of effects.

ICT or Digital Tools Used in STEM

The following categories of ICT tools were identified across the selected studies. **Table 4** provides a comparative overview of the tools, their educational functions, associated studies, and key learning outcomes.

- Block-based programming tools are visual programming environments that allow the user to create programs by stacking blocks that represent different programming commands. This approach simplifies coding as no syntax is required and makes it accessible to beginners, especially children. By dragging and dropping blocks, users can create sequences of commands, which helps them understand programming logic without the complexity of traditional coding languages. A well-known example of an educational context is Scratch (Resnick et al., 2009).
- Game-based learning and educational video games are used to enhance the learning experience. Educational video games are specifically designed to teach concepts and skills while creating an engaging and interactive environment. These games often incorporate elements of competition, collaboration, and problem-solving, making learning more dynamic and enjoyable. A famous example of an educational context is Minecraft education edition (González Pérez & Schewalie, 2019).
- LMS are software applications that facilitate the management, documentation, tracking, reporting, and delivery of educational courses or training programs. Online learning platforms provide access to courses and resources via the internet, enabling flexible and self-paced learning. Famous examples for the educational context are Moodle and Google Classroom (Dougiamas & Taylor, 2003; Mazlan et al., 2025).
- STEM-specific tools are software applications designed to enhance learning in the fields of science, technology, engineering, and mathematics. These tools often provide interactive simulations, visualizations, and problem-solving capabilities that help students understand complex concepts. Important examples for the educational context are GeoGebra and Tinkercad (Bers et al., 2015; Yohannes & Chen, 2023).

Table 4. Types of ICT tools used in STEM education

ICT Tool Category	Description	Key Studies	Reported Educational Outcomes
Block-based programming	Visual coding platforms (e.g., Scratch) enabling logic development without syntax.	Weng et al. (2023), Plangg & Fuchs (2022), Hoffman et al. (2020)	Improved creativity, computational thinking, and engagement
Game-based learning / Educational games	Games designed to teach STEM concepts through interactive and motivating tasks.	Tsai (2016), Hoffman et al. (2020), Mavridis et al. (2017)	Enhanced motivation, increased math engagement
Learning Management Systems (LMS)	Platforms like Moodle or Google Classroom used to manage content and support blended learning.	Ruiz-Palmero et al. (2023), Owens & Hite (2020), Abdullah et al. (2020)	Supported flipped classrooms, online collaboration, and content access
STEM-specific tools	Tools like GeoGebra and Tinkercad offering subject-specific support in math and engineering.	Abdullah et al. (2020), Negara et al. (2022)	Promoted mathematical reasoning, motivation
Project-based / Collaborative learning tools	Digital tools that enable teamwork and real-world applications (e.g., Google Docs).	Owens & Hite (2020), Weng et al. (2023)	Enhanced communication, problem-solving, and collaboration
Robotics	Use of programmable robots in learning activities (e.g., LEGO Mindstorms).	Plangg & Fuchs (2022)	Stimulated STEM interest, gender-related learning patterns
Intelligent Computer-Assisted Instruction (ICAI)	AI-based personalized learning systems (e.g., ALEKS, Knewton).	Del Olmo-Muñoz et al. (2022)	Improved arithmetic problem-solving and adaptive learning

- PBL and collaborative learning are teaching methods that encourage students to learn by participating in real-life projects. In collaborative learning, students work together to solve problems or complete tasks, enhancing their learning experience through teamwork. A common example for the educational context is Google Docs (Bell, 2010).
- Robotics in education involves the use of robots as a teaching aid in various subjects, especially STEM subjects. This often includes programming robots to complete tasks, which helps students learn coding and design principles. One example in an educational context is LEGO Mindstorms (Ouyang & Xu, 2024; de Winter et al., 2025).
- Intelligent computer-assisted instruction (ICAI): refers to computer-based educational systems that adapt to the individual needs of learners. These systems use AI to provide personalized feedback and support for instruction. Examples used in the educational context are Knewton and ALEKS (Aleven et al., 2009; Woolf, 2010).

ICT or Digital Tools Used in STEM and the Gender Gap

Of the 12 studies included in this review, only 6 address the gender gap or gender differences in STEM subjects. Across the six studies reporting gender-related outcomes, three indicate small but consistent advantages for girls in structured collaborative learning contexts, particularly in problem-solving tasks. Two studies report higher confidence levels among boys, although these differences are not accompanied by higher academic performance. Finally, one study reports no significant gender differences in learning outcomes within inclusive digital environments. Overall, the evidence suggests that pedagogical design mediates gendered patterns more strongly than the technology itself. **Table 5** summarizes key findings.

Life Skills Associated with STEM Learning Through ICT

The life skills measured in the studies using various variables were categorized according to the guidelines of the World Health Organization (1994). This framework was adopted as an organizing taxonomy because it provides a well-established and widely used classification of psychosocial competences across cognitive, emotional, and interpersonal domains. In the context of this review, the World Health Organization (1994)

Table 5. Gender-related findings in ICT-based STEM learning

Study	Gender Differences	Summary of Findings
Tsai (2017)	Yes	Boys had more gaming experience; girls had better learning outcomes and preferred single-player modes
Plangg & Fuchs (2022)	Yes	Girls outperformed in task completion; boys scored slightly higher on computational thinking but rated themselves more competent
Del Olmo-Muñoz et al. (2022)	Yes (post-test)	Girls performed better in the post-test, especially under flexible conditions
Mavridis et al. (2017)	No	No significant differences in attitudes or learning effectiveness
Hossein-Mohand et al. (2021)	No	No gender-based differences in ICT use; usage linked to socio-educational variables
Ruiz-Palmero et al. (2023)	No	No gender differences in academic performance or perceptions of flipped classrooms

Table 6. Life skills developed through ICT-supported STEM learning

Domain	Life Skill	Key Studies	Summary of Findings
Interpersonal	Communication, collaboration	Tsai (2017), Owens & Hite (2020)	Positive perceptions but no statistically significant improvement in communication skills
Emotional	Motivation, self-awareness, self-confidence	Mavridis et al. (2017), Hossein-Mohand et al. (2021), Hoffman et al. (2020), Negara et al. (2022), Abdullah et al. (2020)	Motivation improved across multiple contexts; mixed results for confidence and self-awareness
Cognitive	Problem-solving, creativity, critical thinking	Del Olmo-Muñoz et al. (2022), Plangg & Fuchs (2022), Weng et al. (2022, 2023), Negara et al. (2022), Ruiz-Palmero et al. (2023)	Consistent improvement in problem-solving and critical thinking; creativity gains less conclusive

framework was used primarily as a descriptive structure to group heterogeneous outcomes reported in the literature and to facilitate comparability across studies. Therefore, the results of this objective are divided into macro-categories: interpersonal, cognitive, and emotional skills (Mangrulkar et al., 2001). **Table 6** summarizes the studies contributing to each domain.

DISCUSSION

This review is based on a systematic narrative synthesis of twelve studies examining the use of digital tools to support STEM learning in secondary schools and to promote transversal skills and gender-related dimensions. Given the heterogeneity of interventions, study designs, and outcome measures, the findings should be interpreted as exploratory and indicative rather than conclusive. The purpose of the review was not statistical generalization, but the identification of conceptual patterns, recurring themes, and emerging trends. The three RQs guided the organization of the results and allowed us to identify some emerging trends, although there are limitations due to the small number of available studies. Therefore, the following considerations should be interpreted as exploratory and not as conclusive evidence.

To answer **RQ1**, the digital tools used in the articles were divided into categories, each with specific functions and implications. Block programming facilitates beginners' introduction to programming and allows students to focus on logic and problem-solving without having to deal with the complexity of syntax (Weng et al., 2023). The use of tools such as Scratch makes programming accessible and intuitive for younger students. In line with recent findings, digital platforms that integrate learning analytics can significantly improve the effectiveness of block programming environments. As Sagarika et al. (2021) have shown, linking formative assessment and learning analytics in LMS (e.g., Canvas) allows teachers to collect and analyze student data in real time. This facilitates the identification of both high-performing and low-performing students and enables timely, personalized interventions. Game-based learning and educational video games have been shown to increase student motivation and engagement, especially in math, to explain complex concepts (Hoffman et al., 2021). This type of learning makes lessons more interactive and engaging, which is particularly useful in the early stages of STEM education. Research confirms that mathematical computer games not only increase motivation but also contribute to a more efficient and sustainable acquisition of knowledge at all levels of education. As Divjak and Tomašković (2011) point out, 21 out of 27 studies analyzed reported a positive impact of the use of mathematical games on the achievement of educational goals, and 14 out of 17 studies confirmed an improved attitude towards mathematics. LMS have become central tools for distance learning during the pandemic, enabling flexible and personalized classroom management. These systems have allowed teachers to track student progress and customize content to meet individual needs, which is particularly effective in STEM learning environments (Ruiz-Palmero et al., 2023). In this context, the integration of automatic feedback systems in LMS has shown promising results. As Cavalcanti et al. (2021) point out, automatic feedback mechanisms not only improve students' performance in online activities but also provide timely, targeted support that helps to close knowledge gaps and promote students' self-regulation. Although the evidence for reducing teacher workload is inconclusive, the pedagogical value of such feedback, particularly in programming and technical subjects, is consistently recognized. STEM-specific tools such as GeoGebra, that facilitate the understanding of mathematical concepts through dynamic visualizations. These types of tools have been shown to be effective in improving understanding and performance in mathematics by facilitating the exploration of complex concepts such as functions and geometry (Abdullah et al., 2020). This is consistent with the findings of Hillmayr et al. (2020), whose meta-analysis found that digital tools with interactive and adaptive features (such as intelligent tutoring systems and dynamic math tools) have medium to large positive effects on student achievement in secondary mathematics and science. Their findings also suggest that these effects are particularly pronounced when digital tools are used to complement, rather than replace, traditional teaching and when teachers are trained in their use. PBL, a method that promotes the development of collaboration and communication skills in interdisciplinary contexts where students solve real-world problems. PBL has been successfully integrated into STEM fields to enhance critical thinking skills and facilitate deep and meaningful learning (Owens & Hite, 2022). A growing scientific literature underpins the effectiveness of PBL in conjunction with ICT and new digital tools (e.g., Pertiwi et al., 2024; Zainil et al., 2023). For example, the study by Muzana et al. (2021) found that E-STEM PBL significantly improved students' ICT knowledge and problem-solving skills compared to traditional teaching methods. A meta-analysis (Kwon & Lee, 2025) of STEM-based PBL confirmed that the integration of PBL with digital technologies consistently improved active learning, 21st-century skills, and the ability to learn. Educational robotics is designed to stimulate interest in STEM and promote the development of problem-solving skills, and combines elements of engineering, programming, and mathematics by providing a hands-on, applied experience (Plangg & Fuchs, 2022). These findings are supported in the literature by studies such as that of Cam and Kıyıcı (2022), who investigated robot-assisted programming lessons using LEGO® Mindstorms and found that students who participated in robot-assisted learning significantly improved their problem-solving skills compared to those who participated in traditional programming lessons. The practical nature of robotics therefore, appears to not only promote problem-solving skills but also improve academic performance and motivation. ICAI provides personalized, adaptive support through AI and promotes learning tailored to each student. ICAI tools are particularly useful for addressing specific gaps in areas such as mathematics (Del Olmo-Muñoz et al., 2022).

Regarding the **RQ2** on gender differences, about half of the studies reviewed report findings in this area. The evidence indicates that the effectiveness of digital tools varies between girls and boys and is influenced by psychological, emotional, and contextual factors. Some research suggests that boys are more accustomed to competitive and dynamic environments, particularly digital games (Levine & Pantoja, 2021; Tsai, 2017). However, this greater perceived confidence does not always lead to better performance. In several cases, girls achieve higher results in problem-solving activities with educational robots, likely due to a more methodical and strategic approach (Plangg & Fuchs, 2022). In contexts that emphasize autonomy and reflection, as shown by Del Olmo-Muñoz et al. (2022), girls tend to outperform their male peers, highlighting the importance of pedagogical design in mediating gender outcomes (Sáinz et al., 2020; Tellhed et al., 2017). Studies on the role of teachers also show that gender differences can affect the adoption and integration of technologies: in the work of Marange and Tatira (2024), female teachers are more reflective and adaptable in their use of

GeoGebra, despite starting with lower levels of self-efficacy. In addition, the reviewed studies suggest that well-designed ICT-based learning environments may help mitigate the effects of gender stereotypes and support participation among female students. However, the evidence remains largely descriptive and depends strongly on pedagogical design and classroom implementation (Hossein-Mohand et al., 2021; Mavridis et al., 2017). Overall, digital technologies have the potential to promote more equitable access to STEM, but the effects depend greatly on implementation methods, social interactions, and the support provided to students.

The **RQ3** examined which life skills are addressed in the analyzed studies and how integrating digital technologies in STEM contributes to their development. Overall, the evidence shows that digital tools support a range of cross-cutting skills essential for successfully tackling complex tasks in both school and real-world contexts. The first category of life skills is problem-solving, which is widely promoted through tools such as GeoGebra and robotics kits. These technologies enable students to explore complex problems using dynamic visualizations and hands-on activities, facilitating conceptual understanding and the ability to apply effective strategies (Abdullah et al., 2020; Del Olmo-Muñoz et al., 2022; Plangg & Fuchs, 2022). For example, GeoGebra's interactive representations support better integration of spatial and algebraic aspects (Ziatdinov & Valles, 2022), while educational robotics fosters adaptability, logical thinking, and experimental approaches to problem-solving (Eswaran, 2024). Closely related to problem-solving is the development of critical thinking, supported by programming and PBL activities. These approaches require students to analyze complex situations, evaluate information, and produce solutions based on structured logic (Weng et al., 2023). Studies on digital PBL (Darmawansah et al., 2023; Kwon & Lee, 2025) also highlight that such experiences increase the ability to deal with ambiguity, stimulating a reflective attitude that is indispensable in STEM contexts. A third relevant area is self-regulation, supported by the structured environments provided by LMS platforms. Tools such as Moodle and Google Classroom promote independent planning, progress monitoring, and activity organization, contributing to the development of fundamental metacognitive skills (Hossein-Mohand et al., 2022; Ruiz-Palmero et al., 2023). The literature confirms that regular use of these digital environments fosters strategic learning behaviors, informed decision-making, and greater personal responsibility (Broadbent & Poon, 2015; Ifenthaler & Yau, 2020). Effective digital design can also strengthen academic resilience and time management skills (Martin et al., 2020). The integration of technology into STEM also supports the development of creativity, thanks to educational robotics, modeling tools, and digital games that encourage experimentation and the exploration of original solutions (Hoffman et al., 2020; Weng et al., 2022). As Resnick (2017) and Bers (2020) note, learning environments based on exploration and creative learning promote iteration, tolerance for error, and a more open approach to innovation. Another important domain is communication and collaboration skills, which are promoted by digital platforms and PBL activities. Online interactions allow students to compare perspectives, negotiate meanings, and build shared understanding, which are crucial skills in science (Owens & Hite, 2022; Tsai, 2017). Collaborative technologies support knowledge co-construction and contribute to the development of empathy and negotiation skills (Krajcik & Blumenfeld, 2006; Thoms, 2020). Finally, several studies show that activities involving robotics and educational games improve self-efficacy, particularly among female students, who are often less confident in STEM subjects. Engaging and practical digital contexts can reduce performance anxiety, enhance personal success, and help counter gender stereotypes (Mavridis et al., 2017; Papavlasopoulou et al., 2026). Increased confidence in one's abilities directly impacts educational and career choices and can promote more balanced participation in scientific careers (Wang & Degol, 2017). Overall, the studies reviewed indicate that integrating ICT in STEM supports a comprehensive set of life skills, including problem-solving, critical thinking, self-regulation, creativity, collaboration, and self-efficacy, highlighting the potential of digital technologies to promote more comprehensive and inclusive learning.

Limitations

One of the main limitations of this review is the variability of the educational environments, methods and ICT tools used in the different studies analyzed. The diversity of approaches makes it difficult to draw generalizable conclusions about the effectiveness of ICT in STEM subjects, as each ICT tool has different effects depending on the characteristics of the learning environment and the cultural and socioeconomic background of the students. Furthermore, the review was conducted based on a limited number of articles, with samples often limited and of short duration, limiting the ability to examine the long-term impact of ICT on STEM and life skills. In addition to contextual and design-related limitations, the absence of a quantitative meta-analysis should be acknowledged. Due to the substantial heterogeneity of study designs, digital interventions, and outcome variables, statistical aggregation and effect size comparisons were not methodologically justified. Moreover, several studies did not report standardized effect sizes or sufficient statistical details to enable reliable quantitative synthesis. Future research would benefit from more consistent reporting practices to facilitate meta-analytic approaches. Finally, the methodological robustness of the included studies varied, with frequent use of small samples, short-term interventions, and reliance on self-reported measures, which may limit the strength and generalizability of conclusions. Furthermore, the review was conducted based on a limited number of articles, with samples often limited in size and duration. In particular, the number of post-pandemic studies is very small, which restricts the ability to assess changes in ICT usage and its long-term impact on STEM learning and the development of life skills. Another limitation concerns the limited number of studies explicitly examining gender-related outcomes. Only 6 out of the 12 included studies (50%) explicitly address gender-related outcomes in ICT-supported STEM learning, and few explore how these interact with contextual variables such as family support, socioeconomic background, or access to digital resources. This reflects a broader limitation of the current literature rather than of the present review. Another notable gap in the literature reviewed concerns the sparse reporting of social configuration variables, such as team composition and structured interactions, between peers - that may significantly influence the gendered outcomes of ICT-STEM interventions. As Jungwirth (2008) points out, ICT in mixed-gender math groups can unintentionally trigger "gendering effects" that are not due to the math content itself, but to the interaction dynamics. In all-girl groups, the susceptibility to these effects is lower. It is therefore important that future research systematically documents group composition, interaction structure and support strategies and compares the effects of mono- and mixed-gender groups, particularly in relation to role allocation and equality of participants.

FUTURE STUDIES

Future research will focus on the effectiveness of ICT for STEM learning in heterogeneous school environments, including assessing the contribution of these technologies to the development of life skills such as critical thinking, creativity, and problem-solving. In particular, it would be useful to examine gender dynamics and explore which ICT tools are most effective in reducing inequalities, not only in terms of academic achievement but also in terms of students' perceptions of their own abilities. To promote effective and inclusive use of ICT, it is also of paramount importance to develop specific training programs for teachers that teach advanced digital skills and innovative teaching strategies for integrating technology into the classroom. In parallel, research should explore how ICT can be optimized to maximize student engagement by using blended learning approaches and methods that can be adapted to different learning styles.

CONCLUSIONS

This review has attempted to show that ICT-enhanced STEM education holds promise for improving both academic outcomes and the development of essential life skills for the 21st century. The integration of digital tools—such as block-based programming environments, learning games, learning platforms, STEM-specific applications such as GeoGebra, robotics and AI-powered tutoring systems—has consistently led to improvements in problem-solving, critical thinking, motivation and self-regulation. Given the limited number of studies, particularly post-pandemic, these findings should be interpreted as indicative rather than definitive evidence of ICT effectiveness. The analysis shows that these tools not only promote cognitive skills: they also contribute to the development of emotional and interpersonal skills, including self-confidence, collaboration and self-awareness. These dimensions are critical to preparing learners for the complexities of modern life and the modern workplace, and they align ICT-enhanced STEM education with broader educational goals focused on inclusion, empowerment and real-world relevance. Of particular interest are the findings in relation to gender impact, especially in terms of how female students respond to ICT-enhanced STEM learning. In line with the literature, the research shows that girls particularly benefit from environments that encourage active participation and collaboration, which not only reduces performance anxiety but also increases self-efficacy in STEM contexts. However, given the descriptive nature of most gender-related findings, these outcomes should be interpreted as potential influences rather than causal effects of ICT on female students' performance. In fact, female students were found to perform significantly better in problem-solving tasks, especially when working in structured, interactive and supportive learning scenarios. In addition, girls were observed to use systematic and analytical strategies such as careful testing and calculation more frequently than their male peers in these contexts. These findings point to the role of ICT in increasing self-efficacy and self-confidence, particularly for students who otherwise feel marginalized or less represented in STEM subjects. For female learners in particular, the combination of interactive tools, supportive collaboration and structured challenges appears to create a learning environment in which they can flourish intellectually and emotionally. The COVID-19 pandemic has further accelerated the adoption of digital tools and placed an emphasis on personalization through AI and robotics. While the shift has broadened the toolkit of STEM teachers, the long-term effectiveness of these interventions has yet to be fully assessed due to the small number and limited duration of post-pandemic studies. Consequently, the observed benefits should be considered exploratory and indicative rather than conclusive. Nevertheless, it is evident that ICT is opening the door to more flexible, inclusive and student-centered approaches that have great potential to address inequalities in access, motivation and achievement.

In summary, ICT-enabled STEM education can serve as a catalyst for both academic outcomes and educational equity. However, to fulfill this potential, it must be implemented through intentional, inclusive pedagogy that recognizes the diversity of learners, encourages active engagement, and empowers all students—especially girls—to build confidence in their STEM abilities. Through well-designed digital environments and targeted teacher training, ICT may help transform STEM education into a space where life skills, gender equity, and meaningful learning outcomes are pursued as interconnected goals, pending further research to confirm these effects.

Author contributions: ADL, MM, VB, BM, & ER: writing–original draft; **ADL, VB, BM, & ER:** writing–review & editing; **ADL & MM:** formal analysis and software; **ADL, BM, & ER:** methodology; **ADL & ER:** conceptualization; **ER & VB:** funding acquisition and project administration; & **ER:** supervision. All authors approved the final version of the article.

Funding: This article was supported by the PRIN: Research projects of significant national interest–Call for proposals 2022 Prot. 2022LB7WKJ "Class-tAIs: Artificial Intelligence and multi-brain connectivity as a buddy to enhancing competencies in students."

Ethics declaration: Informed consent was obtained from all participants and, where applicable, from their parents or legal guardians in accordance with institutional ethical guidelines. All data were anonymized and handled in accordance with applicable data protection regulations. This study was approved by the Bioethics Committee at the University of Turin on 21 January 2025 with approval number 0173267.

AI statement: The authors used generative AI tools exclusively for language editing and grammar support. All scientific content, interpretation, and final revisions were performed and verified by the authors.

Declaration of interest: The authors declared no competing interests.

Data availability: The data presented in this study are available on request from the corresponding author due to being part of the **Class-tAIs** project.

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