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Trends and Innovations in STEM Education in East Asia: A Comparative Metasynthesis from the Perspectives of China, Japan, and South Korea (2020–2024)

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ABSTRACT

STEM (Science, Technology, Engineering, and Mathematics) education has become a critical focus in global educational reform, particularly in the context of the Fourth Industrial Revolution and rapid technological advancements. This metasynthesis explores the trends and innovations in STEM education across China, Japan, and South Korea from 2020 to 2024, with an emphasis on government policies, pedagogical developments, and the integration of technology. The study systematically reviews and synthesizes existing literature to identify commonalities and differences in each country's approach. China has emphasized project-based learning, AI technologies, and interdisciplinary education. Japan has integrated creativity through STEAM, adding arts to STEM, while fostering innovation with robotics and design thinking. South Korea has focused on STEAM, gender equity, and policy-driven educational reforms. The COVID-19 pandemic accelerated digital and remote learning innovations in all three nations. Despite the varied approaches, the shared emphasis on technology integration, problem-solving skills, and government support highlights the importance of STEM education in preparing students for future global challenges.

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INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education has become a central focus of global educational development, particularly in the era of the Fourth Industrial Revolution and digital transformation. STEM not only provides essential technical skills for technological advancements but also equips students with critical thinking, problem-solving, and collaboration abilities needed to face modern world challenges. The increasing recognition of STEM's importance has prompted educational reforms in many countries, including in East Asia, particularly China, Japan, and South Korea(Li et al., 2019a).

These three nations have emerged as global hubs of technological and economic innovation, and they play a pivotal role in developing effective STEM education approaches. Each country has adopted various strategies to enhance STEM skills among the younger generation, supported by strong government policies and robust infrastructure. For instance, China has launched numerous national programs targeting the integration of STEM into school curricula to strengthen global competitiveness. Japan, known for its technological leadership, has emphasized the importance of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education, integrating creativity and the arts into STEM. Meanwhile, South Korea, with its advanced and rigorous education system, continues to push for innovation in STEM education to stay competitive globally(Li et al., 2019a).

Between 2020 and 2024, the COVID-19 pandemic played a crucial role in accelerating educational transformations worldwide. Online learning and the use of digital technologies have increasingly dominated educational systems, affecting how STEM education is implemented. East Asian countries, including China, Japan, and South Korea, had to adapt swiftly to ensure the continuity of education. These adaptations often involved innovative uses of technology, such as artificial intelligence, project-based learning, and gamification, to engage students in STEM education despite the challenging circumstances. While there is substantial literature highlighting the importance of STEM education in each of these countries, comparative studies that analyze trends and innovations in STEM education across the three East Asian nations remain relatively limited. Therefore, this study aims to review and synthesize the existing literature, specifically from 2020 to 2024, to provide a clearer picture of how STEM education has evolved in China, Japan, and South Korea. By conducting this metasynthesis, the study will identify key trends, implemented innovations, and the similarities and differences in STEM education approaches in these three countries(To Khuyen et al., 2020).

METHOD

This metasynthesis aims to explore and compare trends and innovations in STEM education in China, Japan, and South Korea from 2020 to 2024. The methodology consists of several steps, including literature search, inclusion and exclusion criteria, data extraction, and synthesis of findings. The following sections outline the process in detail.

a. Research Design

The research adopts a **metasynthesis approach**, which integrates and synthesizes qualitative data from various studies to generate new interpretations and insights. Unlike traditional meta-analyses that focus on quantitative findings, this metasynthesis will critically interpret qualitative research and thematic trends found in existing literature. The goal is to provide a comprehensive understanding of the similarities, differences, and innovations in STEM education across the three East Asian countries.

b. Literature Search Strategy

A systematic search was conducted across several academic databases, including **Scopus**, **Web of Science**, **Google Scholar**, and **ERIC**, to identify relevant peer-reviewed articles and conference papers. The search focused on literature published between January 2020 and October 2024, and included sources in English as well as Chinese, Japanese, and Korean.

The following keywords and combinations were used in the search:

- "STEM education" AND ("China" OR "Japan" OR "South Korea")
- "STEM innovation" AND ("China" OR "Japan" OR "South Korea")
- "STEM trends" AND ("China" OR "Japan" OR "South Korea")
- "STEM education" AND ("East Asia" OR "Asia Pacific")
- "Education technology" AND "STEM" AND ("China" OR "Japan" OR "South Korea")

To ensure the literature covered a range of relevant topics, additional searches were conducted using terms related to key innovations, such as "artificial intelligence in education," "gamification in STEM," "project-based learning in STEM," and "remote learning."

c. Inclusion and Exclusion Criteria

The following criteria were applied to select the studies for inclusion in the metasynthesis:

Inclusion Criteria:

- **Published between 2020 and 2024:** Only studies published during this period were included to capture the most recent trends and innovations.
- **Country of focus:** The study must focus on STEM education in China, Japan, or South Korea.
- **Peer-reviewed:** The articles should be from peer-reviewed journals or conferences.
- **STEM education focus:** The studies must discuss trends, innovations, or practices related to STEM (or STEAM) education.
- **Empirical research:** Studies must report on empirical data, either qualitative or mixed-methods research.

Exclusion Criteria:

- Articles focusing exclusively on higher education or non-formal education contexts (e.g., after-school programs) without relevance to formal K-12 education systems.
- Papers lacking substantial discussion on STEM-specific innovations or trends.
- Review articles or theoretical papers that do not present original research findings.

d. Data Extraction and Coding

After identifying relevant studies, data were extracted based on the following variables:

- **Publication year**
- **Country (China, Japan, or South Korea)**
- **Type of innovation or trend** (e.g., use of AI, gamification, project-based learning, integration of STEAM)
- **Educational level** (primary, secondary, or tertiary)
- **Key findings:** A summary of the major outcomes, including impacts on student engagement, learning outcomes, and teacher practices.
- **Challenges and opportunities:** Challenges encountered in implementing STEM innovations, as well as future opportunities or recommendations highlighted in the studies.

The data were organized in a matrix to facilitate thematic analysis and cross-country comparisons.

e. Data Synthesis

A **thematic analysis** was conducted to synthesize the extracted data. Thematic analysis involves identifying, analyzing, and reporting patterns (or themes) within the data. The themes were categorized based on recurring concepts such as:

- **Technological integration** (e.g., AI, virtual labs, and gamification in STEM)
- **Pedagogical innovations** (e.g., project-based learning, interdisciplinary approaches)
- **Government policies** and initiatives aimed at promoting STEM education.

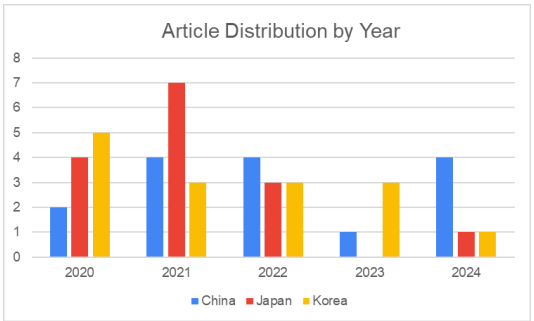
For the comparative aspect, similarities and differences in the trends and innovations of each country were highlighted. China, Japan, and South Korea's approaches to integrating STEM into their curricula, particularly in response to global technological changes and the COVID-19 pandemic, were compared and contrasted.

F. Limitations

The metasynthesis focuses on STEM education in only three countries, which limits the generalizability of the findings to other regions. Additionally, the study relies heavily on English-language sources, potentially overlooking significant studies published exclusively in the national languages of the respective countries. The rapid advancements in technology may also mean that some innovations not yet widely adopted during the study period might be underrepresented.

RESULT AND DISCUSSION

The key findings from the metasynthesis of literature on STEM education trends and innovations in China, Japan, and South Korea from 2020 to 2024.



The chart titled "Article Distribution by Year" presents the number of STEM education-related articles published in China, Japan, and Korea from 2020 to 2024. In 2020, both Japan and Korea published 4 articles each, while China had only 1 article. 2021 saw a significant surge in Japan's output, with 7 articles, marking the highest number of publications across the entire period for any

country. China and Korea maintained steady contributions with 4 articles each. The trend continues to fluctuate in subsequent years, reflecting varying levels of focus on STEM education research in these nations.

Country	Key Themes in STEM Education
China	Engineering design process, STEM project-based learning, AI technologies in education, STEM literacy, gender and subject background in STEM, STEM attitude scale, career awareness, interdisciplinary STEM education, digital game-based learning, educational robotics, teacher professional identities
Japan	STEM conceptual frameworks, AI in STEM education, design thinking in STEAM, transdisciplinary STEM education, remote STEM teaching, gender and STEM talent, historical analysis of STEM education, interdisciplinary teaching, mathematical modeling, STEAM curricula in art education, accessible STEM content, student engagement in STEM
Korea (South Korea)	STEAM program effects, integrated STEM competencies, self-efficacy in STEM, STEM policy, historical integration in STEM, socioscientific issues in STEM education, cognitive load in group work, teacher perceptions of STEAM, aesthetics in STEAM, gender disparities in STEM, classroom-based STEAM, integrated STEM in science courses, female STEM talent development, critical STEM literacy, STEM creative productivity, STEAM policy sensemaking, teacher development in STEM education, engineering design process

The key themes in STEM education across China, Japan, and South Korea highlight each country's unique focus while showcasing some common trends. In **China**, emphasis is placed on the engineering design process, project-based learning, AI integration, and career awareness, with increasing attention to digital tools like robotics and game-based learning(He et al., 2020). **Japan** stands out for its incorporation of design thinking within STEAM, interdisciplinary approaches, and AI in education, blending technical skills with creativity(Dyer-Dyer et al., n.d.). **South Korea** focuses heavily on STEAM, gender equity, self-efficacy, and critical STEM literacy, emphasizing teacher development and policy frameworks(Sulaiman et al., 2024). These themes align with the core findings in the article, particularly the integration of technology, pedagogical innovations, and government policies across the three countries. The shared focus on interdisciplinary learning and AI-driven education demonstrates a collective drive towards preparing students for future STEM careers while addressing country-specific challenges like gender disparities and teacher support systems.

Technology	China	Japan	South Korea
Artificial Intelligence (AI)	Systematic review of AI technologies in STEM education (2011–2021); application of AI in STEM classrooms	Role of AI in STEM education explored in 2021	Not specifically mentioned
Robotics	Not specifically mentioned	Not specifically mentioned	Short-term effects of classroom-based STEAM programs using robotic kits (2023)
Digital Educational Games	Meta-analysis on the effectiveness of digital game-based STEM education (2022, 2023)	Not specifically mentioned	Not specifically mentioned
Design Thinking	Use of design thinking to cultivate future female STEAM thinkers (2021)	Using design thinking to engage students in STEM	Not specifically mentioned

		education (2021)	
STEAM Projects with Technology	Focus on integrating STEM project-based learning with technology; emphasis on interdisciplinary approaches	STEM projects using various technological innovations for problem-solving and design thinking	STEAM projects integrating technology into project-based learning, including robotics and STEAM modules
Assessment Tools for STEM Literacy	Reliability and validity of STEM attitude scale for students (2021)	Not specifically mentioned	Not specifically mentioned
Educational Robotics	Meta-analysis of educational robotics in STEM (2024)	Not specifically mentioned	Not specifically mentioned
Socioscientific Issues (SSI)	Not specifically mentioned	Not specifically mentioned	Incorporating SSI into STEM education to explore argumentation and classroom applications (2020)
Collaborative Technologies	Not specifically mentioned	Not specifically mentioned	Exploring the cognitive load of collaborative group work in STEM (2021)
STEAM Policy and Implementation	Not specifically mentioned	Not specifically mentioned	Exploring stakeholders' sensemaking of STEAM education policy in South Korea (2023)

1. National Policies and Strategic Focus on STEM Education

China:

In China, STEM education has been a focal point of national development strategies, driven by the desire to boost innovation and global competitiveness. During the 2020–2024 period, significant reforms have been introduced to integrate STEM across all levels of education, from primary to higher education. The government has introduced policies that emphasize creativity, critical thinking, and problem-solving skills, which represent a shift from the traditional emphasis on rote learning. Initiatives such as the "New Engineering Education" (NEE) strategy and national STEM curricula reforms highlight China's ambition to cultivate talent in AI, robotics, and biotechnology.

Japan:

Japan's STEM education reforms from 2020 to 2024 have been largely shaped by the "Society 5.0" vision, which aims to integrate advanced technologies into all sectors of society. The Japanese government has placed particular emphasis on promoting science and technology education that fosters interdisciplinary skills, computational thinking, and innovation. Notable initiatives include a significant investment in robotics education and a focus on collaboration between industry and educational institutions to align STEM education with real-world technological applications.

South Korea:

South Korea has implemented comprehensive STEM education reforms aimed at enhancing students' digital literacy, problem-solving abilities, and creative thinking. The "Future Education 2030" vision emphasizes the integration of cutting-edge technologies such as AI, big data, and cloud computing into the STEM curriculum. South Korea has also placed strong emphasis on early STEM education, encouraging hands-on and project-based learning, as seen through its "STEAM" initiative, which integrates arts into STEM education to foster creativity.(Gao et al., 2020a)

2. Innovations in Pedagogy and Learning Approaches

China:

STEM education in China has evolved to incorporate a wide range of pedagogical innovations. Project-based learning (PBL), inquiry-based learning (IBL), and problem-solving-oriented approaches have gained traction, with many schools adopting digital platforms to support remote and blended learning. Online STEM education, accelerated by the COVID-19 pandemic, has led to a surge in virtual laboratories and AI-driven educational tools, offering students more interactive and immersive learning experiences.(Li et al., 2019b)

Japan:

In Japan, the integration of robotics and coding into the school curriculum has been one of the key pedagogical innovations. Coding education became compulsory at the primary school level in 2020, and there has been a steady increase in the use of digital tools and platforms to enhance the learning experience. Collaborative learning models that encourage teamwork, design thinking, and interdisciplinary problem-solving have been central to STEM education reform in Japan.

South Korea:

South Korea has embraced technology-enhanced learning environments, utilizing AI-powered platforms to personalize STEM education for students. Flipped classroom models and maker education, which emphasize hands-on activities, have become increasingly popular. South Korean schools have also integrated virtual and augmented reality (VR/AR) into STEM subjects to create immersive and experiential learning environments, allowing students to engage deeply with scientific concepts(Lin et al., 2021).

3. Role of Educational Technology in STEM Advancements

China:

China has led the region in the deployment of educational technology in STEM education. AI-based tutoring systems, adaptive learning platforms, and big data analytics have been used to track student performance and tailor instruction to individual needs. The rapid expansion of smart classrooms equipped with interactive whiteboards, IoT devices, and cloud-based resources reflects China's commitment to leveraging technology to enhance STEM education outcomes(Dong et al., 2020).

Japan:

Japan has embraced the use of robotics, virtual labs, and digital simulation tools to support STEM education. These technologies have facilitated experiential learning, allowing students to conduct experiments and solve problems in virtual settings. Additionally, Japan has promoted the use of AI in STEM education to analyze student data and provide personalized learning experiences(Chen et al., 2019).

South Korea:

South Korea has been at the forefront of implementing AI-driven platforms that personalize learning, ensuring that STEM education is tailored to meet individual student needs. The integration of IoT devices, digital textbooks, and cloud-based learning environments has transformed traditional classroom settings, making STEM education more accessible and engaging. Government-supported research projects have also advanced the use of educational technologies to improve teaching methodologies and student outcomes(Mun & Kim, 2022).

4. Comparative Analysis of STEM Education Trends

Despite differences in cultural and educational contexts, several common trends emerge across China, Japan, and South Korea:

- **Emphasis on Digital Literacy and Emerging Technologies:**

All three countries have prioritized digital literacy, AI education, and coding as essential components of STEM curricula, reflecting the global demand for tech-savvy professionals(Li et al., 2022).

- **Shift Toward Interdisciplinary Learning:**

China, Japan, and South Korea have all embraced interdisciplinary approaches that blend science, technology, engineering, and mathematics with other fields, such as arts (STEAM) or business, to foster holistic problem-solving skills(Gao et al., 2020b).

- **Increasing Use of Educational Technology:**

The use of AI, virtual reality (VR), augmented reality (AR), and other digital tools has become a central feature of STEM education, enhancing both teaching and learning experiences. This has allowed for greater

customization of learning pathways and the development of interactive, immersive learning environments(Bond et al., 2024).

5. Unique Innovations and Divergence in Approaches

While common trends exist, each country has taken unique approaches to address specific national priorities:

- **China's** focus on creating a robust AI-driven STEM ecosystem is aligned with its broader goal of becoming a global leader in technology and innovation.
- **Japan** has focused on integrating robotics into everyday life, aligning STEM education with its "Society 5.0" vision, which aims to balance technological advancements with social well-being.
- **South Korea** has been a leader in STEAM education, integrating the arts into STEM to promote creativity and innovation, along with strong support for hands-on learning and maker education(Jiang et al., 2024).

CONCLUSION

The metasynthesis reveals that China, Japan, and South Korea have implemented significant innovations in STEM education between 2020 and 2024, driven by national policies aimed at fostering global competitiveness and innovation. Each country has integrated technology, such as AI, robotics, and digital platforms, into their curricula, reflecting their commitment to preparing students for future careers in a rapidly changing technological landscape. China focused on project-based learning and AI integration, Japan emphasized interdisciplinary STEAM education, and South Korea advanced the STEAM initiative, incorporating the arts into STEM to enhance creativity. While these nations share a collective drive toward advancing STEM education, their unique approaches reflect their cultural and economic contexts, highlighting the diverse ways in which STEM education can be adapted to meet national goals. The COVID-19 pandemic further accelerated the adoption of digital technologies, shaping the future of STEM education in these countries.

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