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Policies of STEM Education from the Perspective of International Comparison

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Abstract: *Based on an international comparative perspective, the article compares and analyses the STEM education policies of five developed countries, namely the United States, the United Kingdom, Germany, Finland and Israel. On this basis, the article focuses on China's STEM education policies, and compares and analyses STEM education policies at the governmental level and at the level of educational practices in China and abroad. Finally, the article reveals the shortcomings of China's STEM education policies and proposes specific development paths, with a view to providing references for improving China's STEM education policies.*

Keywords: *STEM Education; Education Policy; International Comparative Research*

1. Introduction

STEM is an acronym for Science, Technology, Engineering and Mathematics (STEM), a highly integrated and interdisciplinary approach to education that has rapidly become a hot topic in international education research. STEM education strategies are an important support for the development of STEM education in each country. Based on this, the article will sort out and compare the STEM education policies at home and abroad to provide some reference value for promoting the development of STEM education in China.

2. STEM Education Policies Abroad

In 2017, China released the White Paper on STEM Education in China, which proposed the "China STEM 2029 Plan" and pointed out that STEM education in China should be developed by drawing on the international experience of developed countries, represented by the United States and Germany. With this as the base, the article intends to select the STEM education policies released by five countries that are at the forefront of STEM education, namely, the United States, the United Kingdom, Germany, Finland, and Israel, and analyze them.

2.1. STEM Education Policies in the United States

STEM education emerged in the United States, and its development can be roughly divided into three stages: STS-STEM-STEAM[1]. In 1986, the report "Undergraduate Science, Mathematics and Engineering Education" issued by the United States was a milestone in its development of STEM education. In 1996, the report Shaping the Future: A Perspective on Undergraduate Education in Science, Mathematics, Engineering, and Technology shifted the focus of STEM education to the K-12 level in response to the national development situation at the time[2]. The year 2006 was a turning point in the development of STEM education in the U.S. The U.S. government released the report "America's Competitiveness Plan", which pointed out that innovation is what leads the world, and that cultivating innovative talents with STEM literacy is the key to global competitiveness. In 2007, the report National Action Plan: Addressing the Critical Needs of the U.S. Science, Technology, Engineering, and Mathematics Education System first articulated STEM education at the K-12 and higher education levels [3]. In 2011, the National Academy of Sciences Research Council published the report "Successful K-12 STEM Education: Identifying Effective Pathways to Science, Technology, Engineering, and Mathematics", which clearly proposed to focus on STEM education issues for special groups such as women and minorities, and established the goal of comprehensively improving STEM literacy of citizens In the same year, President Barack Obama advocated the development of the

"American Innovation Strategy" in "Innovation Education Campaign", mobilizing national efforts to support the development of STEM education[4]. In 2013, the U.S. government issued the Federal Five-Year Strategic Plan for STEM Education to explore how to develop STEM talent and enhance national competitiveness in five strategies[5]. In STEAM 2026: A Vision for Innovation in STEM Education, released in 2016, and in the Presidential Memorandum on STEM Education, signed by Trump in 2017, the U.S. government emphasized increased financial allocations for STEM education and called for community-wide participation in STEM research and learning. In 2018, the U.S. issued the report Charting a Course for Success: a Strategy for STEAM Education in the United States[6], which officially opened the Polaris Initiative to enable U.S. citizens to receive high-quality STEM education and established STEM education as one of the key pathways to lead the nation to success.

STEM education in the U.S. has a more mature system both in terms of policy development and STEM education practice, and is undoubtedly a template for countries around the world to follow in implementing STEM education.The U.S. STEM education policy has been deployed in a targeted manner, with the first phase focusing on undergraduate education, the second phase shifting the focus of STEM education to K-12, and the third phase focusing on special groups such as women and minorities and promoting STEM education for all. In each phase, the U.S. government has provided certain financial allocations and research grants.

2.2. STEM Education Policies in the United Kingdom

In order to improve the UK's international competitiveness and influence, the UK government attaches great importance to the development of STEM education. Not only has a national-level policy been formulated to vigorously promote STEM education, but a National STEM Centre has also been established. In 2002, the report "Science Engineering Technology (SET) for Success" was issued in the UK, which laid a solid foundation for the development of STEM education in the UK. In 2004, the UK released the Science and Innovation Investment Framework 2004-2014, which pointed to the expansion of the focus of STEM education to the quality of science teachers and lecturers. In 2006, the STEM Project Report called for a collaborative approach to STEM education across industries. In 2011, the UK NESTA released the Future Generation report, which advocated the development of STEM+A education and the inclusion of arts and computer science in the Baccalaureate[7]. Since then, STEM education in the UK has officially shifted to STEAM education. In 2014, the report "STEM + ARTS = STEAM" proposed to focus on developing students' problem solving, creativity and analytical skills in order to develop comprehensive talents for the future employment situation[8]. In 2015, NESTA published the report "The Innovation Economy and the Future of Jobs", which pointed out the need to accelerate the shift from STEM education to STEAM education[9]. In 2017, the UK proposed in the Green Paper Building Our Industrial Strategy: to include technical education as a key to the development of modern industry in the UK.

The UK's STEM education policy has undergone a shift from STEM to STEAM, favoring the infiltration of the arts across disciplines and emphasizing the development of people with integrated skills and personalities that enable them to respond effectively to the needs of different environments[10]. Secondly, the UK focuses on the top-level design of STEM education policy and gradually connects STEM education with various sectors of society, jointly promotes STEM education project plans, and seeks to address the skills shortage in the UK through the development of STEM education.

2.3. STEM Education Policies in Germany

The German government has always attached great importance to the cultivation of talents, and in order to cope with the shortage of high-quality STEM workforce, Germany has promoted STEM education through vocational education, and thus promoted the flow of high-quality STEM talents into the job market. In 2008, Germany established the Dresden Resolution, which listed MINT (MINT is the German word for STEM) as the main goal of education, established the "MINT for the Future" alliance between the government and companies, and intensified the teaching of MINT in primary and secondary schools. In 2009, Germany issued the "Recommendation on Strengthening MINT Education", which proposed a series of measures to promote the development of MINT education, such as requiring schools to carry out MINT education in conjunction with extracurricular practices. In 2012, Germany issued the "MINT Vision - A Guide to the Business and Promotion of MINT", pointing out that the federal government's activities should focus on ensuring the quantity and quality of the workforce[11]. In 2019, the German government presents its new MINT Action Plan: Towards the Future in MINT Education, which will invest more funds to address the realities of the MINT

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development process.

Based on the national situation, the German government has used vocational education to promote the development of MINT, focusing on integrating the curriculum with practice and conducting practical courses at the primary and secondary school levels to attract its continuous development along the MINT education chain. The government’s emphasis on "MINT education and lifelong learning" has been prompted by the government’s statement in several reports that "MINT education should be used to fill the workforce gap", with the aim of creating a sustainable MINT education. The main driving force for MINT education in Germany comes from the demand in the labor market, where the shortage of senior skilled workers is so great that ensuring the quantity and quality of the workforce is the focus of the federal government’s activities[12].

2.4. STEM Education Policies in Finland

Between 1996 and 2002, the Finnish National Board of Education launched the LUMA programme (LUMA is an acronym for the Finnish words for natural sciences and mathematics). The original LUMA programme focused on the natural science and mathematics disciplines and is regarded as the cornerstone of the development of interdisciplinary education in Finland. In 2003, the first LUMA Centre in Finland was established at the University of Helsinki to promote LUMA initiatives in science and technology education across Finland[13]. The Finnish LUMA programme promotes the practical implementation of STEM education in two ways. The first is a joint project by the national administration to promote the implementation of the LUMA programme at all levels of education, with the goal of "LUMA for all". The second aspect is the establishment of the LUMA Research Centre, which is responsible for the research, design and implementation of the LUMA programme.

The LUMA programme is the general guideline for the development of STEM education in Finland. Initially focusing on the natural sciences and mathematics, and later covering science, technology, literature and emerging disciplines, the LUMA programme has been continuously expanded and enriched according to the needs of talent development, forming a unique model for the development of STEM education.

2.5. STEM Education Policies in Israel

STEM education is seen by Israel as an important asset in upgrading the country’s science and technology and has been a focus of educational change. In 1953, the Israeli government enacted the National Education Law, which clearly states that education should focus on combining scientific and technological learning with skills training. In 1992, Tomorrow 98: The Report of the Israeli Higher Committee for Science, Mathematics and Technology Education proposed to expand the professional basis of science for students in the field of technology education and to update the relevant curricula[14]. Israel offers courses on STEM at the primary and secondary school levels, requires mandatory military service for high school graduates, conducts STEM education training during military service, and organizes elite training programs related to STEM education.

Due to the specificity of the Israeli national context, the Israeli government does not have an explicit educational policy on STEM. It mainly enacts education laws such as the Compulsory Education Law and the National Education Law through legislative means to guarantee the development of STEM subject areas in basic education from a legal perspective. Israel offers a comprehensive curriculum covering STEM subject areas at the basic education level to foster well-rounded and innovative talent.

3. China’s STEM Education Policy

In 2015, the Ministry of Education proposed the "Guiding Opinions on Comprehensively and Deeply Promoting Education Informatization during the Thirteenth Five-Year Plan (Draft for Comments)" , which stated that new education models such as STEM education and creative education should be actively explored. In 2016, the 13th Five-Year Plan for Education Informatization issued by the Ministry of Education pointed out that emphasis should be placed on interdisciplinary learning, exploring the application of information technology in new education models such as STEM education and creative education, and promoting the all-round development of students. The promulgation of these two documents has provided a direction for the cultivation of STEM education talents in China.

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In 2017, the Ministry of Education released the Science Curriculum Standards for Compulsory Primary Education, which promotes an interdisciplinary STEM learning approach with project-based learning and problem solving to develop students' innovation skills. In June of the same year, the STEM Education Research Center was established, and the Chinese Academy of Education Sciences released the White Paper on STEM Education in China, which systematically analyzed the background, implementation effectiveness, problems and action plans of STEM education in China. In 2018, the "China STEM Education 2029 Action Plan" advocates the integration of STEM education into the national innovation talent training strategy; strengthening the top-level design of STEM education policies; promoting the STEM+ lifelong learning model; and collaborating with all sectors of society to build an integrated STEM education innovation ecosystem. In 2019, the "Mainland-Hong Kong STEM Teacher Training Center" was inaugurated, which will integrate domestic and international research strengths and unite international STEM education training institutions to build a think tank for STEM education research in China.

In response to the Ministry of Education's request, some regions have included STEM education as an educational priority and have introduced relevant policies one after another. For example, the 2015 Shenzhen Three-Year Action Plan for Science, Technology and Innovation Education in Primary and Secondary Schools (2015-2017) requires "vigorous promotion of STEM curriculum, independent research and development of a STEM curriculum system suitable for the needs of Shenzhen students and the interface between primary and secondary schools". It also became the first regional document to pilot STEM education in China[15]. Jiangsu Province has also issued the Notice on the Piloting of Science, Technology, Engineering and Mathematics Education Projects and the Guidance on the Construction of STEM Education Project Schools in Jiangsu Province (for Trial Implementation). Chengdu City has also issued the "Key Points of Work of Chengdu Education Bureau of the Education Work Committee of the CPC Chengdu Municipal Committee in 2016".

Although STEM education in China started late, it is developing very rapidly and is trying to catch up with foreign standards. China's education policy for STEM is becoming clearer and clearer, with the promotion of STEM education mainly being "point by point", with demonstration sites being set up first and then gradually promoted, and the STEM education policy is mainly aimed at the primary and secondary school level, showing the direction for how to train STEM education talents in primary and secondary schools.

4. Comparative Analysis of Domestic and International STEM Education Policies

Given the variability of country-specific conditions, STEM education policies vary at the governmental level and at the level of educational practice in China and abroad, as shown in Table 1.

Table 1: A comparison of domestic and international STEM education policies

Country	Government level	Educational Practice Level
China	National top-level design to guide and coordinate the implementation of STEM	Establishing demonstration sites to lead the way gradually
United States	Building a mature STEM education framework, guiding STEM education implementation, providing financial grants and research funding	Universities lead the way, with 'K-12' as the focus of STEM education, promoting STEM education for all
United Kingdom	Develop a national strategy for STEM education and establish a national STEM centre	Connecting STEM education to all sectors of society and coordinating all parties to promote STEM education
Germany	Government and business build alliances, vocational education to boost STEM development and ensure workforce quantity and quality	STEM education combined with lifelong education to create a sustainable STEM education chain
Finland	Launch of the LUMA programme and establishment of the LUMA Research Centre	Launching a joint project with multiple resources to implement LUMA at all levels of education
Israel	Legislative means to develop education laws to guarantee the development of STEM subject areas in basic education	A comprehensive curriculum covering STEM subject areas and an elite STEM education training programme

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4.1. Government Level

Countries implement STEM education based on their national conditions and ensure the development of STEM through the development of STEM education policies. For example, China has elevated STEM to the level of national strategy and established a STEM education research center to guide and coordinate the implementation of STEM education in various regions. The US government has developed an ambitious blueprint for the development of STEM education, gradually building a mature STEM education framework and investing at least US$200 million per year in learning and research in STEM subjects. The UK has developed a long-term strategic plan for STEM education and established a National STEM Centre to coordinate and develop STEM education in the UK. The German government and companies have established the "MINT for the Future" alliance to promote MINT through vocational education, thus ensuring the quantity and quality of the German workforce. Finland has implemented the LUMA programme and established the LUMA Research Centre to build a nationwide STEM education network through major projects. Israel has enacted education laws through legislative means and focused on funding for basic education to guarantee the development of STEM subject areas in basic education. In summary, governments have played a leading role in STEM education policies, focusing on national top-level planning and strengthening the development of STEM education by setting up institutions or organizations related to STEM education.

4.2. Educational Practice Level

Based on the general layout of the government at the macro level, countries make further refinement of STEM education policies at the level of educational practice. For example, China's STEM education focuses on the primary and secondary school levels, while some provinces have started pilot runs to gradually build a STEM education demonstration base covering the whole country with a point by point approach. In the US, STEM education is first implemented at the tertiary level and then shifts its focus to the K-12 level, with a strong focus on the articulation and coordinated development of all school levels and the promotion of STEM education for all. The UK focuses on aligning STEM education with all sectors of society, coordinating all parties to promote STEM education, and establishing a national science learning website for STEM teacher training, requiring teachers to have STEM professionalism. STEM education in Germany emphasizes the integration of curriculum and practice, attracting students at the primary and secondary levels along the MINT education chain, with the aim of creating a sustainable STEM education chain. The Finnish government has initiated joint projects with multiple resources to encourage community organizations to share their expertise and to reach all students with STEM education so that they can integrate multidisciplinary knowledge to solve real-world problems. In Israel, a comprehensive curriculum covering STEM subjects is offered at primary and secondary school levels, and elite STEM education training programs are offered to enhance students' professional training in STEM fields. In general, STEM education policies at home and abroad have been refined to varying degrees at the practical level, covering basic education, higher education and vocational education.

5. Conclusions

5.1. Shortcomings in China's STEM Education Policy

Looking at the STEM education policies of various countries, we can see that the promotion of STEM education requires top-level design at the national level. There are only two authoritative reports on STEM education policy in China, namely the Report on the Development of STEAM Education in China and the White Paper on STEM Education in China, and the two reports have not reached a unified discourse system[16]. Although China has proposed a national-level action plan, fundamental issues such as how to build a STEM-related curriculum system and how to build a STEM teacher workforce have not been addressed, which will largely hinder the development of STEM education in China. At present, STEM education policies in China are more focused on the basic education level, and the elementary school level is the focus of STEM education, and each school level is separated from each other, and there are problems such as curriculum content cannot be connected. The STEM education policies for higher education and vocational education levels are relatively lacking.

While STEM education is growing rapidly, it may also be putting China in a difficult position. At present, China's STEM education policy mainly tends to focus on how STEM is applied to education, and there is the phenomenon of labeling in the process of practice, pursuing the simple combination of

STEM and education, paying too much attention to the external forms of activities and ignoring the essence of STEM education. Once STEM education becomes formalized, its mission of cultivating innovative talents will be difficult to get off the ground.

5.2. The Development Path of STEM Education Policy in China

STEM education policies need to clarify the specifics of the subject status, curriculum and teaching format of STEM. The Israeli government has clear and specific curriculum arrangements for each stage of STEM education, such as natural science, mathematics, social science, arts and crafts and agriculture in primary school, a comprehensive curriculum in junior high school, and two types of academic and vocational-technical courses in senior high school. China can learn from Israel's experience and introduce more specific STEM education policies, so as to provide a policy basis and concrete guidance for the cultivation of STEM talents in basic education.

The coverage of STEM education policies should involve all school levels of education as much as possible. The US STEM education policy covers all levels of education and focuses on the coordinated development of all levels of education. A good articulation mechanism is established between the different levels of education to form an integrated STEM curriculum, enabling students to master STEM skills in a systematic way. In contrast, STEM education in China is mainly focused on the basic education level, and the primary level is the focus of STEM education. Based on this, China's STEM education policy needs to be based on the nature of education and consider how STEM can be integrated across all levels and categories of education, especially higher education and vocational education. STEM education policies should be tailored to different levels of education to further promote effective articulation between them.

STEM education policies should address the STEM competencies of teachers. In the UK, STEM teacher training has been developed and a national science learning network has been set up with online learning modules for STEM professional teacher development. Finland's LUMA Centre has developed online courses for STEM teachers to meet the requirements of professional training for STEM teachers. In view of this, China can introduce relevant policies to establish "STEM teacher training centers" in each province to provide realistic training and immersive learning for STEM teachers and fundamentally guarantee the quality of STEM education.

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