Creative Education, 2024, 15, 2111-2130
https://www.scirp.org/journal/ce
ISSN Online: 2151-4771
ISSN Print: 2151-4755

Research on Capacity Fostering of STEAM Education's Cluster Innovation Ecology for Students in New Business Specialties

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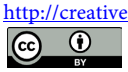
How to cite this paper: Fu, S. J., Fu, Y. T., & Zhang, A. (2024). Research on Capacity Fostering of STEAM Education's Cluster Innovation Ecology for Students in New Business Specialties. *Creative Education, 15,* 2111-2130.
https://doi.org/10.4236/ce.2024.1510130

Received: September 22, 2024
Accepted: October 25, 2024
Published: October 28, 2024



Abstract

With the rapid development of information technology in the world, STEAM education (science, technology, engineering, arts, and mathematics) has become an important field of educational innovation. Based on the grounded theory, this paper previously makes a systematic investigation of STEAM education in developed countries; thereafter, summarizing their development characteristics which include strong policy support, extensive social participation, advanced educational model innovation, and perfect evaluation mechanism. In the following, this paper analyzes the present situation of STEAM education in China, especially in Chongqing municipal. By utilizing the grounded theory and the comparative investigation method, it gets the characteristics and shortcomings of Chinese STEAM development. Finally, given the future innovative development of STEAM education in China, especially in Chongqing municipal, this paper puts forward some policy suggestions on the cluster innovation ecology of STEAM education, which contains strengthening the strategic position and policy guarantee of STEAM education, optimizing the project management of STEAM teacher training, promoting the design and development of STEAM curriculum, as well as improving the STEAM evaluation system and relative standards.

Keywords

STEAM Education, Educational Cluster Innovation Ecology, Capacity Building, Grounded Theory

1. Introduction

With the rapid expansion of the digital economy in the world, the demand for

educational innovation is also increasing. Against this background, STEM education (science, technology, engineering, and mathematics) has gradually become a main force to promote educational innovation. The ideology of STEM education is to encourage students to expand in the fields of science, technology, engineering, and mathematics, and to cultivate students' synthetic quality and innovative ability, so as to improve their professional competitiveness (Zhang et al., 2022). In 2007 year, Dr. Yakman introduced the STEAM concept (science, technology, engineering, arts, and mathematics) by incorporating the humanities and social arts into STEM education as it only focuses on the cultivation of professionals in science and engineering (Yakman, 2007). The STEAM concept is a problem-oriented interdisciplinary knowledge integration as well as an advanced teaching model. This concept was developed to deal with the increasing international competition and the rapid changes in social demands and also reflects the importance of integrating science, technology, engineering, arts, and mathematics education.

The earliest STEAM educational initiative was put forward by the American government. In 1986 year, the American National Science and Technology Council (NSTC) published a document called Undergraduate Science, Mathematics, and Engineering Education, which put forward a guiding recommendation on the integration of science, mathematics, engineering, and technology. This document is seen as the beginning of STEAM education in the United States. In 1996 year, the American National Science Foundation (NSF) further emphasized the importance of teacher fostering problems in STEAM education. STEAM education was in its infancy from 2006 year to 2007 year, when the United States launched a series of programs to promote STEAM talent development, such as the American Competitiveness Initiative, the America Competes Act, etc. During 2009 year and 2011 year, the United States government increased its funding for STEAM education and launched an American Innovation Strategy. These policies enhanced collaboration in STEAM education among the public education institutions and the private sectors. During 2012 year and 2015 year, the United States committed to training more and more STEAM teachers, meanwhile, it also committed to integrating computer science into STEAM education to reinforce the role of information technology (IT) in the STEAM concept.

The STEAM education started relatively late in China. In 2014 year, the Shanghai STEAM Cloud Center was established, and it was the first STEAM education platform in China. In 2017 year, the STEAM Education Research Center was established by the Chinese National Academy of Educational Sciences (CNAES). Subsequently, the first Chinese STEAM Education Development Conference released a document called the Chinese STEAM Educational White Paper in 2017 year. In the same year, CNAES also published another document called the STEAM Teacher's Competency Rating Standards. In 2018 year, CNAES took the lead in launching a program of Chinese STEAM Educational Innovation Action Plan till 2029 year, which was to build STEAM development models in different regions. In the same year, Chongqing municipal held a conference on the first Innovative Action Plan of Chinese STEAM Educational Seed Teacher Training till

2029 year. In 2019 year, the third Chinese STEAM Development Conference held an in-depth exploration of key issues such as breaking the bottleneck of STEAM curriculum shortage as well as teacher shortage, building a STEAM educational ecology characterized by integrating STEAM education and discipline teaching, etc. In 2021 year, the 4th Chinese STEAM Development Conference explored the new STEAM educational ecology and proposed an integrated fusion way to innovative scientific research, learning, and teaching study.

By employing the systematic science and the grounded theory (Gibson & Hartman, 2014; Bertalanffy, 1969), this paper previously investigates the development of STEAM education both at home and abroad; and then analyzes the development trend of STEAM practice in developed countries and the characteristics of STEAM practice in China, especially in Chongqing municipal. Situated on these results, this paper puts forward some policy suggestions on the STEAM educational cluster innovation ecology, aiming at cultivating the innovative ability of new business talents in China.

The following work is organized: Section 2 explores the characteristics and trends of STEAM education in main developed countries. Section 3 previously does a comparative analysis of STEAM education between China and developed countries, and then analyzes the characteristics as well as shortcomings of STEAM education in China. To promote STEAM education development in Chongqing municipal, a detailed STEAM status and features in this region are also explored in section 3. Based on the above work, section 4 elaborates a series of policy suggestions to construct the STEAM educational cluster innovation ecology. Finally, a brief conclusion is summarized in section 5.

2. Characteristics and Trends of STEAM Education in Developed Countries

2.1. America

The United States has adopted a variety of combination strategies to implement the STEAM educational ideology. These combination strategies not only include policy support and financial investment but also involve innovative reform of the education system and active cooperation of all sectors of society. The development of STEAM education in the United States emphasizes the integration of cross-disciplines, the connection between knowledge and the real world, the student-centered pedagogy, as well as the cultivation of future innovative talents.

2.1.1. Creating a Social Environment for STEAM Education Development by Issuing Relevant Laws and Policies

The United States has enacted a series of STEAM education-related bills, in other words, through legislative instruments to support the development of STEAM education. The America Competition Act issued in 2007 year emphasizes that educational innovation requires strong research and development (R&D) investment as well as effective implementation of the STEAM program. Under the American Competes Reauthorization Act of 2010 year, the U.S. government organized a

STEAM education committee (CoSTEAM) to coordinate federal programs and activities, and to study labor market demand and STEAM education at each stage (Ding, 2015). The America Competes Reauthorization Act of 2010 year contains a number of provisions for STEAM education, which has greatly increased the confidence in STEAM education at all levels of American society. They generally agree that STEAM development will help strengthen the U.S. position in the global science and technology race. In 2012 year, the United States launched a Ten-Year Plan for New Technologies in Education, which aims to train 100,000 outstanding STEAM teachers to ensure that one million STEAM graduates will be fostered over the next decade. In 2018 year, the government released a document called Mapping the Road to Success: STEAM Education Strategy for the United States, which aims to promote STEAM competency among Americans, promote fairness, openness, and inclusiveness of STEAM education, and supply more and more STEAM professionals for American society.

2.1.2. Promoting the STEAM System Construction Based on the Characteristics of American Education

Although the American education system is decentralized, its STEAM education has a clear educational goal. The federal government is responsible for coordinating the STEAM research and awareness-raising activities to promote an atmosphere in society to value STEAM education. The STEAM education system includes participants from all sectors of society such as students, teachers, parents, and other stakeholders. The public and community participate in the STEAM education construction and jointly focus on the various needs of the STEAM education project, which greatly promotes the development of STEAM education. The education system in the United States values students as an independent individual, holds a student-entered ideology, emphasizes fostering student's initiative, creativity, and practical ability, and encourages students to solve real problems through teamwork. In 2012 year, the U.S. government also launched a special teacher training program. It aims to train an elite group of qualified STEAM teachers, to highlight the important role of outstanding teachers in STEAM education, to enhance the professional, scientific and teaching capabilities of teachers, and to provide the first-tier human resources support for American society.

2.1.3. Guided by National Strategy, Multi-Department Coordinately Promoting the STEAM Education

In the process of STEAM education development, the government realizes that all social forces and organizations are extremely important. STEAM education development is not only the responsibility of schools and educational departments but also the responsibility of the whole society. The U.S. government, in collaboration with various federal departments and agencies, has mobilized the whole society to jointly promote the popularization and development of STEAM education, especially cooperation with enterprises. Basically, the power of enterprises has greatly promoted the STEAM education development in the United States. In addition to the coordinated efforts of various departments at home, the U.S.

government is also actively promoting communication and cooperation with other countries and regions in the field of STEAM education through international cooperation and communication activities, such as the STEAM Camps Program, etc. These activities not only facilitate the sharing of knowledge and experience but also help participants keep abreast of the latest international trends in STEAM education.

In addition to federal agencies, other stakeholders such as businesses, social organizations, and individuals are actively working on promoting the STEAM education development. Social organizations and groups act as bridges to link government, community, and school. In consequence, the diversification of social investment provides strong support for STEAM education development. Companies provide a large amount of information technology (IT) and material support for STEAM education. For example, companies manufacture innovative teaching tools for STEAM education practices to improve teaching efficiency and learning interest. Hosted by 100 business elites and celebrities, the Equation for Change Program mobilizes American business people to use their unique resources as well as influence to drive STEAM education development.

America has adopted a diverse combination of strategies to promote and implement the STEAM educational ideology, including policy support, education training, teaching method innovation, international cooperation, the application of science and technology, etc. These efforts not only help enhance students' innovative and entrepreneurial ability and comprehensive quality but also make an important contribution to STEAM education in the world.

2.2. European Union (EU)

To promote the transformation to digital education, the EU has constructed an action system from the individual and school levels to the national and EU levels and established guidelines on the transformation, which aims to build an efficient digital education ecosystem and improve skills and digital literacy. To solve the problem that students can not effectively utilize the STEAM multidisciplinary knowledge to solve real problems (Roger et al., 2017), in 2020 year, the EU launched an innovative policy experiment called Assessment of Transversal Skills in STEAM.

2.2.1. Introducing Legal Policies to Encourage STEAM Course Development

In promoting STEAM education, the EU has developed a series of legal policies to deal with the contradiction between demand growth and supply shortage in the labor market and to solve the problem of improving educational effectiveness caused by systemic factors, which is difficult to be solved in a single country. The report of Science and Innovation Investment Framework from 2004 to 2014 Year, issued by the Department of Education and Skills of Britain in 2004 year, has greatly increased the status of science and mathematics in the education system. The German MINT education (Mathematik, Informatik, Naturwissenscha, Technik) is closely tied to the vocational education sector and aims to attract excellent students to further study mathematics, information, natural science and technology,

and seek jobs in the relevant industry. In 2011 year, the European Commission (EC) published a document called Science Education in Europe: National Policy, Practice, and Research, which emphasizes that fostering science consciousness and innovative spirit for citizens is an important objective of innovation education in Europe. In 2017 year, the EU implemented a program of European Digital Education Action Plan, which is marked as a new stage cornerstone of EU education digital transformation.

2.2.2. Adapting to Educational Modernization, Focusing on Development and Evaluation of Digital Literacy for Students

In terms of the development of digital literacy for students, the EU proposes to embed the contents of digital teaching methods and digital teaching innovation into the whole process of pre-service teacher training as well as the field of teacher's professional development and to carry out teacher training program through the European Digital Education Center (EDEC) and other institutions. EU takes basic digital literacy as the core transferable skill for students and sets the action on developing a Universal Digital Skill Certificate (UDSC) based on the EU citizen digital literacy framework.

To effectively evaluate the gains of students and teachers in the process of STEAM education, the digital transformation of the STEAM evaluation system came into being. The digital learning environment not only enhances the teacher's evaluation ability of STEAM education but also provides information technology (IT) support for students to participate in the evaluation process. Students may use the digital evaluation system to clearly understand their weaknesses in the learning process, and precisely improve learning effectiveness.

2.2.3. Promoting STEAM Digital Education to the Direction of Popularization

Concerning digital equipment utilization and network construction, there is a clear gap between low-income and high-income countries in EU member states. To address this problem, EU actively invests in information networks, digital devices, as well as online learning platforms, furthermore, it also provides considerable financial support to member states through a variety of projects (Cui & Shong, 2023). In 2014 year, the Royal Society of Britain published a document called Vision for Science and Mathematics Education, which laid out a road map for education reform in the U.K. over the next 20 years. The document recommends extending the science and math education of students to 18 ages (Liang et al. 2019). From this point of view, we can see that the British government emphasizes the continuous development of mathematics and science literacy from primary school to university, and attaches great importance to the development of STEAM campus culture and STEAM career awareness.

As early as 2000 year, EU has adopted a series of policy documents such as the Lisbon Strategy, which called for the development of an innovative knowledge economy characterized by the internet and digitization. In Britain, while government promotes the STEAM education, it also focuses on the utilization of modern

information technology (IT) to improve the quality and efficiency of traditional education. In 2017 year, the EU launched a program called the Digital Education Action Plan, which aimed to use digital tools to transform the traditional education model. Through the introduction of modern wireless communication technology such as artificial intelligence (AI) teaching systems, online learning resources, and virtual laboratories, students can learn something in a more flexible environment. The program places special emphasis on promoting the development of student's innovative thinking and creativity through digital education. Through interdisciplinary project learning and practical activities, student learns how to use modern scientific and technological means to solve real problems, thus, gradually growing into innovative talents whose ability meets the future economic and social development needs (Shantian & Zhang, 2019).

2.3. Australia

In recent years, the Australian government and academic organizations issued a series of policies to promote STEAM education. These policies are mainly affected by factors of the Australian political system, technological development, gender differences, etc., furthermore, policy actors also have a diverse characteristics. The main content of these policies involves mechanism design, resource allocation, teaching and learning optimization, but mainly focuses on resource allocation. Given policy implementation, these policies adopt a project-based approach, also, focus on inheritance and innovation (Zheng & Gu, 2021).

2.3.1. Developing Strategies at the National Level

In 2014 year, Australian government recognized the importance of investing in STEAM education, hence, it required schools to train their STEAM teachers and recruit more and more STEAM students (Ma & Jia, 2021). In 2015 year, the Department of Education of Australia released a document called the National STEAM School Education Strategy from 2016 to 2026 Year, which lays out the purpose of STEAM education at the national level. Furthermore, this document also clearly lays out the objectives of STEAM education in schools, which aims to ensure that all young Australians have the STEAM knowledge and skills supporting their success in careers. Released by the Australian Association of Engineers, the document titled The National STEAM Strategy from 2019 to 2023 Year, highlights the importance of STEAM skills for national productivity as well as for individual career success and requires to improve the quality of teacher training related to STEAM disciplines. Meanwhile, the Australian government encourages to cultivate good partnerships between schools and businesses to enable students applying what they have learned to real work. Through internships and other ways, school can foster more and more outstanding STEAM business persons to meet the requirements of enterprise development as well as national economic development.

2.3.2. Expanding the Learning Space and Providing a Comprehensive Test on the Learning Process

STEAM education in Australia is actively expanding student's learning space,

increasing opportunities for extra-curricular learning, and encouraging student to actively participate in all kinds of informal STEAM projects. In this way, a student may form his (or her) own critical thinking in the project implementation process. The government has implemented several STEAM programs for different ages and stages of education, such as the Primary Education Linkage Program, the Digital Technology Challenges and In-depth Understanding of Program Codes, etc. These programs aim to stimulate students' learning interests and enhance their STEAM ability through practical activities.

To understand a student's academic performance and the dynamic learning gap between students, Australian government has developed a "Third Generation Assessments" programme based on the socio-economic background of students. The program applies the methods of practical ability assessment, simulation technology, and interactive assessment to the teaching process, which aims to effectively evaluate students' core skills and provides teachers with real-time feedback on students' STEAM learning effect. Teachers can provide effective interventions to address students' performance weaknesses in time, so as to actively improve STEAM learning outcomes of students with weak performance (Loudon, 2019).

2.3.3. Promoting Interdisciplinary Integration through the Discipline Correlation Model (DCM) and Discipline Project

Australian scholars Timms et al. (2018) proposed a novel STEAM discipline correlation model (DCM). The model takes problem solving as the primary goal of STEAM ideology and emphasizes the shift from knowledge learning to interdisciplinary thinking training. However, this shift does not mean that knowledge can be neglected, rather, it is a shift from learning the tedious course matter to the use of interdisciplinary thinking. In addition to the DCM model, Australian government also implements a program called the STEAM Connection Project. It designs all kinds of diverse and subject-based projects according to specific questions and student's interests. In the process of project operation, STEAM teaching methods are comprehensively used to construct the potential relationship among STEAM disciplines.

2.4. Japan

In 2018 year, the Japanese government issued a document called the Third Phase of the Basic Plan for Education Revitalization, which put forward the STEAM educational ideology and developed relevant test indicators (Zheng & Gu, 2021). It has greatly contributed to the reform of university education. From 2016 to 2020 year, Japanese R&D investment budget for STEAM education accounted for more than 4% of GDP (Ma & Jia, 2021), which indicates that the Japanese government attaches great importance to STEAM education.

2.4.1. Enhancing International Cooperation

In recent years, the rapid development of artificial intelligence (AI) has greatly changed the traditional knowledge learning system, and the application of

modern science and technology has brought a profound impact on knowledge innovation. To effectively deal with the socio-economic challenges in the future, advocating global cooperation is an important trend. By strengthening international cooperation, more STEAM students may be fostered in a timely way. In the STEAM education research in Japan, STEAM-robotics provides a new model for STEAM international cooperation (Zhang, 2015). This new model not only facilitates access to broader and more effective data but also expands student's visual horizons in the process of indirect communication, as a consequence, it enriches and develops STEAM education in Japan. Meanwhile, this new model may help strengthen inter-regional cooperation, thus, relieving the imbalance problem in educational development among each region.

2.4.2. Setting an Educational Policy Ideology Characterized as a Practical, Fair, and Systematic Guideline

The STEAM education in Japan emphasizes the educational ideology of pragmatism, which holds that education is life and school is society. Therefore, the STEAM test indicators are also situated on the actual needs, and the ultimate goal of test is to enhance Japanese international competitiveness in science and Technology. Meanwhile, in order to promote society development, Japanese STEAM education pays great attention to the ideology of educational equity, and changes the traditional concept so that women and lower social status people also have the opportunity to participate in STEAM education and jointly promote STEAM workforce training. Japanese government recognizes that STEAM education requires coordinated efforts of many parties in society, hence, it designs and implements STEAM policies in a unified planning way so as to ensure the effectiveness of STEAM policy.

2.4.3. Promoting the STEAM Classroom Teaching Reform

Japanese government sets the goal of STEAM education as the development of qualifications and skills, with the main teaching principle being student-centered idea. Japanese education reform respects students' center status in the teaching process and encourages interaction and communication between teachers and students. This kind of teaching method helps establish an equal and open learning environment and encourages students to cultivate the habits of critical thinking and creative thinking. In order to comprehensively evaluate student's STEAM learning outcomes, Japan established a diversified learning evaluation system, which not only focuses on students' knowledge mastery, but also pays attention to their innovative ability, team spirit, and other aspects of performance.

When carrying out the STEAM practice activities, Japan does not simply complete the specific practice activities. The organizer will adopt a closed-loop management mode to test the specific effectiveness at the end of the practice activities to achieve a virtuous circle of practice activities and evaluation feedback.

2.4.4. Strengthening Teachers' STEAM Professional Development

To enhance teachers' STEAM capacity, the Japanese government has increased

investment in teachers' professional development and organized various forms of teacher training projects. These projects aim to help teachers master the latest STEAM education theory and teaching methods, and improve their teaching level and professional quality. On the other hand, the government also encourages cooperation and communication among teachers, through sharing of teaching resources, experience, and tactics to jointly improve the teaching quality of STEAM education. Of course, this kind of cooperative spirit helps to form a positive teaching atmosphere and promote the overall improvement of teamwork.

2.5. Development Characteristics of STEAM Education in Developed Countries

2.5.1. Strong Policy Support

Policy guarantee is the foundation of STEAM education. Every country has made corresponding policies according to the actual demand of its STEAM education. In America, the policies to promote the development of STEAM education are the most systematic: from defining the national strategic position of STEAM education to defining the requirements of STEAM school education to strong financial support, broad public participation, as well as the introduction of specialized talent strategies, a series of policies have been formulated in each stage of STEAM education development (Chen et al., 2017). For example, to encourage greater communication and cooperation between schools and businesses, the U.S. government has developed a program called the Labor Skills Action Plan for the American Future. It was designed to cultivate the STEAM workforce in an industry-oriented development way (Li, 2014). With such a perfect system support, American STEAM education is developed effectively and steadily,and also becomes a paradigm for STEAM education in many other countries.

2.5.2. Extensive Public Participation

Every country has a comprehensive guarantee from government organizations in STEAM education. The government plays a key role in STEAM education, which is the basis for its healthy development. American STEAM education has become a paradigm for the rest of the world, the reason is that it is a systematic engineering that involves all kinds of forces such as the federal government, congress, social groups, and the public, showing a high degree of unity (Zhu & Kong, 2008). The U.S. government takes the STEAM education as a sustainable human resource strategy for science and technology development, and requires each organization to work closely together to form a strong organizational safeguard.

Schools and enterprises cooperate closely under the active guidance of the government, then, STEAM education is implemented collaboratively by non-governmental organizations (NGOs) and the government. In 2009 year, the U.S. government implemented a program called the Teaching Plan for Innovation, which emphasized the involvement of NGOs to promote the development of STEAM education (Li & Wang, 2018). Germany NOGs create a series of public funds and scholarships to promote MINT education. In Britain, science education in schools

is encouraged, and STEAM courses are funded by all kinds of public projects and activities. The STEAM vocational communication platform has been established by the Australian federal government through a partnership between schools and businesses. In 2015 year, Australian government issued a document called the National Innovation and Scientific Process, which aims to appropriate a total of $112 million to improve the digital literacy and STEAM skills of all people. Under the NGOs' support, a state-led collaboration platform of STEAM education has further promoted efficient cooperation among schools, industries, and the Ministry of Higher Education.

2.5.3. Innovation of Educational Model

Each country has carried on some degree of educational model innovation when training STEAM professional talents. Germany increases the extra-curricular campus experiments through curriculum integration and, correspondingly, implements feedback evaluation. In Britain, programs and activities related to STEAM education are relatively diverse in content, allowing students to increase their STEAM literacy in an interesting and relaxed atmosphere, develop their creativity, skills, and problem-solving ability, and increase their job interest in STEAM-related fields. Japanese government is inclined to strengthen STEAM education through traditional education reform and sending students to the U.S. for exchange and study. In Malaysia, the main approach adopted to favor the STEAM education is concentrated on the curriculum design of school education.

STEAM teachers play a crucial role in the STEAM education, and their professional level determines student's participation enthusiasm, and achievement performance. In Australia, the national strategy clearly emphasizes to support STEAM teaching activities and carries out a national standard for pre-service teacher education, aiming to attract more STEAM graduates to the teaching workforce. The U.S. government proposed a program called the Ten-year Plan for New Technology Education, and one of its goal is to train more and more STEAM teachers. Japan has set up a STEAM elite education fund to strengthen its elite education. In Korea, the government has partnered with the U.S. to set up an organization called the Korea-U.S. Science Cooperation Center to jointly train outstanding teachers in the STEAM field.

2.5.4. Perfect Evaluation Mechanism

To ensure the quality of STEAM education, many countries have established sound evaluation and feedback mechanisms to regularly evaluate the effectiveness of STEAM education, and timely adjust or optimize the current education policy according to the results of the evaluation.

In many developed countries, the evaluation executor of STEAM education has a diversified characteristic, including teacher, student, course designer, representatives of related industries, as well as other stakeholders. Such a diversified evaluation ensures the comprehensiveness and reliability of the evaluation results, and the sustainable development of STEAM education can be realized by the multi-

angle feedback provided by different executors. In addition, the evaluation of STEAM education in developed countries is not only limited to score performance, but also includes student's learning attitudes, and skill development. By doing so, the evaluation results can reflect the impact of STEAM education on students more comprehensively, and help teachers and policy makers better understand the effectiveness of STEAM education, to make a corresponding optimization action. For example, the EU Horizontal Skills Assessment Program has built STEAM's horizontal skills framework in four dimensions: STEAM core competencies, STEAM learning design principles, process and terminal evaluation, and digital tools utilization, to help student solve real-life problems, and to help teacher obtain professional training as well as teaching resources. At the same time, the program will help policymakers to innovate the STEAM digital assessment model and develop an integrated STEAM curriculum. A sound evaluation mechanism not only improves the quality of STEAM education but also promotes educational equity and provides students with equal learning opportunities.

3. Characteristics and Trends of STEAM in China

3.1. A Comparative Analysis of STEAM Education Between China and Developed Countries

Figure 1 shows the annual distribution of paper quantity related to STEAM education in the CNKI database. The result shows that the STEAM education has gradually become a hot topic in Chinese education sector since 2017.

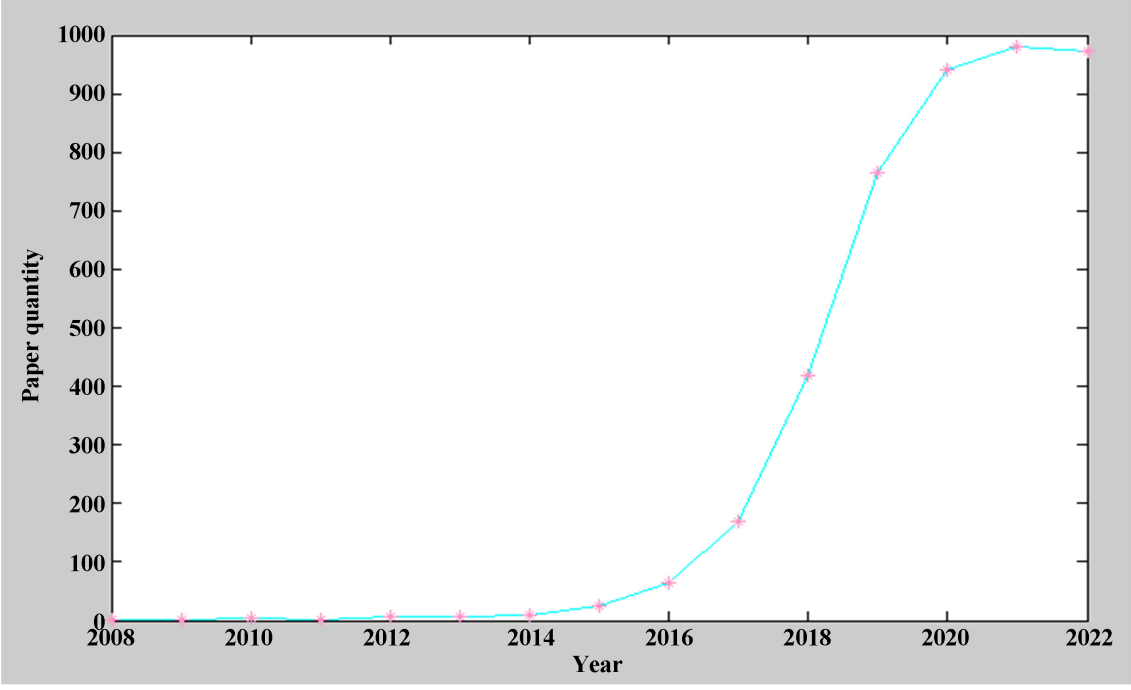


Figure 1. Annual distribution of STEAM educational research papers in China.

Table 1 makes a comparison of STEAM education between China and other

countries. It shows that compared with developed countries, the STEAM education in China still has a big gap. Therefore, China needs to take the initiative to address challenges to education induced by the new round of science and technology revolution. In line with the current situation of STEAM education, China needs to actively explore the STEAM education model for students cultivation and social-economy development.

Table 1. Comparison of the STEAM education features between China and other countries.

Items	China	Other countries
Educational focus	basic knowledge and test-taking ability	innovative ability, critical thinking, and practical application of the curriculum
Curriculum arrangement	relative independent curricula	cross-disciplinary integration, to encourage multidisciplinary integration
Teaching methods	traditional teaching methods, emphasis on memory and training	project-based learning, emphasis on student's initiative exploration spirit and problem-solving ability
Evaluation methods	focus on curriculum test score	comprehensive assessment, including project, report, and teamwork
Teacher's role	imparting of knowledge, the main actor of teaching	the guider and promoter, the student-centered ideology, and encouraging student to learn by self
Innovative technology	increasing emphasis on innovation and technology, but starting relative late	having long attached importance to innovation and technology
Policy support	government has started to support STEAM education in recent years with the introduction of a number of policies	strong policy supports
Society linkage	gradually strengthening the linkage between schools and enterprises, the cooperation pattern is still developing	more matured cooperation pattern between schools and enterprises, more opportunities for student's internship and employment
Social awareness	gradually recognizing the importance of STEAM education, but the prevalence needing to be improved	STEAM education is widely considered to be the key to the development of future talents

3.2. Characteristics of STEAM Education in China

3.2.1. Interdisciplinary Integration

The STEAM education takes science, technology, engineering, arts, and mathematics as an integrated system, and emphasizes an interactive connection and an integrated application of different disciplines. This kind of education model breaks through the traditional discipline boundary, through the project- or question-oriented learning approach, enabling students to integrate multi-disciplinary knowledge and be able to solve the actual problem. At present, the new business specialties efforts in China are highly coordinated with STEAM education which embodies the multi-discipline integration ideology. This multi-disciplinary educational ideology is based on the demand for smart business talents under the

background of the digital economy, cloud business, big data, mobile internet, internet of things (IoT), and artificial intelligence (AI). The new business education model, which is characterized by multi-disciplinary integration and cross-disciplinary reformulation, is constructed through the integration of new business forms, new business models, as well as new technologies. The integrated development of the new business education and the STEAM education further promotes the integration of multi-discipline, which not only adapts to the development of native education in China, furthermore, it also provides a broader application scenario for the STEAM education to integrate the development of related disciplines.

3.2.2. Focus on Innovative Thinking and Problem-Solving Ability

STEAM education focuses on cultivating student's innovative consciousness and critical thinking ability. In the teaching process, teachers often guide students to explore the method of learning, fully respect student-centered status, and stimulate student's curiosity and creativity. STEAM education emphasizes "learning by doing", encourages student to operate, experiment, and create in practice, and promotes deep learning through practical activities. Through project-based learning, STEAM education cultivates students' ability to solve problems in practice, foster creative thinking, and grasp how to face unknown phenomena. In the STEAM teaching process, traditional teacher-centered status is changed into student-centered status, blindly spreading knowledge and ignoring student's practical ability in the teaching process are also avoided. STEAM education adopts an all-around angle to evaluate students' ability, and to understand their ability to independently solve a series of problems between knowledge and practice. Therefore, the STEAM education ideology is in line with the requirements of the new era for talents and is of great significance to global innovative development.

3.2.3. Application of Educational Information Technology

With the rapid development of information technology (IT), STEAM education makes full use of modern technology facilities and network platforms, such as programming software, 3D printers, robot kits, etc. These tools greatly enhance the interactivity of learning and give students a high sense of participation. With the continuous development of IT, digital and online learning has become an important trend in STEAM education, which provides students with a variety of learning resources and up-to-date information. STEAM education makes full use of the internet and digital technology to share online educational resources, providing students with diversified and convenient learning opportunities. At the same time, digital tools also provide more ways to practice and evaluate STEAM education, effectively expanding student's learning space and learning approaches.

3.3. Shortcomings of STEAM Education in China

3.3.1. More Basic Theory Research and Few Practice Activity

Although STEAM education has been widely popularized and accepted in

developed countries in recent years, however, there is still a big gap between Chinese STEAM education and advanced STEAM education in developed countries. In the past decade, the STEAM education research in China has mostly focused on the study of STEAM education policy and its practice in developed countries, as well as the curriculum integration of STEAM education and creator education (Wang, 2021; Li et al., 2019). As can be seen in **Figure 1**, STEAM education is growing year by year, especially from 2015 to 2022 year, STEAM research papers show a rapid growth trend. Despite the rapid growth in the STEAM papers, due to the late introduction of STEAM education from abroad to China, most of the papers are still focused on the basic theory of STEAM education.

The research on the curriculum practice and relevant curriculum development of STEAM education in China is relatively few, and the contents of these papers mainly focus on the combination of STEAM education and creator education. For example, Zhao et al. (2019) have designed a development strategy for the creative curriculum based on the development of core literacy in primary schools and formulated a curriculum goal characterized as a student competency-centered ideology. The literature review also found that some STEAM papers have begun to explore the combination of STEAM education and the advantages of Chinese education, therefore, the STEAM education ideology is gradually fusing into the Chinese education system.

3.3.2. Shortage of STEAM Teacher Training

A comparative study of STEAM teacher development in various countries found that STEAM teacher development in the basic education stage directly determine the quality of STEAM education (Sun et al., 2018). The United Nations Educational, Scientific and Cultural Organization (UNESCO) believes that improving the quality of teachers should be a priority for every country. At present, the professional background of teachers in China is relatively isolated, mainly physics, mathematics, IT, and other professional discipline teachers, in contrast, they do not have an integrated STEAM professional knowledge reserve. However, the STEAM education involves many fields such as science, technology, engineering, arts, and mathematics. There is still an extensive space for Chinese teachers to develop these comprehensive knowledge structures. Fortunately, China has begun to set policies related to STEAM teacher training. In 2019 year, Chinese National Academy of Educational Sciences (CNAES) officially launched a program called the Chinese STEAM Teacher Competency Testing and Rating System, which is a milestone in the field of STEAM teacher training in China. In the future, Chinese STEAM teacher training will develop in the direction of systematization and professional integration, which will provide necessary teacher guarantees for cultivating more and more innovative talents to meet society's needs.

3.3.3. Inadequate Study of All-Around Evaluation System

As a systematic educational ideology, STEAM education needs timely evaluation and feedback according to its implementation and effectiveness, to better promote

the implementation of STEAM curriculum. It is difficult to obtain the true and reliable learning state of students only by quantitative analysis of curriculum scores, therefore, a systematic and comprehensive evaluation system is needed to test the true ability level of students. In China, there is still a lack of relevant research in the systematization evaluation of STEAM education. As described in section 2.5.4, the research on STEAM education evaluation in developed countries is relatively perfect. Therefore, China may first make full use of the existing STEAM measurement system in developed countries, and then gradually establish a series of native education evaluation systems according to the actual situation of different regions in China.

3.4. Current State and Characteristics of STEAM Education in Chongqing Municipal

In recent years, the STEAM education has developed very quickly in China, and many provinces have joined the process of STEAM education construction. In 2023 year, the Chongqing municipal government proposed a program called the 33618 Manufacturing Revitalization Plan, which aims to adapt to the global economic changes as well as the trend of modern science and technology and build a modern manufacturing cluster system. This program emphasizes the importance of STEAM education and provides a macro-policy environment to support the practical activities and innovative development of STEAM education.

Through the 33618 Manufacturing Revitalization Plan, Chongqing Municipal has stepped up its efforts to train more and more skilled human resources, especially in the fields of smart manufacturing, new energy, AI, and autonomous driving. On the whole, this is consistent with STEAM education's goal of developing high-skilled and innovative talents. Meanwhile, the industrial upgrading program described in the 33618 Manufacturing Revitalization Plan also provides more application scenarios and experimental platforms for STEAM education, which will further promote the deep integration of industry and education. Also, the 33618 Manufacturing Revitalization Plan provides students with more opportunities to directly participate in real engineering projects, which is highly in line with the STEAM ideology emphasizing on learning for application as well as developing problem-solving ability. Many universities in Chongqing municipal have responded to the plan. For example, the operations research course at Chongqing University of Arts and Sciences is carried out in a data-driven modeling way and emphasizes applying network resources, programming languages, and mathematical models to effectively solve practical problems (Fu, 2020).

The Education Department of Chongqing municipal actively advocates the capacity building of the integration of humanities and social sciences and STEAM curricula. It advocates the project-based learning method, in the process of solving practical problems, a student can experience teamwork and collaboration as well as understanding how to bear social responsibility. The project-based learning method not only improves the professional skills and learning interests of students

in new business specialty but also strengthens their sense of social participation and moral spirit. Therefore, this learning method is beneficial to train more innovative talents to boost the digital economy revolution and the IT universal service.

4. Implications: Construct the STEAM Educational Cluster Innovation Ecology

4.1. Strengthening the Strategic Position and Policy Guarantee of STEAM Education

The STEAM education has been placed in an important strategic position in more and more countries, for example, it has been promoted as an important national strategy in the U.S. and Australia. To meet the demand of the digital economy and modern technology development for STEAM talents, China needs to strengthen the strategic position of STEAM education. Concretely, it needs to formulate appropriate STEAM development strategy based on native conditions and to support and guarantee the priority development of STEAM education by strengthening legislation and optimizing relevant policy systems, including school education, financial support, social participation, talent introduction, etc. The establishment of the strategic position of STEAM education is conducive to the universal participation of the whole society and to the creation of a good learning and communication atmosphere in the whole society, which will undoubtedly greatly promote the development process of STEAM education in China. Meanwhile, the government may take advantage of building close cooperation among all stakeholders to develop the STEAM training project, hence, providing strong organizational guarantee and financial support for the STEAM education development.

4.2. Optimizing the Project Management of STEAM Teacher Training

Developed countries attach great importance to the role of teacher competency in the process of STEAM education development, and have formulated a series of policies for the STEAM teacher's training. STEAM education requires teachers to have the ability of integrating different disciplines and to have extensive professional knowledge. However at present, most of teachers in China are professional in their specialty rather than all-around talents, therefore, China should strive to train more and more STEAM teachers with cross-disciplinary literacy. The combination of theory and practice should be adhered to the training process. Each province as well as each school may organize a team of STEAM teachers following its educational conditions and regularly exchange teaching and research achievements to promote the rapid development of STEAM education.

Recruiting excellent talents and fostering backbone teachers are two main approaches to teacher guarantee for STEAM education. Firstly, the government should promote teacher integration and cross-discipline development, and guide enterprises and schools working together to build a STEAM-specific platform. This platform may provide teachers with rich teaching resources and up-to-date information, and improve their integrated teaching competency. Meanwhile, the

government may actively invest in the STEAM training base to attract excellent teachers and related organizations to jointly promote the priority development of STEAM education in each region. Secondly, STEAM education major should be set up in normal universities to foster and supply STEAM teachers sustainably. Finally, the stakeholders should collaboratively and constantly enhance the teacher training system, organize special seminars regularly, carry out pre-service and incumbent training for STEAM teachers, exchange relevant information in time, and form a cluster innovation ecology for STEAM teacher cultivation.

4.3. Driving STEAM Curriculum Design and Development

At present, STEAM education in China is still facing many challenges. For example, the existing STEAM curriculum design in China only focuses on the teaching form integration, however, the STEAM curriculum development is scattered and isolated in different disciplines, which can hardly promote students' deep fusion learning. It is an important goal of STEAM education to train STEAM talents for future social needs. And the needs of enterprises may well embody the needs of social and economic development. Therefore, the university should actively collaborate with related enterprises to accelerate the establishment of the STEAM curriculum R&D team, realize resource sharing, and promote the design and development of the STEAM curriculum. These works act as a platform for training students to learn to think problem, learn to master knowledge, and learn to create products, as a consequence, enhancing their ability and core literacy. Jiang et al. (2017) regard STEAM education as an ecosystem in the field of biology and deeply analyze its framework as well as interaction among various elements in the system.

4.4. Improving the Evaluation System and Standards of STEAM Education

At present, the evaluation system of STEAM education in China is relatively deficient, so it is urgent to establish a comprehensive evaluation system and standard of STEAM education. The matured STEAM evaluation system should first make clear the general training goal, the main abilities' goal as well as corresponding test indexes. Secondly, the system should be carried out in a diversified evaluation way. The contents should include not only the evaluation of the results but also the evaluation of the process. And the executors should involve the main stakeholders, including teachers, classmates, professionals in the industry, competent departments, relevant enterprises, etc. Finally, the evaluation tool should be scientific and reasonable. For example, the STEAM educational evaluation can be easily implemented by developing a universal STEAM educational evaluation software. Due to the relative lack of research in this area, China may learn from the matured STEAM software evaluation system of developed countries and, in the meantime, gradually form a native STEAM evaluation system as well as developing the corresponding software system to ensure the effective implementation of the STEAM evaluation.

5. Conclusion

With the deepening of the new-round technology revolution, cultivating innovative talents to adapt to future economic and social development is of great importance to every country. This paper explores the implementation path of Chinese STEAM education from the perspective of an educational cluster innovation ecosystem. Based on systematic science and grounded theory, this paper previously investigates the STEAM education development in major developed countries and extracts its characteristics. In the following, based on the current situation of STEAM education in China, especially in Chongqing municipal, this paper employs the grounded theory and comparative investigation method to extract the characteristics and shortcomings of Chinese STEAM development. Situated on these findings, in view of the innovation development of STEAM education in China, especially in Chongqing municipal, this paper puts forward some policy suggestions on cultivating the cluster innovation ecology of STEAM education.

Acknowledgements

This research was funded by the program of Chongqing Association of Higher Education (No. cqgj23100C) and the programs of Chongqing University of Arts and Sciences (No. P2021JG13; No. 210201).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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