2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
ASEE
Paper ID #37138

The constituent elements of STEM education and their respective effect on talent cultivation performance in the unique context of China: A two-stage study

Mr. Guangpei Chen, School of Public Affairs, Zhejiang University and Institute of China's Science, Technology and Education Policy, Zhejiang University

PhD student at School of Public Affairs, Zhejiang Unvisity, China. Research interests lie at innovation policy, college-industry partnership, engineering education. A member of the Association of Chartered Certified Accountants at the UK.

Yingying Qiao, School of Public Affairs, Zhejiang University and Institute of China's Science, Technology and Education Policy, Zhejiang University

Yingying Qiao a PhD candidate at School of Public Affairs, Zhejiang University and Institute of China's Science, Technology and Education Policy, Zhejiang University; Major: Educational Economics and Management; Research Interests: Science and Technology Policy, Higher Engineering Education.

Yiang Yang

The constituent elements of STEM education and their respective effect on talent cultivation performance in the unique context of China: A two-stage study

Abstracts: Imported from the US, STEM education has been introduced to and widely implemented in China for over a decade. Its priority is particularly promoted as China has come to a turning point called “the new development paradigm”, as the supply of high-end talents in hi-tech fields gradually lags behind and thus hinders economic development. In such a context, STEM education has drawn significant attention from scholars and practitioners in China. Extant research leaves two significant lacunae. First, the exact connotation and constituent elements of STEM education in the context of China remain blurred, as it is often confused with other terminologies including college-industry integration and maker education. Second, the implementation performance of STEM education at Chinese higher education institutions remains under-investigated.

To bridge above lacunae, this paper adopts a two-stage study design; Study 1 uses content analysis based on word frequency counts to refine the exact connotation and constituent element of STEM education in China. By coding the archives, including academic papers, policy documents, and news reports, which add up to more than fifty thousand words, it also identifies four major constituent elements - STEM education research, college-industry partnership, interdisciplinary integration, and maker education, which together constitute the very existing form of STEM education in the context of China. Study 2 employ an empirical analysis based on a sample of 36 first-tier universities in China over a five-year period, and investigates the effects of different constituents of STEM education on the cultivation performance of innovative talents separately.

This paper is expected to theoretically and empirically contribute to STEM education in China. First, it delineates the boundary of STEM education and its relationships with other equally-popular concepts in the context of China. Second, as it examines the effects of implementing different STEM education activities on the cultivation performance of innovative talents, it can also provide a reference for policy making.

Keywords: STEM education, college-industry partnership, interdisciplinary integration, maker education, talents cultivation

1. Introduction

Since the “integration of science, mathematics, engineering and technology education” was first proposed in the “Undergraduate Science, Mathematics and Engineering Education” published in the United States in the 1990s[1], STEM education has been formally proposed and gradually known to the public as an emerging mode of training innovative talents. As a new wave of the S&T revolution characterized by digitalization, intelligence, and green innovation surges, STEM education plays an increasingly important role in the supply of innovative talents. STEM education focuses on real issues, adopts interdisciplinary content arrangement, and emphasizes improving students’ ability to apply multidisciplinary knowledge and stimulating creative thinking. Since STEM education is in line with the practical needs of societal development for talent training, it has soon attracted the attention of governments worldwide, especially those of industrialized countries. For example, at the end of 2018, the U.S. Council on STEM Education launched the North Star program to make high-quality STEM education available to all Americans for a lifetime [2]. Since then, the United States has held a series of academic conferences, including the STEM Education Research and Practice Summit, to strengthen the research on the essential characteristics and historical development of STEM education at the theoretical level. Although STEM education originated in the United States, its popularity is not limited to the American continent. Between 2006 and 2011, an inter-ministerial agreement was made in France to provide government finance for women receiving STEM education to narrow the gender gap in STEM education and promote its universality[3]. At the same time, ISSE (International Society for STEM in English), a worldwide education alliance consisting of eight universities (Columbia University, University of Calgary, University of Sydney, Queensland University of Technology, Beijing Normal University, Northeast Normal University, Southwest University and Shanghai Normal University), started the *International STEM in Education Conference* in 2010 to promote international exchange and collaboration in STEM.

China has always prioritized innovation and human resources development and has put forward essential strategies such as strengthening the country through human resources and rejuvenating the country through science and education. Since the 18th CPC National Congress, innovation has been given greater strategic importance in a new era characterized by myriad global challenges, especially[4]. In essence, STEM education is a kind of innovation in the underlying institutional structure. By rebuilding the concept and model of talent training, it can achieve the sustainable output of innovative talents in line with current social and economic development needs. In this context, China has joined the "movement" of STEM education and established the legitimacy of STEM education in the minds of the Chinese public by launching various reform measures at the level of Regulation, norms and cognition. In 2016, China's Ministry of Education issued the 13th Five-Year Plan for Education Informatization, providing policy support for implementing STEM education in China from the regulatory level. In 2017, the China National Institute of Education Sciences released *the White Paper on STEM Education in China*, which summarized the current development of STEM education in China and clarified the future development direction of STEM education as incubators of high-level and application-oriented innovative talents, colleges and universities have gradually applied STEM education theories into teaching practices and reshaped the cultivation system of students' innovation ability by referring to the essential characteristics of STEM education.

However, while several academic papers and practical policies have been produced, two significant lacunae still exist. First, the exact connotation and constituent elements of STEM education in the context of China remain blurred. On the one hand, as an increasing number of new buzzwords such as meta-discipline, design-based learning, and some other localized varieties emerge, the original conceptual boundaries of STEM education are fading. On the other hand, how STEM education practically manifests itself in China is still a puzzle, as scholars and policymakers find it hard to distinguish between policies and practices specific to STEM education and those not. For example, STEM education is often confused with or even equal to some conceptions, such as college-industry integration and maker education, without clearly elaborating on their relationships. Second, as a scheme aimed at cultivating students' scientific literacy and technical skills, whether STEM education has achieved its goal by improving the capacity of Chinese institutions, especially at the higher education level, to produce quality innovative talents in hi-tech fields remains under investigation, as there are few empirical studies examining the effects of the implementation of STEM education on training quality of innovative talents in Chinese education institutions. Furthermore, as both the connotation and constituent element of STEM education are ambiguous, it is barely possible to reduce STEM education to lower dimensions and examine the effects of its different constituents on talent cultivation performance separately. As a result, policies tailored to a specific aspect of STEM education are hard to formulate and implement.

Based on the above, this paper is committed to two research objectives, namely, to clarify the conceptual boundary and existential forms of STEM education in the context of China and to examine the effects of the implementation of STEM education on the training quality of innovative talents in Chinese higher education institutions. To achieve these goals, we adopt a two-stage study design; Study 1 uses content analysis based on word frequency counts to refine the exact connotation and constituent element of STEM education in China. Study 2 carries out the empirical analysis. Using the sample of 36 first-tier universities in China over five years and multiple data sources represented by annual statistics issued by each university, it investigates the effects of different constituents of STEM education on the cultivation performance of innovative talents separately.

2. The Connotation and Extension of the Universal Concept of STEM Education

2.1 Definition of STEM Education Concept

STEM education is short for Science, Technology, Engineering and Mathematics education[5]. It is found that the academic circle has a high degree of convergence on the definition of STEM education and generally regards solving practical problems and integrating disciplines as the core content of STEM education. On the whole, STEM education can be summarized as a kind of interdisciplinary education that is task-driven by real problem solving, based on the learning process, emphasizes the cross-integration of multiple technologies, and takes cultivating talents with comprehensive scientific literacy and creative, practical ability as its fundamental goal[6]. It can be seen that STEM education is not simply an interdisciplinary course formed by combining disciplines in form, nor is it just project-based learning that focuses on practical and hands-on ability[7].STEM education is centred on real problems in real situations[8], and it flexibly uses the knowledge of various disciplines of inquiry learning, has the characteristics of interdisciplinary, real situation and cooperation and communication[9].

2.2 History of STEM education

Historically, STEM education originated in the United States. As early as 1975, Professor Hurd[10] of Stanford University pointed out that the cross-fusion of disciplines made the concept of traditional disciplines no longer have any substantive significance except as the basis for the division of subject courses in schools. In 1986, the National Science Council published a report titled *Undergraduate Science, Mathematics and Engineering Education*, which first proposed the idea of "integration of science, mathematics, engineering and technology education"[11]. SMET, as advocated at this time, was the precursor to STEM. By 2001, the vice president of the National Science Foundation's Education and Human Resources Directorate used the term STEM for the first time in curriculum development[12]. Later, STEM gradually replaced SMET as a general term for the four disciplines[13]。 In August 2007, the U.S. government issued the America Competes Initiative, which allocated $43.3 billion to STEM research and education programs at the federal level. In 2014, Obama signed the 2015 STEM Education Budget, which allocated education funds exclusively to STEM education. In 2015, the United States officially promulgated the STEM Education Act, which mainly planned the new direction of

STEM education from the aspects of teacher training, teaching system, and the combination of society and school[14]. In 2006, Georgette Yakman[15] integrated Arts into STEM for the first time and proposed STEAM education, further enriching the connotation of STEM education.

Since the concept of STEM education was proposed more than 30 years, the United States has promoted the implementation of the STEM education system through the cooperation between the government and enterprises. It has achieved many fruits, including curriculum development[16], teacher training[17], teaching material research and development[18], and evaluation system construction[19]. For example, Project Lead the Way, a large course provider of STEM education in the United States, aims to promote interdisciplinary curriculum and teaching methods through STEM curriculum projects based on activities, projects and problem-solving[20]. By analyzing the implementation process of Project Lead the Way, it is not difficult to see that in the process of promoting STEM education courses in the United States, project-based teaching methods are mostly adopted to build concrete and real situations for students to enhance students' application of multidisciplinary knowledge and improve their comprehensive ability.

3. Study One: the Existing Form of STEM Education in China

As a recent “import”, STEM education in China has not had a long history. In 2016, the Ministry of Education released *the Thirteenth Five-Year Plan for Education Informatization*, which proposed “actively exploring the application of information technology in emerging education models such as ‘mass innovation spaces,’ interdisciplinary learning (STEAM education), and maker education, and striving to cultivate students’ information literacy, innovation awareness, and innovation abilities.” In 2017, the China Academy of Education Science released *the China STEM Education White Paper*. It launched *the China STEM Education 2029 Innovation Action Plan*[21], marking a new high in the strategic position of STEM education in this country’s education and innovation system and making 2017 the first year of China's STEM education. Against this background, STEM education has become the focus of attention for Chinese scholars, with the number of related literatures reaching 471 in 2017 alone, according to CNKI data (a widely-used scholarly database). In terms of practice, provinces and cities such as Jiangsu and Zhejiang have established pilot STEM schools as the first to do so. The specific implementation forms include: offering dedicated STEM courses, club-based teaching, focusing on science and technology competitions, project-based courses, open laboratory space-oriented, and diversified comprehensive courses[22]. From the gradually "captivating" development of theory and practice, we cannot help but raise the following question: under the unique institutional context in China, what exactly are the core connotations and the primary form represented by STEM education? What factors make it up? What is the relationship between these factors? Answering these questions has important implications for the in-depth promotion of STEM education in China and for improving related policies.

According to this, the article collects secondary data, including policy texts, research papers, and news reports. It conducts a text metric analysis based on keyword frequency statistics to extract the core components of STEM education. The research uses Nvivo software to encode the content in the sample materials and condense the core elements of STEM education presented in the specific practice of universities in China. The literature comes from China Knowledge Network, and 25 articles were randomly selected using the keyword "university STEM education". The policy documents come from the Ministry of Education website (http://www.moe.gov.cn) with a total of 12 articles, and there are 26 related news reports. The final coding results are as follows:

Table 1

Level 1 coding (frequency)	Definition	Level 2 coding	Reference point	Examples
STEM education research（66）	The study of STEM education theories and practical experiences aims to enhance the building of a theoretical framework for	STEM education research	51	STEM education research has shown a growing trend, with the number of research studies rapidly increasing, with explosive growth in 2016, with

	understanding STEM education.			nearly 300 papers published that year.
		Expert discussion	2	Establishing a STEM education expert committee has introduced top-notch expert guidance, organized specialized training, project research, on-site guidance, and other activities to ensure practical exploration's healthy and sustained development.
		theory system	4	Based on the consideration of STEM courses being compatible with the national conditions of our country, collaborative research is carried out to build a theoretical STEM course system that fits the education situation in our country.
		course research	7	Dongbei Normal University's Zhou Dongdai researched the reconstruction of the primary school curriculum system based on the STEAM education concept and proposed a reconstruction process based on the STEAM education concept, providing valuable experience for reforming existing curriculum systems.
		STEM Science Research	2	The collaboration between the school and enterprises to promote STEM education is a strong initiative in response to the program, connecting the high-quality resources of research institutes with enterprises.
integration of industry and education（47）	Industry-university integration is a deep cooperation between industry and education, combining the rich practical opportunities of enterprises with the scientific and technological resources and talents of universities, and is a deep cooperation between universities and industrial enterprises to improve the quality of talent training.	school-enterprise cooperation	23	They effectively connect STEM education with enterprises and other institutions cooperating with STEM, cultivating and outputting talents.
		Multi-subject participation	6	By uniting the forces of the government, schools, high-tech enterprises, social organizations and other parties, a sound and long-term cooperation mechanism is established to mobilize the resources of the entire society to actively participate, communicate and cooperate based on consensus and jointly build a supportive system for STEM education.
		integration of industry and education	3	We are emphasizing the integration of industry and education, utilizing the characteristics and advantages of industry-run schools, deepening the mechanism of collaboration between schools

				and enterprises in education, relying on the advantages and resources of industrial enterprises, and providing more students with opportunities for internships and practical experience in enterprises.
		society linkage	7	A social linkage mechanism needs to be established, integrating various social resources, giving full play to their respective advantages, and forming a joint effort to promote STEM education within the same system.
		Three helix of production, education and research	8	Open-minded acceptance of integrating thoughts from enterprises, universities, and research institutes is needed to promote the integration of production, education, and research in primary education.
discipline integration （103）	Problem-based, the education focuses on the integration of interdisciplinary knowledge to solve problems and enhance abilities.	Interdisciplinary	8	STEM education is a simple addition of four subjects and a new holistic integration of multiple disciplines.
		Break the discipline barrier	4	The proposal of STEM education breaks down the barriers of disciplines and adopts a more flexible learning approach rather than staying within a single subject.
		interdisciplinary	61	Interdisciplinary means that educators in STEM education no longer focus on a specific subject or overly focus on disciplinary boundaries but instead focus on specific problems and emphasize the use of knowledge in science, technology, engineering, or mathematics related to solving problems.
		Multidisciplinary organic whole	8	STEM education is not just a simple addition of science, technology, engineering, and mathematics education but a combination of the content of these four subjects to form an organic whole.
		Integration of disciplines	20	Colleges and universities should promote interdisciplinary STEM education that integrates STEM education with college entrepreneurship education to cultivate innovative and entrepreneurial talents while helping students study the primary subjects of engineering, mathematics, technology, and science.
Maker education （45）	Maker education is a new type of education that integrates information technology and focuses on "learning through creation" as the main learning	Maker education	24	From the perspective of talent cultivation, the rise of maker education and STEM education results from the

	method and aims to cultivate innovative talents. It is actively promoted in our country.			demand for multi-composite talents.
		Mass creation space	4	Areas with conditions should actively explore the application of information technology in new educational models such as maker spaces, interdisciplinary learning (STEAM education), and maker education.
		Entrepreneurship Education	10	STEM education + college entrepreneurship education aligns with the characteristics of "mass entrepreneurship and mass innovation" and is born with the arrival of the new economic era.
		Maker space	2	Many schools have established STEM classrooms or maker spaces and promote project-based learning in classroom teaching.
		Innovation and Entrepreneurship	5	The STEM education concept effectively integrates into innovative and entrepreneurial education and can enrich the specific implementation plan for applied undergraduate innovative and entrepreneurial education.

Through frequency statistics, we distilled four core elements of STEM education: STEM education research, integration of industry and education, interdisciplinary integration, and maker education. In the early stage of STEM development, the relationship between maker education was mainly demonstrated as the maker movement, and STEM education has attracted attention from the academic community [23]. The maker education model has put the STEM education concept into practice[24], promoting the application and promotion of STEM education. After the maker movement took off in major industrial countries, including China, the National Engineering Graduate Education Guidance Committee, the highest authority in the field of engineering professional degree education, has been selecting “National Demonstration Engineering Professional Degree Joint Training Base” since 2014, recognizing universities that perform exceptionally well in joint training with schools and enterprises. The joint training of schools and enterprises can increase students’ practical opportunities, improve their operational skills, and meet the requirement of connecting STEM education theory with reality. At the same time, universities implement STEM education by integrating and optimizing the professional structure through measures such as offering interdisciplinary programs, holding cross-disciplinary seminars, and promoting the development of students' interdisciplinary learning skills. In summary, since the maker movement has driven the rapid growth and development of STEM education in China, universities have conducted a systematic and comprehensive study on STEM education, mainly developing STEM education in practice through the integration of industry and education and the integration of disciplines.

4. Study Two: the Effects of Different Constituents of STEM Education on Cultivation Performance of Innovative Talent

4.1 Hypothesis Proposal

4.1.1 Research on STEM education

With the release of *the China STEM Education White Paper* and the launch of *the China STEM Education 2029 Innovation Action Plan*, STEM education has become the focus of college research workers. The hotspots of STEM education research in China include research on the integration of STEM education and maker education oriented towards cultivating core literacy, research on the reform of primary education courses integrated with STEM, research on STEM interdisciplinary teaching models, and research on the development of American STEM education and its localization[25]. Theoretical research can enhance the awareness of STEM education in colleges and universities and provide a solid theoretical basis for the practice of STEM education. Scholars can strengthen their understanding of STEM education through research and find more feasible and Chinese-characteristic practical implementation plans, upgrading and restructuring teaching methods and ideologies. The research status of STEM education also reflects the level of importance that colleges and universities attach to it. According to the attention-based views[26], focusing research efforts on STEM education helps to allocate relevant resources towards STEM education. Given that the ultimate goal of STEM education is to enhance practical innovation ability, theoretically speaking, strengthening the research of STEM education is beneficial for improving the performance of cultivating innovative talent in colleges and universities. Based on the above analysis, this paper puts forward the following unverified hypothesis: STEM education research in colleges and universities can improve their innovation ability.

H1: Research on STEM education is positively correlated with the performance of innovation talent cultivation in universities.

4.1.2 Integration of industry and education

Research shows that enterprises are essential in promoting STEM education and can provide a testing ground for applying scientific knowledge and skills. They also help strengthen the connection between the classroom and real life, exposing teachers and students to the practical application and frontier development of science, technology, mathematics, and engineering [27]. Promoting cooperation between schools and enterprises is a crucial way to implement STEM education and enhance the technological innovation ability of higher education institutions. In recent years, a series of important documents have been issued in China, such as “Several Opinions on Deepening the Integration of Industry and Education”, “Notice on the Issuance of the Implementation Opinions on the National Pilot Project for the Integration of Industry and education,” and “Notice on the Issuance of the Implementation Plan for National Vocational Education Reform,” which provide direction and blueprint for the upgrading of “integration of industry and education and cooperation between schools and enterprises”. Accordingly, scholars have also started to explore specific practical pathways for the integration of industry and education, proposing various practices such as the “six integrations” development concept [28], the “three steps” three-dimensional teaching model [29], the “government, industry, school, enterprise” production-education-integration innovation model [30], and the “dual-teacher type” teacher team building [31]. Among them, STEM education seeks to create real-life scenarios and solve real-world problems, which can be achieved through joint training bases between schools and enterprises. In 2017, the National Engineering Professional Degree Graduate Education Steering Committee held the third “National Engineering

Professional Degree Graduate Joint Training Demonstration Base” declaration and selection activities, further recognizing the critical role of creating real-life scenarios and requiring students to solve real-world problems in enhancing students’ practical ability and creativity. Based on this, it is proposed that the following:

H2: Integration of industry and education is positively correlated to the performance of innovation talent cultivation in higher education institutions.

4.1.3 Interdisciplinary integration

As the knowledge production model evolves, disciplinary knowledge gradually moves from differentiation to cross-fusion. Single-disciplinary fields are gradually moving towards multi-disciplinary, interdisciplinary, cross-disciplinary, and even transdisciplinary. The crossover and fusion of disciplines have become a source of innovation and a characteristic of the times in the development of science[32], and the core feature of STEM education is interdisciplinary[33]. Focusing on problem-solving, STEM education's educational process is not simply a simple superposition of scientific, technological, engineering, and mathematical knowledge. However, it emphasizes the natural combination of the contents of the scattered originally four subjects to form a whole[34]. Many innovations come from the fusion of emerging disciplines and traditional disciplines, and the cross-fusion and deep integration of traditional disciplines, and the crossroads of disciplines are often the source of new knowledge and breakthroughs[35]. Discipline fusion enhances students' comprehensive ability, breaks disciplinary boundaries for multi-perspective thinking and research[36], and ultimately enhances innovation practice ability. As a result, the following unverified hypothesis is proposed regarding the relationship between discipline integration and innovation:

H3: Discipline crossover is positively correlated to the performance of university innovation talent cultivation.

4.1.4 Maker education

Since the implementation of education in China, many scholars have advocated for the integration of STEM education with maker education[37][38][39][40]. The "Guidance on the Comprehensive and In-depth Promotion of Education Informatization Work during the Thirteenth Five-Year Plan (Draft for Solicitation of Opinions)" issued by the Ministry of Education proposes "to effectively use information technology to promote the construction of 'mass innovation spaces', to explore new education models such as STEM education and maker education, and to enable learners to have a strong awareness of information and innovation[1][2]." As an imported product, STEM education can effectively promote the reform of existing courses in China and implement the STEM education concept through its integration with maker education. Maker education aims to improve students' entrepreneurial and innovation capabilities and is consistent with STEM education's expectation of enhancing students' innovation and practical abilities through interdisciplinary integration. Thus, this paper proposes the hypothesis:

H4: Maker education is positively correlated to the performance of innovation talent cultivation in colleges and universities.

4.2 Study Design

4.2.1 Variable design and measurement

This paper aims to explore the quantifiable impact of promoting STEM education on the performance of university technology innovation. Given that patents are an essential carrier to measure the innovation ability of individuals or organizations and are widely adopted by academia, this paper adopts the number of patent applications recorded in the SooPAT patent retrieval engine by universities during 2015-2019 as a measure of the performance of university innovation talent training IP. This study adopts four indicators to measure how universities promote STEM education: STEM education research, integration of industry and education,

---

[1] The Ministry of Education of China issued the Draft Guidance on Comprehensively and Deeply Promoting the Work of Education Informatization during the 13th Five-Year Plan Period (Draft).

and interdisciplinary and makerspace education. Regarding university STEM education research, the number of papers published in CNKI with STEM education as the theme during 2015-2019 is selected as the proxy variable RS, which can effectively represent the research level of universities on STEM education. The joint patent application of universities and enterprises is selected as the proxy variable IEU to represent the intensity of integration of industry and education. The occurrence of significant adjustments in universities during 2015-2019 is selected as the proxy variable MS for interdisciplinary integration, and the adjustment of major can integrate course resources and provide students with cross-disciplinary learning opportunities, which is the most direct manifestation of universities promoting interdisciplinary integration. The construction of maker space directly reflects the promotion of maker space education by universities, so this paper selects the maker space recorded by the state during 2015-2019 as the proxy variable ME of universities' promotion of makerspace education. To ensure the rigor of the experiment, after referring to relevant literature, we select whether the university is directly affiliated with the Ministry of Education DME, whether it is a comprehensive university CU and the annual scientific and technological expenditure FI as control variables.

4.2.2 Data source and processing

Given the timeliness and availability of the survey data, this experiment is based on the relevant data from 36 top-notch universities listed in “Double First-Class” policy, a Chinese national initiative aimed at promoting the development of selected universities and disciplines to world-class levels, from 2015 to 2019. According to these universities' admission targets, talent cultivation goals, and university development plan, we have excluded colleges of agriculture and normal which are less involved in STEM education. Meanwhile, we believe that the implementation of policies has a certain lag in time. After referring to related literature, we set the lag period as one year.

The data source of the innovation performance of the 36 universities is the SooPAT patent retrieval engine[3]. The basic information about the universities comes from the university websites. The data source of the universities' science and technology expenditures is the compilation of statistics on science and technology in colleges and universities. The universities' research on STEM education comes from CNKI[4]. The data source of the number of joint patent applications between schools and enterprises is the National Intellectual Property Administration[5]. The data source of discipline adjustment is the record and approval results of undergraduate majors, generally higher education institutions under the Ministry of Education. The list of maker spaces comes from the “National Record List of makerspaces” issued by the Ministry of Science and Technology.

4.2.3 Descriptive statistics of the sample

Table 2 Descriptive statistics of the sample（N=36）

variable	mean	median	standard deviation
lnIP	7.462	7.411	7.011
RS	0.722	0.000	1.111
lnIEU	5.320	4.836	5.458
MS	0.677	1.000	0.478
ME	0.528	0.000	0.878
CU	0.722	1.000	0.444
DME	0.806	1.000	0.401
lnFI	14.570	14.391	14.156

The mean of the number of literature (RS) on STEM education research in colleges is 0.722, with a standard deviation of 1.111. Although 2017 was the year of STEM education, the literature has increased compared to previous years. However,

---

[3] http://www2.soopat.com/Home/Index

[4] https://www.cnki.net

[5] http://psssystem.cnipa.gov.cn/sipopublicsearch/portal/uiIndex.shtml

the research intensity of STEM education in double first-class colleges is still low and cannot meet real-world development needs. The mean number of school-enterprise joint patents (IEU) is 5.320, indicating that most colleges actively promote cooperation with enterprises, but there is still a significant gap between colleges. The gap in major college adjustment is small, with a standard deviation of 0.478. In implementing STEM education, colleges use the method of significant adjustment less frequently to enhance innovation capabilities.

4.3 Analysis of Results

4.3.1 Diagnosis of multicollinearity

The text first conducts a Pearson correlation analysis on the independent variables. It adopts a multiple collinearity diagnosis method to explore whether there is a potential problem of multiple collinearities among the independent variables. As seen from Table 4.2, the variance inflation factor (VIF) is less than 10 for all independent variables, indicating that the sample data obtained in this experiment does not have severe issues of multiple collinearities.

Table 3 Correlation

	RS	InIEU	MS	ME	CU	MDE	lnFI
RS Pearson Correlation	1						
Significance							
N	180						
InLEU Pearson Correlation	0.145	1					
Significance	0.400						
N	180	180					
MS Pearson Correlation	0.143	0.048	1				
Significance	0.404	0.782					
N	180	180	180				
ME Pearson Correlation	-0.138	-0.020	-0.182	1			
Significance	0.421	0.907	0.289				

N	180	180	180	180			
CU Pearson Correlation	0.069	-0.050	0.482	0.092	1		
Significance	0.688	0.711	0.003	0.595			
N	180	180	180	180	180		
DME Pearson Correlation	0.004	0.195	0.397	-0.187	0.479	1	
Significance	0.984	0.254	0.017	0.275	0.003		
N	180	180	180	180	180	180	
lnFI Pearson Correlation	0.061	0.777	0.030	-0.084	-0.203	0.108	1
Significance	0.723	0.000	0.864	0.628	0.236	0.532	
N	180	180	180	180	180	180	180
VIF	1.083	2.748	11.471	1.170	1.799	1.551	2.793

4.3.2 Panel data regression

Table 4 Regression Result

Model	1	2	3	4	5	6
DME	0.012	0.009	0.013	0.005	0.018	0.006
CU	-0.478**	-0.508**	-0.489**	-0.456**	-0.548**	-0.592**
lnFI	0.089	0.092	0.078	0.113*	0.082	0.138
RS		0.187**				0.112**
LnIEU			0.569**			0.497**
MS				0.207		0.188*
ME					-0.126	-0.078
Constant	3.021	3.292	2.991	2.983	2.801	3.300
R square	0.756	0.818	0.831	0.786	0.758	0.838
Observations	180	180	180	180	180	180

The results showed that hypotheses 1 and 2 passed the verification, while hypotheses 3 and 4 did not.

5. Conclusion and Discussion

Through historical review and text analysis, this paper first finds that in the Chinese context, the core constituent elements of STEM education include STEM education research, integration of industry and education, interdisciplinary integration, and maker education. These four aspects play different roles in different stages of STEM education development, acting as alternating historical events and promoting each other in specific periods.

Through empirical research based on double-first-class universities, this paper further finds that STEM education that emphasizes the development of students' hands-on practical ability is mainly carried out by integrating industry and education in China. Deep cooperation between universities and enterprises positively impacts universities' cultivation of innovative talents and helps enhance universities' innovation capability. Universities attach importance to promoting cooperation between universities and enterprises in implementing STEM education, providing students with more abundant practical platforms and introducing complementary resources from enterprises to build a "work-learn" educational model, enabling students to apply the theoretical knowledge learned in class to practical operational environments, thereby effectively enhancing universities' practical innovation capability.

Integration of disciplines is another typical form of STEM education in China. However, according to empirical results, compared to the integration of industry and education, the promotion of the training performance of innovative talents in universities in China still needs to be further improved. While integrating disciplines, universities have not grasped the laws and characteristics of disciplines and found the complementarity of knowledge, and integration of disciplines has a superficial characteristic.

The guidance of theory on practice is equally important in promoting STEM education. Research has found that the depth of research in STEM education directly determines the implementation of STEM education in the unit, which affects innovation talent cultivation performance. To effectively implement STEM education policies and carry out local innovation and improvement, it is necessary to understand STEM education accurately. Only then can it guide the development of related work and promote innovation and talent cultivation.

Implementing STEM education concepts with maker education has not yet reached a consensus among relevant stakeholders, and the awareness of maker education in colleges and universities has not fully awakened. In promoting maker education, colleges and universities focus more on student cultivation during their school years and wait to follow up continuously. They have yet to introduce measures to support students' innovation development after leaving school. On the contrary, maker education is more of a preparation for students' entrepreneurial activities after leaving school. The disconnection of colleges and universities in talent cultivation often leads to the difficulty of making education play its role.

This paper still has many things that could be improved, such as the selection of samples, as we only selected colleges and universities from the Double First-Rate program (an initiative to build world-class universities). Although they have certain representativeness in promoting STEM education, they still need to be more extensive. Future research should be based on a more extensive sample base.

References

---

[1] National Science Board, "Undergraduate Science, Mathematics and Engineer ing Education," [Online]. Available: http://www.nsf.gov/nsb/publications/1986/nsb0386.pdf, Mar. 15, 2019.

[2] C. Peng, Y. Tian, and W. Liu, "North Star: Global Innovative Talent Development Program with STEM Education as the Core: Interpretation based on 'Charting a Course for Success: America's Strategy for STEM Education' (2019-2023)," JOURNAL OF DISTANCE EDUCATION, vol. 37, no. 02, pp. 3-14, 2019.

[3] W. Sun, Y. Ma, and X. Zhu, "The Analysis and Inspirations of the STEM Promotion Policy in Europe," China Educational Technology, no. 03, pp. 131-139, 2018.

[4] "The background and definition of the concept of innovation and development in Shifeng," [Online]. Available: http://www.fx361.com/page/2019/0625/5247142.shtml, Jun. 25, 2019.

[5] M. Long and Z. Zhao, "The contribution of STEM education to national competitiveness in the United States," Modern University Education, no. 02, pp. 41-49 + 112, 2015.

[6] J. Qin and G. Fu, "STEM education: interdisciplinary education based on real-world problem scenarios," China Electrification Education, no. 04, pp. 67-74, 2017.

[7] Y. Yu and H. Xiang, "STEM education concepts and interdisciplinary integration models," Open Education Research, vol. 21, no. 04, pp. 13-22, 2015.

[8] Z. Zhan et al., "Discipline integration education oriented towards cultural inheritance (C-STEAM): 6C model and practical cases," Modern Distance Education Research, vol. 32, no. 02, pp. 29-38 + 47, 2020.

[9] Y. Li et al., "Construction of evaluation index system of STEM education quality," Modern Distance Education Research, vol. 32, no. 02, pp. 48-55 + 72, 2020.

[10] P. D. Hurd, "Science, Technology and Society: New Goals for Interdisciplinary Science Teaching," The Science Teacher, no. 42, pp. 27-30, 1975.

[11] Y. Fan, "Research on STEM education – a new focus on K-12 curriculum reform in the United States," Master' s thesis of the School of Education Science, East China Normal University, Shanghai, 2011.

[12] J. Ramaley, "Facilitating Change: Experiences with the Reform of STEM Education," [Online]. Available: http://www.wmich.edu/science/facilitating-change/Products/RamaleyPresentation.doc.

[13] Y. Yushengquan and H. Xiang, "STEM education concepts and interdisciplinary integration models," Open Education Research, vol. 21, no. 04, pp. 13-22, 2015.

[14] Q. Jinruo and G. Fu, "STEM Education: Interdisciplinary Education Based on Real-World Problem Scenarios," China Electrification Education, vol. 2017, no. 4, pp. 67-74, 2017.

[15] G. Yakman, "STEM education: An overview of creating a model of integrative education," [Online]. Available:

---

http://steamedu.com/wp-content/uploads/2014/12/2008-PATT-Publication-STEAM.pdf, Aug. 07, 2010. Accessed on: Sep. 13, 2017.

[16] P. Chen, Y. Tian, and R. Huang, "Research and inspiration on innovative STEM education curriculum based on design thinking - taking d.loft STEM course of Stanford University as an example," China Electrification Education, vol. 2019, no. 8, pp. 82-90, 2019.

[17] L. Qiao and Z. Wan, "STEM teacher pre-service training in New Jersey Academy of the United States," Research on Basic Education, vol. 2018, no. 6, pp. 38-46, 2018.

[18] S. He, "How to carry out STEM education in scientific education - Based on the characteristics of engineering technology education in the American 'Science Fusion' textbook," Journal of Educational Theory and Practice, vol. 39, no. 32, pp. 42-46, 2019.

[19] H. Zhao, Y. Zhang, J. Ma, and N. Zhang, "Construction and enlightenment of quality evaluation system for young people's extracurricular STEM projects - Based on the analysis of the 'Indiana extracurricular project standards and professional standards: STEM education'," Journal of Electrical Education Research, vol. 40, no. 10, pp. 115-122, 2019.

[20] Y. Song, H. Ma, and J. Yao, "The value motivations, course prototypes and action paths of the US 'Project Lead the Way' program-Take Wisconsin as an example," Journal of Distance Education, vol. 35, no. 6, pp. 31-40, 2017.H. Wang, L. Liu, and C. Ma, "Exploration of STEM education aimed at deep learning," Modern Education Technology, vol. 30, no. 3, pp. 108-113, 2020.

[21] China Academy of Education Sciences, "White Paper on China STEM Education (Deluxe Edition)," [Online]. Available: https://www.docin.com/p-2129567009.html. Accessed on: Jun. 20, 2017.

[22] H. Fang, H. Liang, Y. Xie, S. Zhou, and X. Zhou, "A study of the implementation cases of the first batch of pilot schools based on the 'China STEM Education Action Plan 2029'," Basic Education Reference, vol. 2019, no. 13, pp. 31-34, 2019.

[23] Y. Chang, Y. Zhang, and X. Jin, "STEM education status research based on quantitative perspective," China Electric Education, vol. 2017, no. 6, pp. 114-119, 2017.

[24] X. Wang, "Research on maker education model for STEM education," China Electric Education, vol. 2015, no. 8, pp. 36-41, 2015.

[25] F. Ying, "Research hot spots and development trends of STEM education in China - A visual research based on co-word analysis," Education and Equipment Research, vol. 36, no. 03, pp. 12-17, 2020.

[26] W. Ocasio, "Towards an Attention-Based View of the Firm," Strategic Management Journal, vol. 18, no. S1, pp. 187-206, 1997.

[27] X. Li and Y. Li, "Strategies for promoting STEM education in the United States," Comparative Education Research, vol. 41, no. 12, pp. 87-93, 2019.

[28] Y. Liu and J. He, "Promoting the Development of Modern Apprenticeship and Integration of Industry and Education Based on Top-level Design," Chinese and Foreign Entrepreneurs, no. 14, pp. 151, 2020.

[29] L. Wang and L. Zhao, "Application of the "Industry and Education Integration +" Applied Bachelor Market Marketing Major's "Three-step Walk" Three-dimensional Teaching Model," Chinese and Foreign Entrepreneurs, no. 14, pp. 162, 2020.

[30] T. Xia and J. Wang, "Research on the Operation Mechanism of "Government-Enterprise-School-Enterprise" Integration of Industry and Education Innovation Model," Chinese and Foreign Entrepreneurs, no. 15, pp. 152-153, 2020.

[31] Y. Xin, "Analysis of the Deep Integration of the Pharmaceutical Professional Industry and Education in Higher Vocational Colleges under the Perspective of School-Enterprise Cooperation," Chinese and Foreign Entrepreneurs, no. 13, pp. 169, 2020.

[32] S. Yuan, Z. Huang, and F. He, "Thinking about Discipline Construction under Cross and Integration - Taking Peking University as an Example," China University Science and Technology, vol. 2019, no. 12, pp. 4-7.

[33] S. Yu and X. Hu, "STEM Education Concept and Interdisciplinary Integration Model," Open Education Research, vol. 21, no. 04, pp. 13-22, 2015.

[34] J. Morrison, "Workforce and school," in Briefing book. SEEK-16 Conference, Washington, D.C.: National Academy of Engineering, 2005, pp. 4-5.

[35] G. Gao, "A New Model for Undergraduate Talent Cultivation under the "Three Constructions + Two Integrations" of World-class Universities and World-class

---

Disciplines Driven by Innovation," Higher Education Academy, vol. 2019, no. 25, pp. 13-15.

[36] J. Zhao and Q. Lu, "Discipline Integration is not Simple Cross-disciplinary Education-Practice and Reflection of Discipline Integration Education," Jiangsu Education Research, vol. 2016, no. 31, pp. 32-34.

[37] H. Meng, B. Huang, M. Wang, and B. Zhou, "Exploration of the Problems of STEAM and Maker Education and Its Integrative Path," Modern Education Technology, vol. 30, no. 03, pp. 114-119, 2020.

[38] Y. Yaning, "Teaching Design Model of Maker Talent Cultivation Based on STEM Education Concept," Think Tank Era, vol. 2020, no. 01, pp. 176-177.

[39] J. Kang, "School-based Strategies to Promote the Mutual Growth of Maker and STEM Education," Modern Education, vol. 2019, no. 09, pp. 7-10.

[40] Liu Binli, Liu Guozhang. Maker Education Based on STEM[J]. Science Education and Museum, 2019, 5(02):175-177.