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STEM in vocational education and training: The future direction

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ABSTRACT

Vocational education and training (VET) and Science, Technology, Engineering, and Mathematics (STEM) education are two distinct but interconnected forms of education that play complementary roles in preparing individuals for the workforce. This work first discusses the relationship between vocational education and STEM education. The breakdown of students in secondary vocational schools (institutions) by subject categories in China in 2021 illustrates that 63% of students in current vocational education in China engage in STEM-related learning. Vocational education and STEM education have a solid inherent logical connection, but vocational education mainly focuses on training within a specific professional field, lacking the integration and comprehensive approach in STEM education. Furthermore, this work explores whether vocational learning would lose competitiveness due to increased labor mobility. It reveals that VET's competitiveness decreased with increased population mobility. Government policies might consider promoting the integration of vocational education and STEM education, enhancing workforce competitiveness through effective generalization of vocational skills in a STEM education framework.

Key words: STEM, vocational education and training, mobility

INTRODUCTION

Vocational education and training (VET) and Science, Technology, Engineering, and Mathematics (STEM) education are separated yet interrelated educational domains that synergistically contribute to preparing individuals for the workforce. VET provides students with practical proficiencies and specialized knowledge of particular occupations or industries. The type of education encompasses immersive, hands-on training, apprenticeships, and internships that foster skill development directly applicable to specific professional pathways.[1,2] Vocational education programs span diverse fields such as automotive technology, healthcare, construction, culinary arts, *etc*. The primary objective of vocational education is to endow individuals with the necessary aptitudes to seamlessly enter the job market and succeed in their chosen vocations.

STEM education is centered around science, technology, engineering, and mathematics, aiming to cultivate critical thinking, problem-solving, and analytical skills.[3,4] Its primary objective is to equip students with the knowledge and competencies necessary for careers in STEM-related fields. STEM education provides a robust foundation in scientific principles, mathematical concepts, and technological proficiencies.[5,6] This educational approach often incorporates theoretical learning, hands-on experimentation, and project-based activities to enhance students' comprehension and application of STEM concepts. Though STEM education is becoming increasingly popular in China,

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STEM education in VET in China is facing a situation where the government is enthusiastic. At the same time, the public gives a frosty reception. Its essence lies not only in the educational dilemma of choosing between general high schools and VET but also in the economic question of selecting between general skills and specialized skills, often within the STEM subjects. Investigating the potential synergistic effects of combining STEM education with VET might benefit both education styles. The benefits might include increasing the attractiveness of vocational education, reducing adverse effects of population mobility on skill performance in the workplace, and enhancing alignment between educational offerings and industry demands. We, therefore, would like to employ in-depth research and analysis to delve into these complex interrelationships and provide valuable insights for policymakers, educators, and stakeholders in the field of vocational education.

To shed light on the future direction of the VET, this paper first analyzes the development of STEM education in VET in various countries to illustrate how VET in China should further progress with the integration of STEM concepts. The desirability of vocational education programs for specific skill acquisition has evolved in the past decades. The extent to which individuals aspire to engage in vocational education for targeted skill learning could be affected by increased population mobility. To comprehensively examine this phenomenon, the paper assesses the correlation between the birth year and the employers' performance of vocational education programs for skill acquisition purposes. We find that the skill level differences between the cohort with VET education and high school education are decreasing with the time proceeding in the population born between 1965 and 1982. This partially confirmed our analysis of the relationship between population mobility and the competitiveness of VET education. Finally, the paper proposes future directions that show that the integration of STEM education into vocational training would increase individuals' preference for vocational education and mitigate the impact of population mobility on the acquisition and application of professional skills.

STEM IN VET

The origin of STEM education can be traced back to the United States in the mid-20th century.[7,8] Recognizing the interdisciplinary nature of STEM fields and the importance of integrating science, technology, engineering, and mathematics, the U.S. National Science Foundation (NSF) began promoting the term "STEM" in 2001. STEM education emerged as a framework that emphasized the integration of these disciplines to foster critical thinking, problem-solving skills, creativity, and innovation. STEM education has since gained international recognition and has been embraced by many countries worldwide. STEM education is not limited to traditional academic settings but extends to VET, which aims to inspire students' curiosity, promote inquiry-based learning, and prepare them for diverse STEM-related vocational careers and challenges.

STEM education in VET in Germany

"STEM" is equivalent to the term "MINT" education in Germany, which refers to an emphasis on the subjects of Mathematics (Mathematik), Informatics (Informatik), Natural sciences (Naturwissenschaften), and Technology (Technik) in the country's education system. Germany has a strong tradition of VET, known as the "dual system", which combines classroom instruction with practical, on-the-job training. In VET, STEM subjects are emphasized to equip students with the necessary technical skills and knowledge for specific professions and industries. The curriculum typically includes a combination of theoretical and practical coursework, ensuring that students develop a solid foundation in science, technology, engineering, and mathematics, which is exactly the representation of STEM education. Vocational schools in Germany offer a wide range of STEM-focused programs covering various fields such as engineering, information technology, construction, automotive technology, and electronics.

The STEM-integrated VET curriculum in Germany is closely aligned with the needs of industries and the labor market. Industry representatives actively participate in curricula development, ensuring that the skills taught align with the demands of the job market. This collaboration between vocational schools and industries helps to bridge the gap between education and employment, increasing graduates' employability.

Germany's vocational education system benefits from a well-established infrastructure and extensive resources. Vocational schools have modern facilities, equipment, and technology that reflect industry standards. The government provides substantial funding to support vocational education, ensuring the quality of programs and enabling continuous improvement. Germany offers numerous opportunities for career advancement within the vocational education system. After completing initial vocational training, individuals can pursue further education and acquire advanced qualifications, including a technical or engineering degree in STEM-related fields. The emphasis on continuous learning and professional development of VET in STEM-related fields enhances the long-term career prospects of vocational education graduates in Germany.

STEM education in VET in the USA

In the USA, vocational education is often called Career and Technical Education (CTE). STEM education is a crucial component of CTE programs, offering diverse STEM-focused courses and pathways. These include computer science, information technology, engineering technology, health sciences, and advanced manufacturing. Students enrolled in these programs receive classroom instruction, hands-on training, and work-based learning experiences.

STEM education in vocational schools in the USA strongly emphasizes practical application and real-world scenarios. Students engage in project-based learning, solving problems, designing prototypes, and collaborating in teams to address technical challenges. This approach helps students develop critical thinking, problem-solving, and teamwork skills essential for success in STEM-related careers. Vocational schools often partner with local businesses, industries, and community organizations to enhance the relevance and industry-readiness of CTE programs. These partnerships provide students with opportunities for internships, apprenticeships, and mentorship, allowing them to gain real-world experience and exposure to the demands of the workforce. CTE programs prioritize the development of career readiness skills and employability skills. The USA government has implemented supportive policies and allocated funding to strengthen and expand CTE programs.

STEM education in VET in Japan

The curriculum of STEM-oriented vocational schools in Japan is designed to align with industry needs and technological advancements. It often incorporates industry-standard equipment and facilities, allowing students to gain practical experience using modern tools and technologies. Additionally, vocational schools in Japan frequently collaborate with industry partners to provide students with internship opportunities, industry visits, and guest lectures, enhancing their understanding of real-world applications. Furthermore, vocational schools in Japan often offer pathways for students to further their education. Graduates can continue their studies at specialized technical colleges or pursue higher education at universities to deepen their knowledge in specific STEM disciplines.

STEM education in VET in China and its comparison with other countries

STEM in VET is a crucial aspect of China's educational landscape, aimed at equipping students with practical skills and knowledge in science and technology-related fields. China has recognized the significance of promoting STEM education to maintain its position as a global leader in technology and innovation. The government has emphasized the importance of integrating STEM disciplines into VET programs as part of this effort. China's approach to integrating STEM in vocational education involves collaborating with industry partners and academic institutions. This collaboration ensures that the curriculum remains relevant and up-to-date with the current needs of the job market. By aligning vocational training with STEM, students can acquire the necessary technical skills and knowledge to contribute effectively to various industries, including manufacturing, engineering, information technology, and other technology-driven sectors.

Furthermore, the Chinese government has invested significantly in establishing specialized STEM-focused vocational schools and upgrading existing vocational institutions to meet international standards. These schools provide students access to state-of-the-art laboratories, advanced equipment, and experienced instructors, enabling them to gain hands-on experience and expertise in STEM-related fields. STEM vocational education in China and other countries share some commonalities while exhibiting notable differences due to variations in education systems, cultural contexts, and economic priorities. STEM vocational education in most countries places a strong emphasis on hands-on learning and practical skills development in STEM vocational education. Students are trained to apply theoretical knowledge to real-world scenarios. Also, the curriculum faces real industrial needs, often with partnerships between educational institutions and industries. However, the major differences between China and other countries might include: (1) pathway to higher education: many other countries offer a more fluid system for VET students to acquire higher education or primary education; (2) social Recognition: vocational education in Germany or Japan is relatively highly esteemed and offers a respected career path comparable to academic routes.[9,10]

To further analyze the relationship between STEM and VET in China, we first identify STEM education and qualifications by their field of education. We further classify all the VET fields of education into six different categories (Table 1).

We consider the first four categories all STEM-related. According to the summary statistics by the Ministry of Education of the People's Republic of China, shown in Figure 1, 64% of all VET education is STEM-related. Among them, manufacturing, engineering, and related technologies ranked first, with about 27% of all the graduates studying this category, followed by information technology with 17% of all the graduates. The statistics indicate a strong correlation between VET and STEM-related fields, underscoring the significance of integrating VET with STEM to enhance the overall

Table 1: The categories of vocational education and training education

Number	Categories	Subcategories
1	Agriculture, environmental, and related studies	Agriculture, forestry Husbandry and fisheries Resources and environment Energy resources and new energy resources Light, textile, and food industries
2	Information technology	-
3	Manufacturing, engineering, and related technologies	Civil engineering and water conservancy Manufacturing Petroleum and chemical industries Communication and transport
4	Health	Medicine, pharmaceuticals, and health care Recreations services and make-up artists Sports and body-building
5	Social sciences and related fields	Finance, economics, commerce, and trade Tourist services Culture and arts Education Legal services Public administration and services
6	Others	-

education level. This correlation suggests that by combining VET and STEM, educational institutions can create a more comprehensive and practical learning experience for students.

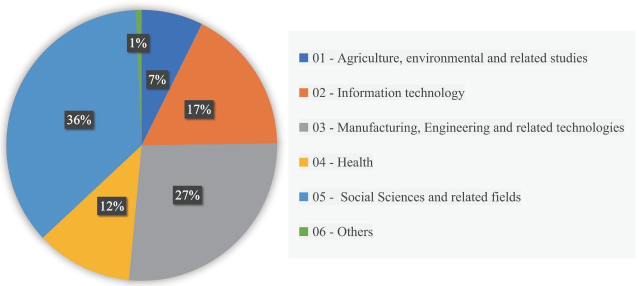

Figure 1. Enrollment in VET by selected STEM-related fields of education in China in 2021.[11] VET: vocational education and training; STEM: Science, Technology, Engineering, and Mathematics.

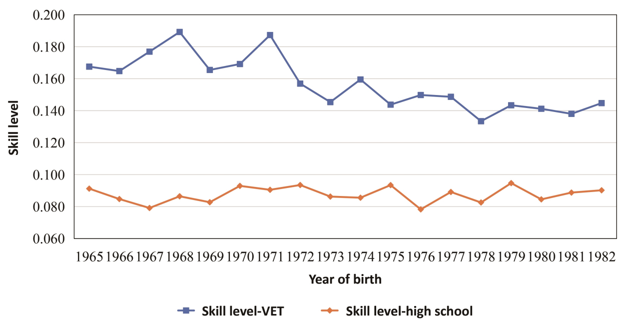

Figure 2. The narrowing skill gap of VET and high school graduates. The calculation of the skill levels directly adopts the skill level evaluation statistics of different occupational practitioners measured by Ye based on the China Social Survey data.[27] The authors calculate the weighted average skill levels of the cohort born in from 1965 to 1984. After taking the reciprocal and logarithm, the larger the numerical value, the higher the skill level of the occupation they were engaged in. VET: vocational education and training.

THE DISADVANTAGED VET IN CHINA

VET in China faces a stark contrast in attitudes from the governmental and the public perspectives. The public regards VET as choosing specialized skills rather than general skills. Research on vocational education in China has predominantly focused on educational issues themselves. For instance, studies have examined the impact of expanded enrollment in universities on the job market for secondary vocational school graduates and the declining comparative advantages in education returns and occupational outcomes for secondary vocational school graduates relative to general high school graduates after the expansion of university enrollments,[12,13] which have contributed to the predicament of current secondary vocational education.

Based on the classification of specific and general skills, previous literature introduced the concept of wage growth over the life cycle of workers, with 20% to 25% attributed to specific skills and at least 50% to general skills.[14,15] Other scholars have examined the differential labor market performance of different types of skills from the perspective of industrial transformation[16–18] or explored the impact of different educational systems, specifically general education and vocational education, on technological innovation[19–22] and the medium- to long-term employability and unemployment of workers.[23] Consensus has been reached in these studies, indicating that vocational education's specialized skills do not exhibit a clear comparative advantage in rapidly evolving market environments driven by technological advancements. In contrast, general education's emphasis on learning ability and foundational knowledge highlights its comparative advantage.

Traditional skill theories assume that the labor market is static and that the level of labor market mobility remains unchanged. Under this premise, workers with specific skills are believed to have higher skill-job matching and shorter job search duration.[24] It is also assumed that through on-the-job learning, individuals can continuously enhance their specific skills and improve labor productivity.[25] On the other hand, general skills are considered more versatile but lack job specificity, thus lacking a skill premium compared to specific skills.[26] For example, during the planned economy in China, under the labor market regulations of "centralized assignment" and lifelong employment for graduates from universities and colleges, the level of mobility was low and almost static. Workers enjoyed strong employment stability, but general skills lacked job specificity, resulting in more incredible employment difficulty and relatively lower labor productivity. During this period, the public had a greater preference for vocational education. With the increased mobility level, we witness a narrowing skill gap between VET and High School graduates born between 1965 and 1982, shown in Figure 2, accompanied by VET education's decreasing popularity.

THE FUTURE DIRECTION OF VET

To increase the competitiveness of VET after the increased mobility of the labor force, we need to utilize the interaction between VET and STEM to achieve better resource allocation of the labor force. The similarities between STEM education and VET make these two areas more easily integrated. STEM fields and VET are closely aligned with technological advancements and industrial needs. Also, many vocational jobs require technical skills, problem-solving, and critical thinking in a project-oriented situation.

The global economy increasingly demands a workforce proficient in STEM skills. Vocational education programs integrating STEM concepts can help address this demand by equipping students with the technical skills and knowledge needed in STEM-related industries. By combining vocational and STEM education, individuals can be better prepared to meet the job market's needs and access a broader range of career opportunities. Vocational education and STEM education are interconnected, with vocational programs integrating STEM concepts and principles and STEM education providing a foundation for students interested in pursuing careers in STEM fields. Integrating STEM with VET could also help students enhance their chances of employment after graduation and generate more innovation with interdisciplinary skills. Meanwhile, since STEM is also aligning with future industrial innovations, it could also help with the convergence of scientific and industrial innovation. Together, they contribute to a well-rounded education that prepares individuals for the demands of the modern workforce.

Regarding integration mode, there are several classifications regarding integration breadth and style. Researchers categorized the prevailing models conceptualizing integrating all four STEM education disciplines.[28] These models range from less integrated to more integrated, and they include: (1) single-discipline reference; (2) science and math reference: STEM refers to separate science and math disciplines; (3) science disciplines with incorporation; (4) separate disciplines; (5) science and math connected by technology or engineering; (6) coordination across disciplines; (7) combination of two or three disciplines; (7) integrated disciplines; (8) transdisciplinary course or program. These categorizations illustrate the integration continuum, progressing from isolated disciplines to more cohesive and comprehensive approaches that blend and merge STEM education disciplines. Regarding implementation modes in STEM education, previous literature[29–31] categorizes the implementation modes of STEM courses into the Correlated Curriculum model and the Broad Fields Curriculum model. Based on the integration modes, we suggest the future direction of VET is to integrate STEM education into the curricula and the daily teaching and learning process utilizing either the Correlated Curriculum model or the Broad Fields Curriculum model, to better align education with workforce needs in VET and technical education settings.

Firstly, the future VET should include STEM literacy into the VET. With the further development of science and technology, the world faces a more fast-changing environment evolving with its associated knowledge. Vocational education often incorporates STEM concepts and principles relevant to specific industries in the hands-on education system. For example, vocational programs in manufacturing may include training in engineering principles and computer-aided design (CAD). Integrating STEM literacy into vocational education enhances students' technical skills, knowledge, and problem-solving abilities, making them more versatile and adaptable in the workforce.

Our analysis suggests that integrating VET with STEM promotes a more holistic education system that values academic knowledge and technical proficiency. Vocational education and STEM education are not mutually exclusive. Many educational institutions offer programs that blend vocational and STEM elements, creating an education continuum. For example, some schools offer STEM-focused vocational programs, such as biomedical technology or renewable energy engineering. These programs provide students with hands-on technical skills and a strong STEM foundation. STEM fields are often at the forefront of innovation. Students can gain the necessary skills to contribute to technological advancements and economic growth by integrating VET with STEM. This well-rounded approach can lead to a more comprehensive understanding of real-world challenges. STEM fields often require interdisciplinary collaboration. Integrating VET with STEM can encourage teamwork and cooperation among students with different skill sets, fostering a collaborative learning environment.

Finally, to capitalize on the benefits of integrating VET with STEM, educational policymakers and institutions should work together to design and implement curricula that seamlessly blend theoretical knowledge with practical applications. Additionally, partnerships between academic institutions and industry players can further strengthen the connection between VET and STEM, ensuring that education remains relevant and current with current industry trends and needs.

DECLARATIONS

Author contributions

Feng J: Conceptualization, Formal analysis, Methodology, Resources, Writing—Original draft, Writing—Review and editing. Hou HB: Data curation, Formal analysis, Methodology, Resources, Writing—Original draft, Writing—Review and Editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The author has no conflicts of interest to declare.

Data sharing

Technical appendix, statistical code, and dataset available from the corresponding author at herbhou@foxmail.com.

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