VTE VOCATION, TECHNOLOGY & EDUCATION

ORIGINAL ARTICLE

Exploring the digital transformation of TVET program development: A case study of Shenzhen Polytechnic University

Qianmin Lin[1,*], Helen Hoi Ning Pang[2]

[1]UNEVOC Centre, Shenzhen Polytechnic University, Shenzhen 518055, Guangdong Province, China
[2]Li Ka Shing School of Professional and Continuing Education, Hong Kong Metropolitan University, Hong Kong SAR, China

ABSTRACT

As the digital economy rapidly evolves, so too do the jobs and skills required by the labor market, necessitating a corresponding digital transformation (DT) in technical and vocational education and training (TVET). TVET programs serve as cornerstones of TVET delivery, making it imperative to examine DT within them. However, there is a persistent dearth of comprehensive practical research in this area. We addressed this gap by conducting an in-depth case analysis of Shenzhen Polytechnic University (SZPU)—a pioneering institution within China's TVET landscape—to explore DT in TVET program development. We investigated SZPU's institutional DT strategies, TVET program planning, and ecosystem development, yielding valuable insights into SZPU's practices.

Key words: technical and vocational education and training, program development, digital transformation, ecosystem

INTRODUCTION

With the fast development of digital technologies, such as artificial intelligence (AI) and robotics, the world of work has changed rapidly. Relative to the original Industrial Revolution, the shift prompted by advances in AI is occurring at a speed tenfold greater and with a magnitude 300 times larger, amounting to an impact that is about 3000 times more profound.[1] Pricewaterhousecoopers (PwC) researchers predicted that by the early 2030s, the proportion of jobs likely to be automated will be about 20%-25% in Nordic countries and East Asia, and more than 40% in Eastern Europe.[2] Within the next 20 years, AI and other technologies designed to reduce labor requirements will replace 26% of existing jobs in China's service, construction, industrial, and agricultural sectors.[3] The number of jobs at high risk of automation is even higher in the United States.[4] However, digital technologies also create new jobs. An estimate suggests that, by 2025, around 85 million jobs may be replaced due to changes in the distribution of tasks between humans and machines, although approximately 97 million new positions could arise that align better with this evolving distribution of work among humans, machines, and algorithms.[5] The primary catalysts for job expansion are predicted to be big data analytics, advanced climate change and environmental management technologies, and encryption and cybersecurity.[6]

To address the rapidly evolving demands of the global workforce, digital transformation (DT) initiatives have been actively promoted in education, including technical and vocational education and training (TVET). In recent years, several reputable international organizations have released documents aiming to foster DT in education. In

***Corresponding Author:**
Qianmin Lin, UNEVOC Centre, Shenzhen Polytechnic University, No. 7098, Liuxian Avenue, Nanshan District, Shenzhen 518055, Guangdong Province, China.
Email: linqianmin@szpu.edu.cn; https://orcid.org/0009-0009-9772-6660
Received: 22 May 2024; Revised: 5 June 2024; Accepted: 13 June 2024
https://doi.org/10.54844/vte.2024.0606

2019, the Organization for Economic Cooperation and Development (OECD) published *OECD Skills Outlook 2019: Thriving in a Digital World,* which focuses on changing skills and education in the digital era and underscores the role of educational DT in addressing these changes.[7] Similarly, in 2021, the World Bank issued *Steering Tertiary Education: Toward Resilient Systems that Deliver for All,* which emphasizes the need for educational systems to embrace DT to meet the requirements of contemporary society and learners.[8] In UNESCO's *Medium-Term Strategy for 2022-2029*, three of four strategic objectives are intricately linked with DT and digitalization in TVET, with five out of nine corresponding outcomes closely associated with DT in TVET and digital skill development.[9] *Transforming Technical and Vocational Education and Training for Successful and Just Transitions: UNESCO Strategy 2022-2029* underscores the importance of identifying and developing skills for digital and green economies.[10] Additionally, various publications, such as *The Digital Transformation of Education: Connecting Schools, Empowering Learners*, jointly released in 2020 by Broadband Commission for Sustainable Development (BCSD), International Telecommunication Union (ITU), United Nations Educational, Scientific and Cultural Organization (UNESCO), and United Nations International Children's Emergency Fund (UNICEF); the *Beijing Consensus on Artificial Intelligence and Education,* issued in 2019 by UNESCO; and the European Union's *Digital Education Action Plan (2021-2027)*, all emphasize the significance of global digital education.[11–13]

Furthermore, over 170 countries and regions have developed their own national DT strategies to enhance national competitiveness and adapt to shifting economic realities.[14] Collectively, these efforts significantly drive the DT of education, including the TVET sector.

DT in TVET is a complex and systematic process involving TVET operational systems, infrastructure, and maintenance; student registrations; classroom delivery; and the knowledge and skill components of curricula.[15] TVET institutions are the main venues for implementing TVET, and TVET programs are the fundamental units of TVET delivery. Therefore, the DT of TVET programs is considered an important aspect of broader DT in TVET, which warrants significant study.

In recent years, international organizations have begun to release reports on DT in education, including the TVET sector. For example, the International Center for Higher Education Innovation, under the auspices of UNESCO (UNESCO-ICHEI) and Tsinghua University, published a research report on the DT of higher education teaching and learning, identifying and discussing the characteristics and scope of DT in higher education programs.[16] A report by UNESCO, *Enhancing TVET through Digital Transformation in Developing Countries*, explored the context, trends, and challenges of DT in TVET through case studies in Brazil, India, Jamaica, Kenya, and Tunisia.[15] In China, some studies have conceptually discussed DT in TVET and TVET program development. For example, Chen and He considered the value, characteristics, and pathways of DT in TVET programs,[17] while Hou analyzed the situations and problems in specific logistics programs and provided four suggestions for DT in logistics program development.[18]

Overall, previous studies have tended to focus on conceptual discussion and provide general directions and pathways for the DT of TVET program development. Practical research on how to conduct DT in TVET program development is still lacking due to variations in the social contexts and analytical perspectives of the few case studies that have been conducted. Consequently, there is considerable value in conducting case studies in various socioeconomic contexts to glean actionable insights into the practical aspects of DT.

In this study, we selected Shenzhen Polytechnic University (SZPU)—a vanguard institution in China's TVET landscape—for an in-depth case analysis. The primary aim was to delve into successful DT practices in TVET program development, with a specific focus on SZPU's strategies, TVET program planning, and ecosystem development. Our objective was twofold: to provide a practical guide for TVET providers embarking on DT journeys and to enrich the body of knowledge concerning DT within TVET program development.

LITERATURE REVIEW

The impact of digital industrialization and the digitalization of industry

Digital industrialization and the digitalization of industry are the foundational elements of the digital economy.[19] Digital industrialization refers to the industrialization of digital technology and data elements, which encompasses the establishment of entirely new industry sectors propelled by digital technologies such as AI, big data analytics, cloud computing, and the Internet of Things.[20] Conversely, the digitalization of industry refers to the DT and upgrading of traditional industries, which means not merely adapting but completely overhauling traditional industries, enabling them to remain relevant and thrive in an increasingly digital-driven world.[21] As digital industrialization and industrial digitalization continue to gain momentum, they are inevitably reshaping the nature of jobs and the skill sets demanded by the labor market. Rapid advances in technology necessitate the corresponding evolution of the skills and expertise required to navigate the new

digital terrain. Consequently, TVET institutions are tasked with the critical responsibility of reimagining and reformulating their TVET programs to ensure they remain aligned with the evolving needs of the digital economy.[22]

Trends in TVET program development in the digital era

TVET program development trends should respond to the needs of the digital era. We consider the following trends to have the most significant influences on the DT of TVET program development.

Training objective trend: Fostering versatile abilities and cross-disciplinary competencies

The World Economic Forum predicted that the future job market would require a systematic approach and well-rounded skills, encompassing not only advanced methods and technologies but also a strong emphasis on digital and business marketing abilities.[5] Whereas previous job markets placed a premium on specialists with deep knowledge in a particular domain, current and future scenarios favor professionals who possess diverse specializations combined with a generalist's grasp of various disciplines. The demand for such well-rounded individuals is growing in today's job market.[23,24] Interdisciplinary competencies are increasingly important for adapting to the digital economy and fostering innovation and personal development,[25] and there is a trend in education toward fostering versatile and cross-disciplinary talent.[16] This trend is exemplified by China's November 2020 *New Liberal Arts Development Declaration*, which promotes the fusion of digital technologies, such as AI and big data, with the liberal arts to promote innovation and development.[26] By integrating such versatility and aligning it with the training objectives of TVET programs, TVET practitioners can equip students with the broad skills needed to be competitive in multiple fields. This trend mirrors the changing needs of the workforce in our tech-driven age.

Program management trend: encouraging program clustering

Program cluster development is an approach for promoting program structure development in the digital age. Program clusters are a novel form of educational organization that benefits the development of interdisciplinary fields, the cultivation of applied composite talents, and the provision of more flexible career options for students.[27] In China, the aim of TVET program cluster development is to integrate well-established programs or programs with high employment rates with other programs that share similarities but also possess distinct characteristics. This integration facilitates the merging of educational resources and enhances the quality of educational offerings.[28] It also responds to the emergence of industrial clusters in the digital age.[29]

Learning pathway trend: enhancing flexibility

With the development of digital technologies, learning pathways have become more flexible. Digital technologies facilitate personalized learning itineraries, which can unbundle traditional programs into separate entities, permitting a more flexible curriculum structure and enabling students to control their own learning paths based on individual needs and motivations.[30,31] For example, microcredentials are a recent development offering flexible, short-term learning environments that are reshaping education and training.[32] On the one hand, microcredentials permit flexible upskilling and reskilling, allowing learners to adapt to rapidly changing job markets and technologies;[33,34] on the other hand, formal education institutions are increasingly integrating microcredentials into their existing programs to make learning pathways more flexible.[35,36]

Stakeholder relationship management and ecosystem development

Ecosystems are complex networks involving various stakeholders. UNESCO-UNEVOC has pointed out that it is important for TVET institutions to identify their stakeholders and manage relationships with them to develop an ecosystem conducive to innovation.[37] Thus, it is essential for TVET institutions to develop a DT ecosystem.

Grech[38] identified various stakeholder groups with legitimate interests in the DT of the TVET sector and developed a model recognizing the significant roles they play in creating a coherent TVET system that aligns education and skill development with labor market demands, as shown in Figure 1. Sgarzi[39] divided TVET stakeholders into macro-level stakeholders (ministries, statutory bodies, *etc.*), meso-level stakeholders (business associations, trade unions, research institutes, non-governmental organizations [NGOs], *etc.*), and micro-level stakeholders (TVET schools, companies, and other TVET providers). The author emphasized the roles and contributions of meso-level stakeholders in identifying new qualifications and competencies demanded by the future labor market and prompting their integration into curriculum development and implementation.[39]

The stakeholders identified by Grech and Sgarzi include external stakeholders, such as governments and business sectors, and internal stakeholders within TVET institutions. Both studies affirmed the contributions of the business sectors to TVET. However, Grech's study considered the impact of the information and communication technology (ICT) sector, which Sgarzi did not emphasize. Grech's model is more comprehensive and appropriate for the context of DT in TVET.

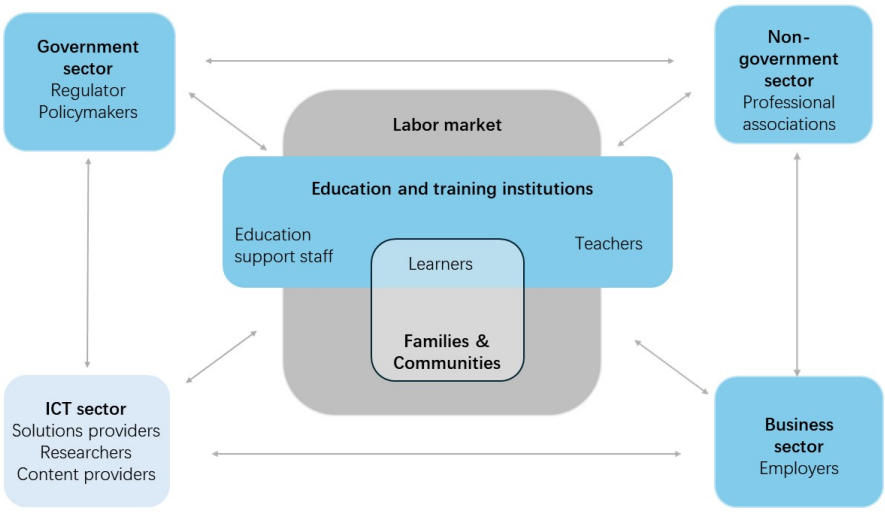

Figure 1. Stakeholders in the TVET and skill development ecosystem. Data source: Grech.[38] TVET, technical and vocational education and training; ICT, information and communication technology.

China definitely emphasizes the involvement of industry stakeholders in TVET. The government has introduced a series of guidance documents aimed at fostering collaboration between industries and TVET providers to bolster the quality of TVET.[40] Engaging with industries is also regarded as a pivotal strategy for TVET providers to spearhead DT efforts.[41]

In summary, studies from diverse countries have uniformly underscored the need to nurture ecosystems to support DT in TVET, and they have highlighted the pivotal contributions of stakeholders from various industry sectors.

MATERIALS AND METHODS

The case study method can deepen comprehension and enrich learning outcomes, acting as a conduit between theoretical knowledge and practical application, thereby fostering a conducive environment for exploration and critical thinking.[42–44] Consequently, we employed a case study approach to delve into the pathways and strategies facilitating the DT of TVET program development.

According to the *Digital China Development Report (2022)* issued by the Cyberspace Administration of China, the exponential growth of China's digital economy to RMB 50.2 trillion in 2022, positioning it as the world's second-largest, with a significant contribution of 41.5% to the country's gross domestic product (GDP),[45] underscores the importance of studying how TVET providers in China are responding to this rapid development. SZPU—a tertiary-level public TVET institution in China—was founded in 1993 as Shenzhen Polytechnic (SZPT) and was later upgraded to a university in 2023. It offers a wide range of higher TVET diploma programs for secondary graduates, and it began offering undergraduate degree programs in 2023 to fulfill the needs of Shenzhen and the wider area. SZPU has received numerous educational accolades and boasts a consistently high graduate employment rate.[46] Given its prominent position as a leading TVET provider in China, SZPU presented an intriguing case for investigation.

The research questions (RQs) guiding this study were as follows: (1). How does SZPU execute the DT of TVET program development in relation to institutional strategies, TVET program planning, and ecosystem development? (2). What valuable insights can be gleaned from SZPU's DT practices?

We gathered the qualitative data for this study from various sources accessible to the authors, as follows: (1). SZPU documents, including strategies, policies, action plans, guidelines, regulations, program syllabi, and statistics from the SZPU Academic Office. (2). Twenty-one promising practice reports about the aims, approaches, and outcomes of the DT of different TVET programs, which were collected through a survey distributed to TVET program directors/faculty leaders at SZPU. (3). Previous academic research papers regarding educational concepts, strategies, and practices at SZPU. (4). Relevant public documents issued by Chinese educational departments at various levels, which were consulted to contextualize the university's initiatives within broader educational policies. (5). Information from the official websites of SZPU and its stakeholders, as well as from other relevant authorities. We analyzed these documents to ensure a comprehensive understanding of the DT of TVET programs at

SZPU and to provide valuable insights into SZPU's DT practices.

Given its suitability for examining qualitative data, such as those drawn from open-ended questions, textual materials, and interviews, content analysis can offer valuable insights into intricate human cognition and language usage,[47] and we therefore chose it as the primary method of data analysis for this study. We conducted the analysis using the following steps.

Step 1: selection and screening of SZPU documents

The first step involved identifying and selecting SZPU documents that were crucial to the DT of TVET programs and filtering them to extract content specifically related to the DT of TVET programs.

Step 2: content organization and summarization

After identifying the relevant documents, we organized and categorized the content into three main themes: DT strategies, TVET program planning, and ecosystem development and stakeholder relationship management.

Step 3: analysis of promising practice reports

TVET program directors and faculty leaders implemented the DT of TVET programs at SZPU. We analyzed promising practice reports to discover implementers' responses to and views about SZPU's DT strategies, which helped us understand the outcomes of the strategies.

Step 4: enrichment and corroboration with additional sources.

In this step, we reviewed previous academic research and consulted relevant documents issued by Chinese educational departments to obtain supporting examples and evidence from the Internet to validate the analysis conducted in Step 2.

Step 5: formulation of findings

We summarized the analytical results from the preceding steps and formulated them to answer RQ1.

Step 6: identification of valuable insights

In this step, we combined the findings and outcomes of the literature review to highlight the unique aspects and successful strategies of SZPU's DT, identify the factors underpinning SZPU's successful DT initiatives, and highlight practices that can be adopted by other institutions. Based on these steps, we answered RQ2.

FINDINGS

SZPU's DT strategies and implementers' responses

To stay abreast of rapid advances in digital technologies and meet the evolving demands of the labor market within the digital economy, SZPU initiated three institutional action plans to serve as cornerstones of its DT strategies.

In 2019, SZPU released the *Artificial Intelligence Action Plan*—a strategic initiative crafted in response to the burgeoning growth of the AI industry. The aim of this action plan is to enhance the integration of AI technologies across various SZPU operations, thereby catalyzing the transformation of TVET within the institution's purview. Comprising 20 distinct actions, the plan encompasses a broad spectrum of institutional functions, including the development of TVET programs and resources, capacity building for teachers, infrastructure enhancements, scientific research endeavors, and improvements in institutional services and management. Key components of the plan pertaining to TVET program development include the development of an AI program, along with associated teaching and learning resources and infrastructure. Additionally, the plan underscores the need to infuse AI technology into other TVET programs, thereby ensuring their relevance and alignment with contemporary industry demands.

In 2020, SZPU unveiled its *Action Plan for the Transformation and Upgrading of TVET Programs*, marking a pivotal step toward the DT of TVET program development. This comprehensive strategy encompasses 10 strategic actions aimed at modernizing and digitizing various aspects of TVET programs. It represents a systematic and comprehensive approach to conducting the DT of TVET program development. The 10 actions are as follows.

1. Enhancing the TVET program structure by developing new TVET programs, improving traditional TVET programs, and enhancing program cluster management.
2. Elevating the quality and relevance of program content to meet contemporary industry standards.
3. Revamping curricula to integrate emerging technologies and industry trends.
4. Enhancing practical training by upgrading training environments to create more practical training opportunities and forms, encouraging skill development.
5. Developing teaching and learning resources, especially digital resources.
6. Strengthening teachers' and trainers' professional capacities.
7. Improving the delivery of teaching and learning

experiences through innovative pedagogical approaches and by developing smart online and offline learning environments.

8. Enhancing evaluations, including enhancing learning assessment methods to effectively gage student learning outcomes and provide evaluation and corrective services for program development.
9. Fostering educational research initiatives to drive innovation and excellence in TVET.
10. Facilitating international exchange programs to promote cross-cultural peer learning and collaboration.

In 2022, SZPU released the *Digital Transformation Action Plan*, which includes 30 actions for the next 5 years that are practical across all aspects of the university's operations. This action plan is comprehensive and systematic, following the global DT trend. Compared with the previous two action plans, this action plan includes the following improvements: (1). Vigorously investing in the development of various digital resources, platforms, and data banks. (2). Strengthening the development of qualifications and skill certificates, with an emphasis on the development of microcredentials. (3). Emphasizing the importance of cooperation with industries and enterprises. (4). Placing greater emphasis on international cooperation and exchanges to conduct international academic activities, reflecting a desire to engage in mutual learning with international counterparts and to jointly promote the development of vocational education. (5).Catering to the needs of both full-time and part-time learners seeking upskilling and reskilling opportunities.

According to the analysis of the promising practice reports, SZPU implementers' responses to the DT of TVET programs can be summarized as follows: (1). The methods and approaches adopted by DT implementers for TVET programs were derived from the aforementioned action plans, such as enhancing program content, developing digital resources, and improving the digital teaching environment. (2). Implementers reported that DT efforts in recent years have improved teaching outcomes. Specific achievements included teachers winning teaching awards, students winning professional skill competition awards, successfully conducting teaching activities during the COVID-19 pandemic, and receiving positive feedback from employers. (3). Implementers expressed strong agreement with the strategies mentioned in the aforementioned action plans, believing that these strategies effectively guide the DT of TVET program development and are worth promoting among their peers.

TVET program planning

Industry tracking

SZPU mainly uses three methods to ensure the relevance and effectiveness of TVET programs, including the timely and accurate tracking of industry DT and corresponding shifts in labor market needs.

A large-scale "Investigation into One Thousand Enterprises" is conducted annually, targeting enterprises located in Shenzhen and its surrounding areas. The total number of surveyed enterprises exceeds 1000, with a minimum of 30% representing the world's top 500 enterprises, industry leaders, or large-scale establishments. The remainder comprise small, medium, and micro-sized enterprises, alongside entities classified as "unicorns", "little giants", or "specialized and newly emerging" enterprises. The investigations take various forms, including enterprise visits, expert consultations, discussions, exchanges, participatory activities, and questionnaire surveys. The primary foci of the research are as follows.

1. Examination of the market environment and developmental trajectories of industry enterprises.
2. Analysis of the industry's DT trends.
3. Evaluation of job positions, tasks, knowledge, skills, and quality requirements for prospective graduates.
4. Facilitation of cooperation initiatives.
5. Investigation of the employment situation of graduates, such as salary, employers feedback.
6. Assessment of enterprises' expectations regarding curriculum structures and qualification requirements.
7. Identification of bottlenecks that may hinder enterprises' technological advances
8. Exploration of enterprises' demands for new technologies and products through research and development.
9. Identification of needs for university-enterprise joint research and development centers.

Another industry tracking method is deep cooperation with enterprises to codevelop TVET programs and joint research. Enterprise partners bring the most recent industry information to the cooperation, and they discuss the findings of research on ecosystem development and stakeholder relationship management.

Furthermore, recognizing the critical importance of data-driven insights, SZPU has implemented a robust big data analysis platform. Leveraging cutting-edge digital technologies, this platform facilitates expedited data collection and sophisticated data analysis techniques, empowering SZPU to track and analyze evolving industry needs with greater speed and precision.[48] According to SZPU's *Digital Transformation Action Plan*, the big data platform will continue to be updated and improved, and the accuracy and timeliness of data tracking will be further improved.

By continuously tracking the development and needs of industry, SZPU can ensure the relevance and effectiveness of TVET programs, the timely and accurate tracking of industry DT, and monitoring of the corresponding labor market shifts in Shenzhen and the surrounding area.

TVET Program Evaluation

SZPU has introduced a robust evaluation mechanism specifically tailored to its TVET programs. The evaluated factors include the rationality of program syllabi and curricula development, teachers' capacities, teaching and learning resource development, and the feedback and satisfaction of employers. This systematic evaluation process is conducted annually to assess the alignment of each program with the evolving needs of various industries. By implementing this mechanism, SZPU can rigorously measure the extent to which current curricula adhere to and support the developmental trajectories of relevant industry sectors. This ongoing evaluation plays a pivotal role in ensuring that TVET programs are both contemporaneously and proactively adapted to the DT of industry. The findings derived from these evaluations are critical for directing DT in the TVET program setting.

Directions of DT of TVET program design

Based on the results of industry tracking and program evaluation, SZPU designs DT for TVET programs by establishing new programs, upgrading traditional programs to new programs, and improving current programs.

Establishing new programs

In recent years, SZPU has developed several TVET programs relating to digital technology. The Table 1 lists the new programs introduced from 2018 onward.

These new TVET programs mainly cover two categories: emerging digital technology programs, such as Artificial Intelligence Technology and Big Data Technology, which are designed to provide talent for digital technology industries, and interdisciplinary programs, such as Smart Health and Elderly Service Management and Cross-Border E-Commerce, which are designed to meet the needs of new positions generated by the application of new technologies in traditional industries. Overall these new programs fill new and future positions in Shenzhen and the surrounding areas. For example, Shenzhen is working on health services innovation,[49] and the Smart Health and Elderly Service Management program is designed to support this innovation.

Upgrading traditional programs to new programs

In response to the DT of traditional industries, SZPU upgraded some traditional programs to news programs. The Table 2 shows the upgrades from 2021 to 2023.

The programs in Table 2 serve the printing, automobile, financial, and construction industries. Technological developments in recent years, including the development of digital technologies, have catalyzed tremendous changes in these industries. For example, FinTech encompasses a broad range of technologies aimed at improving financial services, including data security, service delivery, and infrastructure, which have revolutionized the financial industry.[50] Meanwhile, the digital economy has become the most active component of Shenzhen's economic and social development, with digital finance being particularly prominent.[51] Thus, SZPU upgraded its Financial Services and Management program to FinTech Application to keep pace with the development of Shenzhen's financial industry and to help students obtain both financial knowledge and FinTech operational skills.

Improving current programs

Improving current programs primarily involves the timely integration of the latest technologies into both program syllabi and curricula. This approach is applied not only to current digital technology programs but also to traditional, nondigital technology-related programs. For example, the Electronic Information and Engineering Technology program was developed in 1994 to cultivate talent for the ICT industry. Although it is one of the SZPU programs with the longest history, it is still keeping pace with the rapid development of the ICT industry and remains one of the university's most popular programs for students and employers. The secret of its success is its continual integration of the latest ICT technologies into its syllabi in cooperation with leading enterprises. In recent years, SZPU has worked with Huawei to develop the knowledge and skills required for Huawei certification in its program syllabi and curricula. Thus, it helps students obtain Huawei certification through their university studies, preparing them for jobs following graduation.[52]

Program cluster development

Developing program clusters is one of SZPU's strategies for ensuring the DT of TVET program development. Currently, SZPU has developed 16 program clusters, each of which includes several relevant TVET programs. For example, the Artificial Intelligence Technologies cluster includes the Artificial Intelligence Technologies, Computer Application Technology, Software Technology, Cloud Computing Technology Application, Big Data Technology Application, Virtual Reality Application Technology, and Blockchain Technology Application programs. The programs under the Artificial Intelligence Technologies program cluster coalesce within the realm of computational sciences and share

Table 1: List of SZPU's new TVET programs

Names of new programs	Year of establishment
Application of Information Security Technology	2018
Big Data Technology	2018
Industrial Robotics	2018
Virtual Reality Technology Application	2019
Artificial Intelligence Technology	2020
Smart Health and Elderly Service Management	2020
Animation Production Technology	2020
Integrated Circuit Techniques	2021
Blockchain Technology Application	2021
Communication Software Technology	2021
Industrial Internet Technology	2022
Cross-Border E-Commerce	2022
UAV Application Technology	2022

Data source: Compiled by the author based on statistics from SZPU's academic office. SZPU, Shenzhen Polytechnic University; TVET, technical and vocational education and training; UAV, unmanned aerial vehicle.

Table 2: List of the new programs upgraded from traditional programs

Name of traditional (original) programs	Name of new programs	Year of upgradation
Digital Graphic Printing Technology	Digital Graphic and Information Processing Technology	2021
Automobile Detection and Maintenance Technology	Intelligent Connected Vehicle Technology	2021
Financial Services and Management	FinTech Application	2021
Real Estate Management	Smart City Management	2023
Construction Management	Intelligent Construction Technology	2023

Data source: compiled by the author based on statistics from SZPU's academic office. SZPU, Shenzhen Polytechnic University.

interdisciplinary integration, common fields of application, and mutual dependence. While each program focuses on distinct technologies or applications, the programs intersect significantly, collectively equipping students with the essential skills needed to excel in the evolving modern computational science and technology workforce.

SZPU adopts a comprehensive approach to developing program clusters, encompassing the creation of TVET program syllabi, curricula, teaching and learning resources, online platforms, training centers, and other related resources, primarily designing each cluster as a unified entity rather than a collection of individual programs. The practical benefits of this approach are diverse. First, it fosters commonality and relevance among the programs to support resource development efforts. Second, the approach promotes interdisciplinary collaboration on student projects, nurturing students' proficiency in diverse skills and fostering interdisciplinary aptitude. Third, through shared elective curricula within a cluster, students benefit from enhanced flexibility of learning content while maintaining a structured approach to their education.

Ecosystem development and stakeholder relationship management

SZPU has diverse stakeholders in the DT ecosystem. SZPU's internal stakeholders include administrators, support staff, teachers, and learners. External stakeholders include the government, industry sectors, the digital technology sector, other domestic TVET organizations and providers, international organizations, and global TVET providers.

Stakeholders' roles and contributions to the ecosystem

Each stakeholder in SZPU's ecosystem plays a distinct and vital role in the DT process. Internal stakeholders are directly involved in the implementation and use of digital technologies, while external stakeholders provide the necessary support, resources, and frameworks to ensure that these efforts are successful and sustainable. Effective collaboration and communication among all of these stakeholders are essential for achieving full DT potential. Table 3 summarizes the roles and contributions of each stakeholder in SZPU's DT ecosystem for TVET program development.

"Nine Joint Actions with Industry Sectors" education model and industrial colleges

Relationships with industry sectors are vital for SZPU. After years of exploring such relationships, SZPU's leaders developed an education model—the "Nine Joint Actions with Industry Sectors" model—to establish relationships with stakeholders from different industry sectors. The nine joint actions include joint governance and culture development, joint development of program syllabi and curricula, joint building of faculty teams, joint research on applied technologies, joint development of industrial standards, joint development of qualifications and certificates, joint provision of innovation and entrepreneurship education, joint engagement in modern apprenticeships and community services, and joint establishment of overseas TVET skill development centers.[55] SZPU has established 18 joint industrial colleges with large corporations in appropriate industries, such as Huawei, BYD Auto, Han's Laser, and China Merchants Group,[46] to implement the nine joint actions.[55] Employing this approach provides many benefits for both sides. In terms of the DT of TVET program development, SZPT can leverage the most up-to-date DT expertise from the private sector, thereby bolstering the relevance of TVET programs. Meanwhile, industry sectors can benefit from jointly establishing and promoting industrial standards and ensuring that graduates meet the needs of enterprises to reduce human resource costs.

DISCUSSION

The findings presented in this paper illustrate and analyze SZPU's institutional DT strategies, TVET program planning, and ecosystem development, answering the first RQ regarding how SZPU executes the DT of its TVET program development. By examining SZPU's practices in detail, the following valuable insights can be drawn to answer RQ2.

Digital leadership

Leadership has played a paramount role in SZPU's DT journey and implementors' responses. The institution's leaders have been instrumental in steering and overseeing the implementation of DT initiatives. They meticulously craft and regularly update SZPU's action plans for DT, providing the guiding ideology and strategic blueprint for the entire process. This proactive approach to leadership has been pivotal in ensuring SZPU's successful digital evolution. An analysis of SZPU's three successive action plans reveals a deepening understanding of DT in TVET, underscoring the continuous refinement of the institution's digital leadership. This iterative process not only reflects SZPU's commitment to staying abreast of evolving digital trends but also highlights the leaders' dedication to enhancing their digital acumen. Contemporary research corroborates the significance of leadership in fostering DT endeavors and emphasizes the pivotal role of digital leadership.[56] Therefore, SZPU's experience underscores the need for leaders in TVET institutions to possess and continually enhance their digital literacy. Thus, they can effectively spearhead institutional DT efforts, ensuring their relevance and competitiveness in today's rapidly evolving digital landscape.

Meeting the demands of digital industrialization and the digitalization of industry

SZPU's directions for TVET program design reflect its response to the impact of digital industrialization and the ongoing digitalization of industry. The establishment of new emerging digital technology programs, and the enhancement of existing ones, demonstrates a proactive response to digital industrialization. Meanwhile, the development of interdisciplinary programs and the upgrading of traditional nondigital technology-related programs are also strategic responses to the broader trend of industry digitalization. Together, these initiatives constitute a compelling rationale for the DT of TVET program design. By aligning TVET programs with the evolving needs of diverse industries, SZPU demonstrates a strategic approach to adapting TVET programs to meet the demands of a rapidly changing digital landscape, which could serve as a reference for other TVET institutions.

Alignment with DT trends in TVET program development

Through the literature review, we identified three key areas of SZPU's DT practices. First, SZPU emphasizes the development of interdisciplinary programs, promoting collaboration across disciplines and integrating the latest technologies into syllabi and curricula to cultivate versatile abilities and cross-disciplinary competencies. Second, SZPU strategically develops program clusters, capitalizing on the advantages they offer. Third, SZPU enhances program flexibility by sharing elective curricula within clusters and offering microcredentials. These practices serve as valuable references for institutions seeking to adapt to the digital era in TVET program development.

Success in cooperation with enterprises

Industry sectors are an indispensable part of SZPU's DT ecosystem. SZPU's "Nine Joint Actions with Industry Sectors" model effectively addresses the skill mismatch between supply and demand. The success of this model hinges on two key factors. First, the cooperation between TVET and industry sectors is built upon industrial colleges jointly established by TVET institutions and leading enterprises. These industrial

Table 3: Roles and contributions of stakeholders in SZPU's ecosystem

Stakeholders	Stakeholders' roles	Examples of the main contributions to SZPU's DT
Administrators (including SZPU leaders, development and planning officers, academic affairs officers, *etc.*)	Leaders and coordinators: develop strategies, provide vision, establish policies and regulations, develop action plans, provide guidance, allocate resources, *etc.*	Developed three action plans Developed strategic guidance for TVET program development Developed a DT ecosystem Evaluate TVET program development annually
Teachers (including faculty leaders, program directors, teachers, and trainers)	Main implementers: track industry developments and needs, develop program syllabi and curricula, develop teaching and learning resources, develop new qualifications, deploy digital tools to support the educational process, *etc.*	Developed program syllabi and curricula Developed online courses on the iStudy platform and national platform Used digital education technologies and pedagogies to enhance teaching outcomes
Support staff (including IT personnel and other nonteaching staff)	Supporters: ensure the smooth operation of digital systems, manage technical issues, and support teachers and learners in using digital tools	Developed the iStudy online platform Provide annual teacher training Developed a big data platform for industry tracking
Students (including full-time and part-time students)	Learners: end users of the DT efforts	Understood digital learning targets Acquired digital skills Provided feedback
Government (national authorities, statutory bodies, and local regulatory departments)	Policymakers, advisors, sponsors, and coordinators: develop policies, provide guidance, offer funds, encourage cooperation	Launched a series of DT policies and regulations Developed the *Catalog of TVET Programs (2021)*[53] Developed Smart Education Platform of China[54]
Industry sectors (companies across all types of industries)	Program codevelopers: provide updated information on industry developments and codevelop TVET programs with SZPU	Provided expertise Codeveloped program syllabi and curricula Codeveloped qualifications and certifications Provided enterprise trainers
Digital technology sector (digital technology researchers, companies, *etc.*)	Technology leader: leading technological innovation	Developed emerging digital technologies that impact all industry sectors, including the TVET sector Provided lastest digital educational technologies
Domestic TVET organizations and providers (including TVET associations, NGOs, and other TVET providers)	Peer teaching and learning resource codevelopers: cooperate to enhance the DT of TVET	Organized and participated in academic activities to offer peer learning and sharing Codeveloped online resources for national public online platforms
International organizations (*e.g.*, UNESCO and UNEVOC)	Theoretical leaders: facilitate knowledge exchanges and provide platforms for international collaboration	Published research reports Organized international cooperation projects, such as the i-hub and BILT projects
Global TVET providers (TVET providers in other countries)	Peers: provide peer learning and sharing	Provide peer learning and sharing through international conferences, projects, *etc.*

SZPU, Shenzhen Polytechnic University; TVET, technical and vocational education and training; NGOs, non-governmental organizations; DT, digital transformation; IT, information technology; UNESCO, United Nations Educational, Scientific and Cultural Organization; UNEVOC, International Centre for Technical and Vocational Education and Training; BILT, bridging innovation and learning in TVET.

colleges align their educational frameworks with the needs of the industrial chain, leveraging resources from both sides to create a synergistic advantage. They can also quickly adopt the latest technologies and accurately forecast vocational and professional skill needs. Second, the "Nine Joint Actions with Industry Sectors" model facilitates nine cooperative approaches, fostering close TVET institution-industry partnerships that enable TVET institutions to create an innovative ecosystem with industry sectors to support DT and enhance the relevance, quality, and attractiveness of TVET.

Expanding the groups of stakeholders in the ecosystem

Unlike Grech and Sgarzi, SZPU identified more refined groups of stakeholders. SZPU also considers relationships with domestic TVET providers and international TVET organizations and stakeholders. By engaging with a broad range of entities, SZPU ensures their comprehensive involvement in its activities, fostering stronger relationships and collaborations across different sectors and geographical boundaries. This inclusive approach also provides SZPU with diverse perspectives and expertise, enriching its decision-making processes and enhancing program quality through the incorporation of global best practices. Fostering relationships with domestic and international stakeholders enriches SZPU's stakeholder engagement, strengthens its global presence, and enhances its capacity to effectively address complex education challenges.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

In this study, we explored SZPU's DT practices for TVET program development. Our analysis of SZPU's institutional DT strategies, TVET program planning, and ecosystem development offers valuable insights into the execution of DT in TVET program development.

Leadership emerged as a critical factor for driving DT, and SZPU's proactive leadership set the scene for successful DT. By continually refining their digital acumen and action plans, SZPU's leaders demonstrate the importance of digital leadership in overcoming the complexities of DT. Moreover, SZPU's response to the demands of digital industrialization and industry digitalization underscores the institution's strategic alignment with evolving industry needs. The establishment of new digital technology programs, the enhancement of existing ones, and the development of interdisciplinary initiatives highlight SZPU's commitment to staying relevant in a rapidly changing digital landscape. Additionally, SZPU's success in cooperating with industry sectors exemplifies the importance of public-private partnerships for addressing skill mismatches and fostering innovation in TVET. By leveraging resources from both sides and adopting collaborative approaches, SZPU has created an innovative ecosystem that supports DT and enhances the quality and attractiveness of TVET.

Future researchers could continue to explore the DT practices of TVET from different perspectives using different research methods. For example, the development and introduction of microcredentials is worthy of study. In China, higher TVET institutions, represented by SZPU, are exploring the development of microcredentials, but their integration into formal education still raises many issues that must be discussed and solved.

DECLARATIONS

Author contributions

Lin QM: Conceptualization, Writing—original draft preparation, Writing—review and editing. Pang HNH: Writing—Review and Editing. All authors have read and approved the final version.

Source of funding

This research received no external funding.

Ethical approval

Not applicable.

Conflict of interest

The authors have no conflicts of interest to declare.

Data availability statement

Data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES

1. Dobbs R, Manyika J, Woetzel J. *No ordinary disruption: The four global forces breaking all the trends*. Public Affairs; 2015.
2. Hawksworth J, Berriman R, Goel S. *Will robots really steal our jobs? An international analysis of the potential long term impact of automation*. PwC; 2018.
3. PwC. *What will be the net impact of AI and related technologies on jobs in China?* PwC; 2018.
4. Frey CB, Osborne MA. The future of employment: How susceptible are jobs to computerisation? *Technol Forecast Soc Change*. 2017;114:254-280.
5. *The future of jobs report 2020*. World Economic Forum; 2020.
6. *Future of jobs report 2023*. World Economic Forum; 2023.
7. OECD. *OECD skills outlook 2019: thriving in a digital world*. OECD; 2019.
8. Arnhold N, Bassett RM. *Steering tertiary education: toward resilient systems that deliver for all*. The World Bank; 2021.
9. UNESCO. *Medium-term strategy for 2022-2029*. UNESCO; 2022.
10. UNESCO. *Transforming technical and vocational education and training for successful and just transitions: UNESCO strategy 2022-2029*. UNESCO; 2022.
11. Broadband Commission for Sustainable Development, ITU, UNESCO, UNICEF. *The Digital Transformation of education: connecting schools, empowering learners*. Broadband Commission for Sustainable Development; 2020.
12. UNESCO. *Beijing consensus on artificial intelligence and education*. UNESCO; 2019.
13. European Union. *Digital education action plan (2021-2027)*. European Union; 2020.
14. Hu M. *Digital Transformation: from strategy to execution*. Huawei; 2022.
15. UNESCO. *Enhancing TVET through DT in Developing Countries*. UNESCO; 2023.
16. UNESCO-ICHEI, Tsinghua University. *Research report on DT of higher education teaching and learning*. UNESCO-ICHEI; 2022.
17. Chen X, He S. [The value, characteristic and pathway of DT in TVET programs]. *Educ Vocat*. 2023;1041(17):56-60.
18. Hou X. [Exploration on DT of higher vocational logistics education]. *J Liaoning Prov Coll Commun*. 25(6):68-71.
19. [*White Paper on China's Digital Economy Development (2017)*]. CAICT; 2017.
20. Sun Z, Fu B. [On the difinition and uniform use of "digital industrialization"]. *Credit Ref*. 2022;40(12):16-24.
21. Fang Z, Ji L, Cheng C. [Research on industrial digitalization characteristics and its new requirements for vocational education]. *J Beijing Polytech Coll*. 2020;19(2):48-51.
22. Zhou C, Li J. [Research on the influence of vocational education in the era of digital economy]. *Shanghai Light Ind*. 2024;(1):156-158.
23. Ely R. DevOps Institute's "Upskilling 2020: Enterprise DevOps Skills Report" Spotlights Need for Human Transformation. DevOps Institute. Accessed May 9, 2024. https://www.devopsinstitute.com/devops-institutes-upskilling-2020-enterprise-devops-skills-report-spotlights-need-for-human-transformation/
24. Adams RS, Turns J, Atman CJ. Educating effective engineering designers: the role of reflective practice. *Des Stud*. 2003;24(3):275-294.
25. Malinnikova TV, Rabinovich PD, Matviyuk ES, Kulikova IY, Nekrasova OA, Apenko SN. Organization and methodology for interdisciplinary training for functional literacy in the digital economy. *Educ Self Dev*. 2020;15(4):111-126.
26. Education on Line. [The New Liberal Arts Declaration was officially released]. Accessed May 9, 2024. https://news.eol.cn/yaowen/202011/t20201103_2029763.shtml
27. Li Y. [The development and trend of specialty cluster in developed countries or areas-Case study of America, Japan and Taiwan]. *Educ Exam*. 2019;(1):85-90.
28. Zhang Y, Lu L. [Research on the construction of professional groups in higher vocational colleges under the background of integration of industry and education]. *Shipbuild Vocat Educ*. 2023;11(6):14-16.
29. Ma T, Wang J. [From specialties to specialty group: industrial demand logic of specialty group construction in higher vocational colleges]. *Chin Vocat Tech Educ*. 2021;37(8):11-15.
30. Pérez-Garcias A, Tur G, Villatoro Moral S, Darder-Mésquida A.

Flexible Learning Itineraries in Digital Environments for Personalised Learning in Teacher Training. *RIED-Rev Iberoam Educ Distancia*. 2022;25(2):173-188.

31. Vanermen L, Vlieghe J, Decuypere M. Curriculum meets platform: A reconceptualisation of flexible pathways in open and higher education. *Curric Inq*. 2022;52(4):443-468.
32. Micro and Alternative Credentials. Size, Shape and Scenarios—Part 1. HolonIQ. Accessed May 16, 2024. https://www.holoniq.com/notes/micro-and-alternative-credentials-size-shape-and-scenarios-part-1
33. Pirkkalainen H, Sood I, Napoles PC, Kukkonen A, Camilleri A. How might micro-credentials influence institutions and empower learners in higher education? *Educ Res*. 2023;65(1):40-63.
34. McGreal R, Mackintosh W, Cox G, Olcott Jr. D. Bridging the Gap: Micro-credentials for Development: UNESCO Chairs Policy Brief Form—Under the III World Higher Education Conference (WHEC 2021) Type: Collective X. *Int Rev Res Open Distrib Learn*. 2022;23(3):288-302.
35. Berkling K, Hänisch T, Schütz F. Transforming CS Curricula into EU-Standardized Micro-Credentials. *Athens J Technol Eng*. 2023;10(3):161-174.
36. Martin M Van der Hijden P. *Short Courses, Micro-Credentials, and Flexible Learning Pathways: A Blueprint for Policy Development and Action: (Policy Paper)*. UNESCO-IIEP; 2023.
37. UNESCO-UNEVOC. *Innovating Technical and Vocational Education and Training: A Framework for Institutions*. UNESCO-UNEVOC; 2020.
38. Grech A. *Digital transformation of TVET and Skills Development Systems in Africa: Strategic planning framework*. IIEP-UNESCO Dakar; 2023.
39. Sgarzi M. *New Qualifications and Competencies for Future-oriented TVET-Volume 2 TVET Advocacy: Ensuring Multi-stakeholder Participation*. UNESCO-UNEVOC; 2021.
40. Cai R, Li Y. [The transition between old and new dynamics to facilitate the high quality development of the integration between enterprises and universities in a new era]. *Mod Educ Manag*. 2020;8:115-112.
41. Yang C. [Research on Digital Transformation of Higher Vocational Education Under the Background of Deep integrationof Industry and Education]. *J Shangqiu Vocat Tech Coll*. 2024;23(2):54-57.
42. Cousin G. Case Study Research. *J Geogr High Educ*. 2005;29(3):421-427.
43. Gerring J. What Is a Case Study and What Is It Good for? *Am Polit Sci Rev*. 2004;98(2):341-354.
44. Hamilton L, Corbett-Whittier C. *Using Case Study in Education Research*. SAGE; 2012.
45. Cyberspace Administration of China. [*Digital China Development Report (2022) was issued by Cyberspace Administration of China*]. Accessed May 12, 2024. https://www.cac.gov.cn/2023-05/22/c_1686402318492248.htm
46. Shenzhen Polytechnic University. About Shenzhen Polytechnic University. Accessed May 13, 2024. https://www.szpu.edu.cn/xxgk/xxjj.htm
47. Content Analysis. Columbia University Mailman School of Public Health. Accessed May 12, 2024. https://www.publichealth.columbia.edu/research/population-health-methods/content-analysis
48. Xu J, Jiang T, Wei M, Qing Z. The digital transformation of vocational education: Experience and reflections of Shenzhen Polytechnic University. *Vocat Technol Educ*. 2024;1:2.
49. Shenzhen Government Online. High-Quality Development. Shenzhen Government Online. Accessed May 14, 2024. https://www.sz.gov.cn/en_szgov/aboutsz/profile/content/post_10870036.html
50. Goldstein I, Jiang W, Karolyi GA. To FinTech and Beyond. *SSRN Electron J*. 2019; 32(5):1647-1661.
51. [Relying on the digital economy to build new heights of digital finance in Shenzhen]. Shenzhen National high-tech Industry Innovation Center. Accessed May 15, 2024. https://fgw.sz.gov.cn/hiic/zlzx/zyztyj/jjgc/content/post_8650537.html
52. Shenzhen Polytechnic. Huawei Certification to ICT Programmes. UNESCO-UNEVOC; 2021.
53. [Catalog of TVET Programs (2021)]. Ministry of Education of the People's Republic of China. Accessed May 21, 2024. http://www.moe.gov.cn/s78/A07/zcs_ztzl/2017_zt06/17zt06_bznr/zhijiao/
54. Smart Education Platform of China: Laureate of UNESCO Prize for ICT in Education. UNESCO. Accessed May 21, 2024. https://www.unesco.org/en/articles/smart-education-platform-china-laureate-unesco-prize-ict-education
55. Wu F, He S, Chen Q. [Exploration and Research on the "Nine Commons" Practice in industrial Colleges Taking the Yutong School of Graphic Communication at Shenzhen Vocational College as an example]. *Green Packag*. 2023;(10):56-60.
56. Türk A. Digital leadership role in developing business strategy suitable for DT. *Front Psychol*. 2023;13:1066180.