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ORIGINAL ARTICLE

A critical examination on EdTech integration in TVET curriculum: Insights from a Chinese TVET institution

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ABSTRACT

This study critically examines the integration of educational technology (EdTech) within the curriculum of a leading technical and vocational education and training (TVET) institution in China through 32 case studies. By employing qualitative methodologies—including content analysis, network analysis, and textual analysis—this study examines the EdTech spectrum, educational impacts, pedagogical adaptation practices, educational inclusivity, and EdTech applications' socio-technical complexities at the institution. Using a critical perspective, the research highlights EdTech integration practices' current state and challenges. The findings provide a comprehensive understanding of the multifaceted factors that influence EdTech integration in TVET and offer strategic recommendations to develop more supportive, inclusive, and human-centered EdTech integration strategies and practices.

Key words: educational technology, educational technology integration, technical and vocational education and training, Chinese technical and vocational education and training institution

INTRODUCTION

Digital transformation—driven by rapid advancements in cloud computing, artificial intelligence (AI), Internet of Things (IoT), and automation—is profoundly reshaping the global economy, societal structures, and the fabric of individual lives.[1,2] This transformation is redefining business operations, the nature of employment, and societal interactions at an unprecedented pace.[3] As the *UNESCO Strategy for Technical and Vocational Education and Training (TVET) 2022-2029* pointed out, processes such as digitalization and automation are drastically reshaping the workforce and certainly require skilling, reskilling, and upskilling.[4] Within this context, TVET's significance has been amplified, positioning it as a critical mediator in equipping individuals with the necessary vocational skills, adaptability, and 21st century competencies required in the modern workplace. TVET's role extends beyond mere skill acquisition, involving preparation of a workforce so that it is responsive to technological advancements and evolving societal and labor market demands. Despite its potential, TVET systems globally are challenged by the need to remain current amid these rapid technological changes, necessitating integration of innovative approaches in education delivery, development of teachers and trainers' digital skills, and continuous content relevance.[5–7]

In the past 20 years, digital technologies have been used widely among educators, learners, and institutions in educational practices. Educational technology (EdTech),

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within the broader field of educational sciences, refers to the systematic use of technology in education to enhance teaching and learning processes. By leveraging digital tools such as AI, virtual reality/augmented reality (VR/AR), massive open online courses (MOOCs), and collaboration technologies, EdTech promises to enhance TVET's accessibility, engagement, and industry alignment, thereby improving TVET quality.[8] Integrating education technologies is one of the most critical areas of EdTech research.[9] EdTech's value can be viewed primarily as two narratives: (1) EdTech can enhance teaching and learning quality. For example, intelligent tutoring systems and other AI-powered tools can foster knowledge and skill acquisition.[10–12] Furthermore, digital simulation technologies like VR and AR deepen learning immersion and interaction,[13–16] aligning with TVET's focus on practical, skill-based education and facilitating acquisition of vocational skills in a controlled, replicable, and scalable manner. (2) EdTech can enhance educational equity and inclusivity. Broadband Internet, mobile devices, and connected applications allow educators and learners to access educational content anytime, fostering continuous learning opportunities beyond traditional classroom settings. Furthermore, ubiquitous computing technologies enable those in regions with poor educational infrastructures to access global information and computing resources, thereby promoting inclusive learning environments.[17] Open educational resources (OER) provide free, equitable access to quality educational materials; reduce costs; and bridge the digital divide.[18] Finally, online learning platforms and MOOCs have overcome barriers related to time, location, and learning costs to become important alternatives during the COVID-19 pandemic.[19]

In recent years, China has been at the forefront of applying new digital technologies in education, driven by strong market competition and enthusiastic adoption by both the government and education sector, thereby accelerating its development. EdTech's rapid growth in China is supported by abundant data, a flexible regulatory framework, increasing technical expertise, and significant public funding and support; however, structural barriers—such as the pre-eminence of results from admission exams, inadequate technology-related talent, insufficiently qualified teachers, and lack of resources to measure quality—persist.[20] The Chinese government has addressed these limitations proactively by promoting local educational reforms that are scaled nationally based on proven success, reflecting a dynamic and responsive educational policy environment. During the COVID-19 pandemic, China's EdTech sector experienced a "boom time", with public and private initiatives significantly narrowing the educational gap between under-resourced areas and urban centers, demonstrating immense educational potential and economic benefits.[19,20] In the TVET sector, as a crucial component of the public education system in China, an exemplar of this promise in action is Shenzhen Polytechnic University (SZPU), which has integrated EdTech strategically to enhance its TVET offerings, serving as a model of how EdTech can revolutionize TVET in alignment with industry needs.[21]

However, integrating EdTech in TVET delivery requires critical examination. For example, the *Global Education Monitoring Report 2023* pointed out that little evidence exists of any added value from technology use in education.[19] As Castañeda and Williamson have noted,[22] compared with "mainstream" discourse, diverse and critical voices regarding the research and application of EdTech are notably lacking. This critical view of EdTech does not aim to undermine its potential for educational enhancement, but rather urges us to go beyond the goal of finding evidence of its effectiveness in teaching and learning by calling for a critical examination and response to EdTech integration's broader societal impacts. Drawing on the philosophical tradition of the Critical Theory of Technology from the Frankfurt School, Delanty and Harris[23] have argued that awe over technology fosters an affirmative view of society, thereby concealing an ideology of uncritical acceptance. Echoing this perspective in EdTech: "What seems to have been a democratization of information exchange is, in fact, an expedited elite capture of information exchange processes".[23] This perspective gains particular resonance against the backdrop of generative AI's rapid advancement and the intense debates over its role in reshaping future employment, skill requirements, and the workplace.[24]

According to a UNESCO publication, "An ed-tech tragedy?", the enthusiastic adoption of EdTech raises critical questions about its educational effectiveness, accessibility, and equity, particularly in light of the pandemic-induced acceleration in its use.[25] As in the case of the pandemic, it was demonstrated that technology supplanting school-based learning can lead to widening inequalities, decreased mental and physical health among learners and teachers, and risks stemming from increased data capture, surveillance, and machine processes. Despite technological advancements and promises that digital solutions would "save" education, education quality has declined during the pandemic across multiple levels, underscoring the complex dynamics between EdTech and educational practices, institutions, and systems.

Mindful of "technological solutionism" pitfalls, this paper examines a collection of application cases of EdTech use critically in the curriculum from different sectors at SZPU, a leading TVET institution in China. This examination aims to reveal the dynamic interactions between EdTech and educational practices, institutions, and systems, as well as its role in societal relations. By examining EdTech's multifaceted impacts and implementation paths, this study aims to illuminate critical considerations and challenges involved in integrating EdTech. The insights gained aim to inform the development of more supportive, inclusive, and human-centered EdTech integration strategies and practices within TVET.

THE NECESSITY OF SHIFTING TO CRITICAL PERSPECTIVES

Evidence gaps and theoretical voids in EdTech's impact

Notably, research into EdTech integration faces fundamental challenges. First, the extent to which EdTech can enhance education quality remains a highly debated issue. It is well-recognized that EdTech can improve some types of learning in certain educational contexts, but according to the *Global Education Monitoring Report 2023*,[19] reliable and impartial evidence is notably lacking on EdTech's impact in general based on multiple systematic reviews and meta-analyses of studies.[26–30] One possible reason is that EdTech's evolution far outpaces the ability to assess it and provide robust evidence reliably.[19] Similarly, the World Bank's report, *Unleashing the Power of Educational Technology in TVET Systems*, discusses the lag in evaluation and research, noting that the rapid deployment of EdTech has not been accompanied by rigorous assessment, resulting in scarce and fragmented studies covering different technologies, educational and occupational fields, and diverse geographical and institutional contexts.[31] Consequently, the research outcomes are often mixed and indicate no significant effects on the TVET system.

Furthermore, EdTech research has been characterized as lacking well-developed theoretical frameworks. A systematic literature review of 503 high-quality peer-reviewed empirical studies concluded that the EdTech integration field lacks sufficient theoretical foundations, in that only 35% (n = 174) of studies indicated explicit theoretical engagement, making it a highly under-theorized area of research.[32] One possible reason is that most EdTech research is often practice-oriented and context-specific. This lack of robust theoretical frameworks not only undermines the field's academic rigor, but also potentially hampers the effective application and scalability of EdTech solutions in educational settings.

Illusion of inclusivity in digital education

EdTech's potential benefits in TVET are moderated by significant global disparities in TVET access and quality, particularly in low- and middle-income countries.[33] These disparities are influenced by factors such as economic constraints, infrastructural deficits, and limited digital literacy, which collectively contribute to an educational unbalance from a global perspective, as highlighted in the *2020 Global Education Monitoring Report*.[34] The *Global Education Monitoring Report 2023* also shed light on a critical issue within the educational sector: while technology can enhance learning opportunities, it also has the potential to exacerbate existing inequalities in content access.[19] For example, extant research has found that on the primary platforms for MOOCs, 80% of the participants already hold higher education degrees, and a significant proportion of the learners are from developed countries.[19] During the pandemic, it was estimated that approximately half of all students and teachers who were expected to utilize remote learning systems were unable to access these resources, primarily due to significant technological disparities.[35]

Even with proper technological tools and resources in place, the digital skills gap remains a significant barrier to effective EdTech implementation in educational practices. Students lacking specific digital knowledge and skills necessary to utilize technology effectively may not fully benefit from the resources provided, thereby exacerbating the skills gap. This was supported by findings from an Organization for Economic Cooperation and Development (OECD) survey and Program for International Student Assessment (PISA) results from 2018, which suggest that while younger individuals may have easier access to digital tools, those with deficiencies in basic digital skills struggle to handle digital information presented in various formats.[36,37] Furthermore, the challenges observed during the pandemic have underscored that merely providing access to EdTech is insufficient without targeted efforts to bridge these digital skills gaps.[24]

Pedagogical adaptation challenges

Increasingly, researchers are emphasizing that the key factor is how technologies are incorporated into teaching methods, rather than how often they are used.[38] One of the frequent challenges encountered in pursuing EdTech integration is instructors and trainers' capabilities. Numerous studies on EdTech use have suggested that traditional teaching methods often fail to adapt to technology-driven learning.[19,33,35,36]

A critical gap exists in teachers' skills and competencies for adopting new learning modes, and the importance of closing this gap is often overlooked at institutional and governmental levels. The full potential of digital solutions or blended learning—its flexibility, adaptability, and other benefits—can be realized only when adult educators or facilitators receive appropriate training in digital pedagogies.[35] Anderson[39] proposed a four-stage model on adoption and use of information and communication technology (ICT) in teaching (see Figure 1) to contextualize the EdTech integration and pedagogy transformation process. The model underscores a shift from the systematic application of ICT to enhance traditional teaching toward creating and managing more innovative and open learning environments that promote autonomous and facilitated learning experiences.[39] To achieve this progressive enhancement, it is essential to provide additional structured support for teachers and lecturers to facilitate a phased transition in their practices.[14] Policymakers and institutional decision-makers must ensure adequate support for digital transformation initiatives, which include allocating sufficient budgets, establishing dedicated EdTech teams, and providing systematic training programs to enhance teachers and trainers' digital competency.

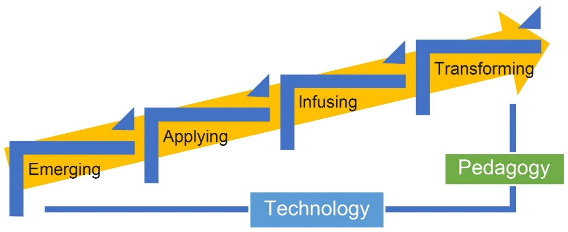

Figure 1. The four stages of ICT adoption in education. Adapted from Anderson.[39] ICT, information and communication technology.

Sociotechnical complexity when integrating EdTech

Notably, integrating EdTech is more than just implementing technology. It involves a complex interplay between social practices, institutional arrangements, policy initiatives, and cultural values. Therefore, it is crucial to consider how technology interacts with TVET institutions' social structures, including the roles and impacts of teachers/trainers, students, management, and external stakeholders. As Castañeda and Williamson noted,[22] the EdTech ecosystem, which expanded rapidly during the COVID-19 pandemic, now includes diverse players such as technology investors, market intelligence agencies, and teacher influencers, who significantly influence its discourses, practices, and policies. Teräs *et al.*[40] examined the education sector's datafication, resulting in a seller's market that prioritizes profit over quality education. As a result, TVET institutions must understand these actors and navigate the EdTech landscape strategically to achieve their educational goals and values through partnerships and technologies. To implement EdTech successfully in TVET, unique educational, societal, and policy contexts must be considered, and technological solutions must be customized to address specific challenges and leverage opportunities for enhancing individual learning outcomes.[41] In our study, we highlight the necessity of being aware of EdTech's integration in broader technological, business, economic, and political contexts, which is vital for TVET as it navigates these complex relationships to integrate EdTech effectively and meet evolving workforce demands.

Research objectives

Having examined the manifold challenges associated with EdTech integration, this paper underscores the importance of adopting a critical perspective. Next, we shift our focus to a TVET institution in China, SZPU, a leading recipient of government investment whose EdTech integration practices provide a unique lens through which to examine these issues. In the following section, we delve into specific instances of EdTech integration at SZPU, demonstrating how lessons can be learned in practice and highlighting areas in need of further improvement. Based on the available data's nature and our study's context, our study examined the following EdTech aspects. 1. The EdTech spectrum: What types of EdTech have been adopted at SZPU at the present time? How do these technologies impact TVET practices? 2. EdTech integration's impact: What significant positive effects from EdTech integration have been reported? 3. Educational inclusion: What major inclusion issue has been identified at SZPU? How was educational inclusion addressed in the EdTech integration process? 4. Pedagogical adaptation: How was pedagogical adaptation achieved when integrating EdTech? 5. Stakeholders and their roles: Who are the key stakeholders, and what key roles are they playing?

ANALYZING EDTECH INTEGRATION CASE STUDIES AT SZPU

Data collection

Given EdTech integration's rather heterogenous nature in TVET, we adopted a holistic approach to delve into practices at SZPU regarding EdTech integration into the curriculum. Our analysis includes a series of comprehensive case studies that documented implementation of EdTech around specific courses, from applied technology disciplines (*e.g.*, Computer Programming in Java, Food Industry Inspection, and Architectural Engineering) to courses in humanities and social sciences (*e.g.*, Entrepreneurial Management, Vocational General English).

These case studies were selected based on the following inclusion criteria: case studies must focus on EdTech integration, represent a diverse range of disciplines, have been implemented for at least one year, cover all teaching units at SZPU, and provide comprehensive documentation. Case studies that lacked detailed documentation, had been implemented for less than one year, or were not representative of SZPU's general practices were excluded. After applying these criteria, we identified 32 suitable case studies that were solicited from 19 departments at SZPU, forming the core content from a comprehensive survey. The case studies meticulously recorded each case's implementation background, educational status prior to transformation, policy roots, and specific implementation pathways. Furthermore, these case studies included goal setting for each case, process management, educational outcome evaluations, and potential issues. Each case's transferability also was considered carefully to assess its applicability and sustainability in different contexts.

These case studies' representativeness stems from their coverage of all teaching units at SZPU and their advanced level of EdTech integration, serving as models for other courses within the institution. We collected these case studies in December 2023, with each one submitted by the course development team responsible for the respective educational program. To enrich the data, we also conducted online interviews with some members of selected course development teams and updated the case studies accordingly.

Approach to analysis

We adopted qualitative methods in our study—including content analysis, network analysis, and textual analysis—to provide a critical evaluation of EdTech practices at SZPU. Our analysis was based on 32 comprehensive case studies. A metadata repository was developed, as outlined in Table 1, to create a structured framework for our analysis. Data relevant to our research questions were extracted and organized using an Excel spreadsheet for comprehensive analysis. Previous systematic literature reviews on similar research interests, such as Lai and Bower's,[42] also adopted this approach. Two trained coders coded the data. Given the small sample size, the coders independently conducted all the coding back-to-back and compared their results upon completion. All discrepancies were discussed repeatedly until a consensus was reached. Recognizing the limitations of a purely meta-analytical approach, we supplemented our analysis with unstructured data from case study texts, interviews with course development teams, and internal administrative documents.

RESULTS AND DISCUSSION

EdTech spectrum overview

To address the study's first research question/aspect, we conducted a content analysis on 32 case studies to identify the array of EdTech integrated across various courses at SZPU. We developed a streamlined categorization system, as outlined in Table 2, based on the preliminary review, with a manual coding process employed to classify these technologies accordingly.

Our analysis revealed a sophisticated adoption of a broad range of technologies at SZPU, with 10 major EdTech categories identified in these case studies, including online platforms, digital simulation, and digital materials, among others (see Table 2). Among these, online platforms (20 cases), digital simulation (18 cases), and digital materials (16 cases) were the most prevalent EdTech forms.

The widespread use of online platforms (20 cases) highlights their central role in modern education. The result was linked closely to SZPU's proprietary online learning platform, iStudy, which was mentioned in 16 cases and was developed around the holistic TVET delivery processes (*e.g.*, catering to digital materials, integrating online teaching activities, student management, assessments, *etc.*), thereby establishing a robust foundation for online and blended learning at the institution. This platform played a pivotal role during the pandemic by ensuring educational continuity and supporting a blended learning model that enhances accessibility and flexibility in education delivery. Furthermore, SZPU collaborates with at least 10 different online learning platform providers, creating an ecosystem with iStudy at its core and various commercial platforms flourishing around it.

The extensive integration of AR, VR, and extended reality (XR) technologies (18 cases, 56.3%) highlights a robust emphasis on immersive learning environments that simulate real-world scenarios, reflecting SZPU's strategic alignment with TVET's core principles—practicality, applicability, and real-world relevance. Cases employing this technology highlighted the importance of adapting practical and experiential learning pedagogies, and mentioned the related pedagogical shift records. The cases also highlighted the affordability of developing digital simulation content, provider involvement, and industry-academic collaboration's essential role in developing simulation-based technologies and educational materials.

Digital materials such as digital textbooks, videos, and animation ranked third, indicating that digitalization has become the norm in educational content delivery. Analyses reveal that they often intersect with other technologies, particularly online platforms (*e.g.*, MOOCs), reflecting their foundational roles in digital learning.

Table 1: The case studies' metadata repository

Category	Indicator	Description
General information	Case ID	From CURR1 to CURR32
	Title of the curriculum involved	-
	Implementation period	-
EdTech integration process	Technology used	Types of technologies used, including AI, VR/AR, LMS, collaborative online platforms, *etc.* Multiple EdTech could be integrated into the same course
	Objectives and goals	The technology's pedagogical intentions and expected outcomes
	Operational steps	The process from technology selection to deployment and utilization
	Stakeholders	Examples include educators, learners, administrative staff, technology providers, *etc.*
	Limitations	Specific limitations encountered during implementation and their potential impacts on outcomes
Impact	Positive impacts identified	Examples include changes in academic performance, engagement levels, satisfaction, *etc.*
	Evidence	Feedback or evaluative data from those involved
Pedagogical adaptation	Pre- and post-EdTech instructional methods	Evolution of teaching strategies due to EdTech adoption
Sociotechnical complexities	Governing policies and regulatory factors	Influence of (national-, municipal-, and institutional-level) policies and regulations on EdTech integration
	Industrial/private-sector factors	Industrial or private sectors' involvement and influence, including partnerships and contributions
	Internal repercussions	EdTech's impact on institutions' internal architecture, culture, and processes
	External engagement	Collaborations with tech vendors, governmental bodies, and sectoral associations
Other	Additional notes	Any additional notes or relevant observations

Some indicators might be inapplicable or not reported in some case studies. AI, artificial intelligence; VR/AR, virtual reality/augmented reality; LMS, learning management system.

Table 2: EdTech used in the case studies

EdTech category	Examples	Number of cases	% of total cases
Online Platforms	"Online Platforms", "MOOC", "Smart Classroom Cloud", "Online Training", "Video Conferencing", "E-learning Platform", "Learning Access Discussion Platform", "Blended Learning"	20	62.5%
Digital Simulation (AR/VR/XR)	"Virtual Reality", "VR", "Virtual Simulation", "Simulation Technology", "Augmented Reality", "AR", "XR"	18	56.3%
Digital Materials	"Digital Textbooks", "Digital Resources", "Teaching Materials", "Course Materials", "Teaching Videos", "Course Animation", "Animation Demonstration", "Video", "Animation"	16	50.0%
Software Tools	"Software Tools", "Figma", "LabVIEW", "UiPath", "CRM software"	11	34.4%
Interactive Systems	"Interactive Data Course Activities", "Interactive Demonstrations", "Interactive Tools"	11	34.4%
Artificial Intelligence	"Artificial Intelligence", "AI", "GPT", "Machine Learning"	6	18.8%
Automated Systems	"Automatic Recording", "Digital Assessment Platform", "Online Judging (OJ) System", "Automated Assessment"	3	9.4%
Digital Twins	"Digital Twins"	2	6.3%
IoT	"Internet of Things"	1	3.1%
3D Printing	"3D Printing"	1	3.1%

Altogether, 32 case studies were analyzed. Multiple EdTech could be employed simultaneously within a single case study. EdTech, educational technology; MOOC, massive open online courses; VR, virtual reality; AR, augmented reality; XR, extended reality; IoT, Internet of Things.

Software tools (11 cases, 34.4%) and interactive systems (11 cases, 34.4%) were also relatively frequent. The use of software tools is often related to the course's nature, frequently appearing in courses focused on emerging digital industries (*e.g.*, using Figma in a UXD Design for Communication Software course) or in the digital transformation of traditional courses (*e.g.*, introducing CRM software in the traditional business course Customer Relationship Management). Interactive systems may point to innovations in teaching methods and student engagement, such as the introduction of online discussion modules in the Detection and Control course.

Preliminary application of AI and automated systems revealed the emerging trend in TVET. Notably, generative AI technologies, implemented in three cases (representing 9.4% of instances), have been instrumental in developing course-specific knowledge bases and providing tailored, intelligent feedback. This supports a personalized learning experience for students, enhancing their engagement and understanding. Conversely, technologies such as Digital Twins, IoT, and 3D Printing are employed less frequently, indicating that they are likely in experimental or initial stages of integration within TVET. These technologies have been found to be highly specific to particular course needs. For instance, IoT technology is utilized in the course Fire Protection Training to deliver real-time fire situation alerts, 3D printing is applied in the course 3D Modeling Technology, and Digital Twins are used in the course Mechatronics Engineering to create accurate digital replicas of physical systems, enabling the synchronization of real-time data and states. These applications, while innovative, represent significant investment and experimental efforts at SZPU.

EdTech integration's impact

To understand EdTech integration's positive impact, we adopted the same content analysis method used in the last section, plus an additional network analysis to understand the nexus of different aspects of EdTech integration's positive impact. Table 3 revealed the identified variables/constructs from EdTech's positive impact from case studies. Figure 2 of the network analysis graph provides a visual representation of the co-occurrence between various identified aspects of EdTech's positive impact. In this graph, node size represents the frequency of aspects across case studies. The edges' thickness denotes the extent of overlap between aspects. Nodes' proximity indicates how often themes are addressed together within the same case studies.

The results revealed that pedagogical efficiency and quality (23 instances, 71.88% of case studies), enhanced practical skills (18 instances, 56.25% of case studies), industry links and collaboration (18 instances, 56.25% of case studies), and employability (9 instances, 28.13% of case studies) were the four largest nodes, indicating they were the most mentioned aspects of EdTech's positive impact within the case studies. A strong interconnection has been observed among these four prominent aspects. Their frequent co-occurrence underscores the interdependency and synergy between pedagogical effectiveness, practical skill enhancement, industry collaboration, and employability enhancements resulting from EdTech integration. A content analysis of case studies provides the following insights: Pedagogical efficiency and quality are at the core of EdTech integration's positive impacts, closely linked with enhanced practical skills, industry links and collaborations, as well as improved employability. The enhancement of practical skills is often related closely to industry collaboration, reflecting the importance that TVET places on integrating theoretical teaching with practical skill application. Simultaneously, industry links and collaboration provide practical scenarios for applying learned skills, thereby increasing students' employment opportunities. These interconnected aspects together comprise EdTech integration's main advantages, not only enhancing overall pedagogical efficiency and quality, but also paving the way for students' successful employment.

However, "competition and innovation", "engagement and interaction", and "certification and evaluation" were reported at a moderate frequency and maintained moderate co-occurrence with other aspects. We also observed that "student and teacher satisfaction" and "academic achievement" appeared as smaller, peripheral nodes in the network, suggesting that they are often cited as independent and less frequent aspects of positive impacts. This observation might resonate with issues mentioned in the *Global Education Monitoring Report 2023* regarding the lack of generalizable evidence of EdTech's effectiveness,[19] which does not imply that EdTech is ineffective.

Nearly all case studies provided data supporting EdTech integration's positive effects, but two key issues have been identified based on the analysis. First, the indicators used in these case studies are not standardized and are highly unstructured, an inconsistency that makes it challenging to aggregate comparable data across different studies, thereby weakening the reliability of conclusions drawn about EdTech's effectiveness. Second, statistical evidence on specific programs to which these courses belong is lacking within internal management documents, making it difficult to evaluate EdTech integration's true impact. Several factors may explain this phenomenon: (1) Assessments of EdTech integration are complex, context-driven, and practically oriented, requiring long-term processes that many institutions may not be able to conduct. (2) TVET administrators may find it impractical or challenging to generate informative outcome metrics in actual TVET delivery. (3) There may be an indifference toward deep analysis, with institutions focusing more on rapid deployment of technology and its short-term effects, rather than a systematic evaluation of its long-term educational impact. (4) Based on interviews with stakeholders, internal politics, economic interests, and/or market forces may drive EdTech's introduction. In some cases, it may be used to enhance an institution's image, attract investments, or fulfill political campaigns advocated by the government, rather than genuinely aim to improve educational quality. Despite positive feedback from various stakeholders—such as improved employment rates and higher certification pass rates—the lack of generalizable evidence indicates a crucial need for a rigorous monitoring and evaluation system.

Educational inclusion

In the SZPU context, EdTech integration is conducted

Table 3: Identified themes/aspects of EdTech's positive impact from case studies

Themes/aspects	Examples	Number of cases	% of total cases
Pedagogical efficiency and quality	"Improve teaching efficiency and quality using AI and hybrid intelligent systems", "enhance teacher teaching quality through digital teaching methods and strategies"	23	71.88%
Enhanced practical skills	"Improve practical skills", "enhanced students' packaging design", "project-based vocational skills", "improved hands-on programming experience"	18	56.25%
Industry links and collaboration	"Achieve long-term sustainability by engaging with corporate experts, curriculum updates, and current resources"	18	56.25%
Employability	"Provide industry skills and increase the employment rate", "improve employability"	15	46.88%
Competition and innovation	"Win competitions", "applied for patents", "strengthened students' entrepreneurial skills", "enhanced skills in packaging design leading to winning competitions and applying for patents"	10	31.25%
Engagement and interaction	"Enhance student engagement and interaction (*e.g.*, through integration of virtual and physical elements)", "enhance comprehension and learning experience through digital tools (*e.g.*, application of digital animations and intelligent support systems)"	9	28.13%
Certification and evaluation	"Pass rate for intermediate certification", "recognized as a provincial quality course", "Achieved high pass rates in HCIA, CCIE, and HCIE certifications"	8	25.00%
Student and teacher satisfaction	"Increase student satisfaction through improved teaching methods and higher engagement", "increase teacher satisfaction through innovative teaching resources and support systems"	7	21.88%
Academic achievement	"Improve student grades and academic performance", "successful completion of digital simulation exercises", "student mean scores improved from 80 to 85"	6	18.75%

Altogether, 32 case studies were analyzed. A single case study simultaneously could identify multiple positive impacts from EdTech integration. EdTech, educational technology; HCIA, Huawei certified ICT associate; CCIE, Cisco certified internetwork expert; HCIE, Huawei certified ICT expert; ICT, information and communication technology.

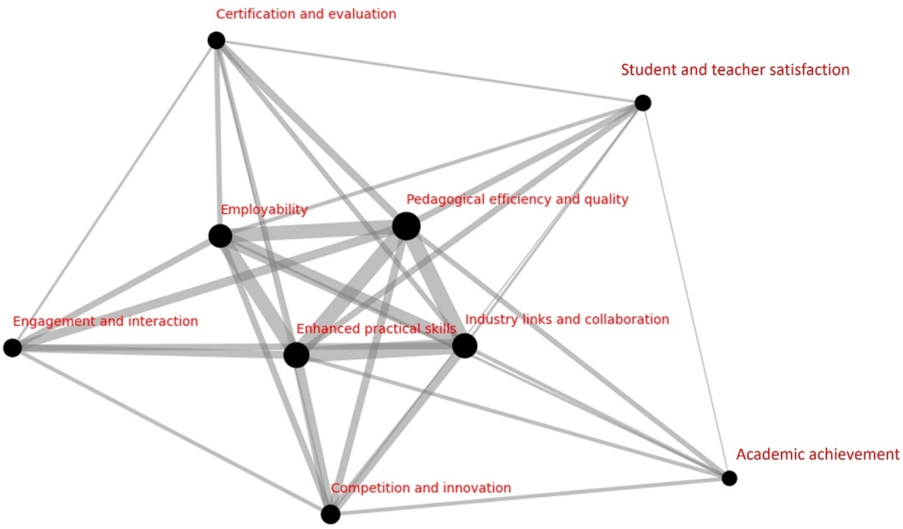

Figure 2. A network analysis of the aspects of EdTech integration's positive impact mentioned in cases. EdTech, educational technology

primarily within the confines of the physical campus, which contains robust technological infrastructure, including comprehensive hardware facilities, software solutions, and campus-wide network coverage. This infrastructure ensures uniform physical access to technological resources for all students, effectively mitigating issues related to technological accessibility and affordability. However, the core issue of educational inclusion has shifted toward whether students with lower digital skills can benefit equally from EdTech integration.

Based on the review of these case studies, the following conclusions were drawn about the institution's efforts. First, the institution's digital transformation strategy encompasses specific policies aimed at enhancing students and faculty's digital skills and competencies through structured capacity-building programs. These include allocating annual continuing education funds to each faculty member to boost future-oriented professional skills, with an emphasis on digital literacy. Additionally, all students must complete compulsory foundational computer skills courses, and strong support was found to help them pass national IT certification exams. Second, SZPU utilizes various AI-based or intelligent assessment technologies, such as online judging systems and adaptive learning platforms, as well as automated evaluation and feedback systems mentioned in some case studies. These adaptive tools and technologies provide immediate feedback and personalized learning suggestions, which are crucial in acclimating students to various learning styles and ability levels, particularly for students with significant skill disparities.[43–45]

Pedagogical adaptation

An analysis has identified that 100% of the case studies involve pedagogical adaptation, highlighting the course teams' deep integration of digital teaching methods into a technology-enhanced curriculum. Based on our analysis, development teams have designed adaptive teaching strategies based on EdTech's features and pedagogical rationale. For instance, in the course Urban Rail Transit Operation Organization (CURR06), the curriculum successfully integrates digital assets, case resources, and engaging materials tailored for students, fostering adaptable learning approaches. The course Building Construction Technology (CURR23) introduces an immersive, task-oriented teaching method with role-playing case studies. Furthermore, the course Fundamentals of Traditional Chinese Medicine (CURR17) showcases the independently developed VR Six-Step Case-based Learning Method, which enhances learning through virtual reality simulations by incorporating preliminary research, in-depth study, VR case observation, analysis, skill competitions, and implication, thereby deepening knowledge acquisition.

In over 60% of the cases, the "work-based learning" principle is mentioned extensively, a TVET hallmark. Specifically, this involves students completing learning tasks in real or simulated work environments, ideally using authentic equipment and sites under the guidance of industry mentors and centered around industry norms and enterprise standards for hands-on training. When real-world environments and equipment are not available, teaching through highly simulated virtual scenarios is used to enhance students' practical skills in many case studies.

The cases record the pathway for the courses' digital transformation, indicating that the most representative development models reflect simultaneous innovation in pedagogy and EdTech integration right from the start. They also highlight various EdTech tendencies to align with specific teaching methods. For instance, online platform technologies often involve flipped classrooms and blended learning approaches; digital simulation technologies usually promote student-driven exploration, emphasizing collaboration, interaction, and a learner-centered approach using methods such as collaborative problem-solving, project-based learning, group discussions, and inquiry-based learning.

Assessment is also a crucial component of improving teaching methods. For example, the case study PCB Design Technology (CURR20) documented a bidirectional evaluation mechanism between teachers and students, employing a blended, multi-dimensional grading system that validates digitalization strategies by utilizing teacher evaluations of students' academic performance and student feedback on teaching, which collectively helped enhance teaching quality.

Key stakeholders and their roles in EdTech integration

EdTech integration frequently involves stakeholders from three main clusters: institutions, industry, and government.

Institutions

In the case studies we analyzed, 100% mentioned that teachers and students are the most crucial stakeholders. Students are the focal point of all case studies, underscoring that EdTech integration must be student-centered, thereby prioritizing their needs. Course design should consider students' engagement, learning outcomes, and students' acceptance of technology. Meanwhile, cases showed that teachers/trainers play a pivotal role in the educational process, serving not only as instructors, but also as direct project managers and coordinators of curricular EdTech integration. Many cases showed that teachers are involved directly in EdTech development and implementation. It also documented that professional development of teachers and their effective use of EdTech are key to enhancing teaching effectiveness during the EdTech integration process.

In a few specific cases, some dispersed and specialized roles have been defined, illustrating the trend toward fine division of different roles in instructional design. For instance, inclusion of Digital Materials Experts, Course Development Consultants, and Career Service Experts on the advisory team for the Structural Packaging Design (CURR05) case highlights this trend. In the Network Interconnection Technology (CURR14) case, integration of Third-party Certification Assessors into course transformation aims to enhance students' abilities to pass professional certificate exams from industrial providers such as Cisco and Huawei. This specialization trend is further corroborated by the *2020 EDUCAUSE Horizon Report*, which notes that the increasing complexity of educational design has led to the emergence of novel roles, such as learning experience designers (LXDs) and learning engineers,[46] indicating that instructional design is becoming increasingly specialized and technology-driven.

Management and leadership's role within SZPU is crucial in fostering a robust digital governance capability that significantly propels EdTech integration across its curriculum. This strong leadership presence is highlighted repeatedly across numerous case studies in which course development teams receive systemic support in areas such as EdTech procurement, teaching models, evaluation methodologies, and administrative services. Moreover, SZPU ensures that funds and specialized support are available for enhancing teachers' digital competencies, acknowledging the critical role of faculty readiness in successful EdTech implementation. Policy-wise, SZPU has implemented a comprehensive institutional-level digital transformation strategy that empowers instructors to undertake digital reform initiatives within their courses. The institution's Educational Information and Technology Center, beyond providing ICT services, plays a pivotal role as the primary entity responsible for developing digital teaching resources and managing the online learning management system (LMS), known as iStudy. This strategic approach is bolstered by targeted technical support facilitated through special funding initiatives, such as the significant investment of over 100 million yuan in the "Gold Course" project aimed at developing high-quality, national-level online courses.

Industry

At least 27 cases (84%) revealed that industry stakeholders play a significant role in EdTech integration. The underlying reason is the close ties between TVET and the industry. Industry experts were involved in at least 62.5% of the cases, contributing to curriculum content creation, guidance in practical training, or development of educational resources. Partnerships with enterprises were mentioned in over 50% of cases, in which industry partners collaborated with institutions to develop course resources or practical training programs, or provide internship and employment opportunities. "Industry associations have articulated new demands for the skills of future graduates, advocating for the alignment of curricula with real-world workflows and industry standards", as stated in the "Structural Packaging Design" case (CURR05).

An intriguing observation from the reviewed case studies is that EdTech providers are mentioned in only six instances, which might not necessarily indicate a lack of involvement, but rather might reflect a narrative choice. The institution allocates special funds annually to implement government procurement from EdTech providers for purchasing equipment, supporting digital systems, developing digital educational materials, and obtaining technical consulting. These narratives contain two underlying logics: Educational-industrial collaboration that emphasizes mutual resource sharing between partners, in which enterprises are often industry leaders or future employers of students. Thus, publicizing these relationships is both safe and encouraged. Conversely, the relationship between institutions and EdTech providers involves suppliers or buyers and entails commercial interactions. A cautious stance on narratives concerning these relationships has been taken within China's public education system. This caution may stem from factors such as commercial confidentiality or a policy of maintaining neutrality by not endorsing specific vendors.

Government

In all cases, government and policymakers are highlighted as key stakeholders. It also has been stated widely in the case studies that EdTech integration into curricula is part of a top-down hierarchical model of digital policies or strategies enacted by senior governments at the national, provincial, and municipal levels. We can conclude that China's progress in EdTech integration in TVET institutions is strongly policy-driven, and to some extent, the development of the EdTech industry is the result of policy orientation. For example, the top-down administrative push for high-quality online digital course development projects—such as "gold courses" (national high quality courses), MOOCs, and online quality courses—coupled with government investment, its integration into institutional performance assessments, and the linkage to teachers' career development are policy reasons behind the proliferation of online course platform providers in the market and the popularity of the online platform and digital materials at SZPU.

CONCLUSIONS AND RECOMMENDATIONS

The EdTech integration practice model at SZPU corroborates Postman's statement in his book *Technopoly: The Surrender of Culture to Technology*, in which he says, "Technological change is neither additive nor subtractive. It is ecological".[47] This ecological perspective echoes that the introduction of EdTech at SZPU is not merely about incorporating new tools; it signifies a systemic transformation that permeates throughout the institution's infrastructure, governance, and culture. Two structural layers have emerged as pivotal in this integration process: (1) the application of technology, and (2) the governance thereof. The first layer, concerning technology application, has seen SZPU make significant strides, as evidenced by the proliferation of AR/VR-enhanced classrooms and adoption of cloud-based courses and online platforms. The second layer, technology governance, involves a more intricate web of social practices, institutional frameworks, policy directions, and cultural integrations, which are indispensable for effective and sustainable EdTech deployment.

A key takeaway from our study is that TVET institutions need to align their EdTech initiatives with overarching national and institutional strategies to secure the support and resources required for successful implementation. Furthermore, engagement with a diverse set of stakeholders—from students and educators to industry experts and policymakers—is paramount. SZPU's deep and collaborative engagement with local industry partners in EdTech integration has fostered shared responsibilities and mutual benefits through digital skills training. This partnership not only supports employment, but also facilitates local industrial upgrades, aligning perfectly with TVET's role as an enabler of industrial advancement. Teachers' enthusiasm for adopting EdTech is notable, with rapid and comprehensive pedagogical adaptation stemming from a systematic digital capacity-building plan for teachers, a supportive professional career and promotion evaluation system, and advocacy of institutional cultural values. Students, as recipients of EdTech-enhanced TVET delivery and key stakeholders in the EdTech integration ecosystem, exert their influence primarily through various key performance indicators (KPIs) gathered at the curriculum level, such as in-class satisfaction, employment rates, and final academic scores. Our results revealed clear and existing evidence of a positive effect between EdTech integration and its outcomes; however, the evidence chain is relatively weak.

Drawing from an analysis of SZPU's case studies, we highlight several critical considerations and recommendations for the broader TVET community regarding EdTech integration. Firstly, a critical concern involves the gaps in the evidence chain concerning EdTech's impact, an issue also highlighted in the *Global Education Monitoring Report 2023*. To bridge this gap, we advocate for a scientific and standardized assessment system. Recognizing evidence of return on investment is crucial to enabling TVET leaders to make informed decisions regarding EdTech integration based on data on what works, in which contexts, and why. This ensures that technology implementations align with expected outcomes and genuinely enhance TVET quality and effectiveness. Secondly, drawing on experiences from SZPU, effective EdTech integration requires comprehensive assessments of students' skills gaps to identify essential skills needed for successful technology use. Regular monitoring and evaluation of EdTech's impact, particularly on lower-skilled students, are necessary. Adjustments to teaching strategies and technology applications should be based on these results. Finally, in EdTech's design, implementation, and evaluation, it is imperative to consider ethical risks and societal impacts, ensuring data security, privacy protection, fairness, and transparency during use.

In reflecting on SZPU's practice, we are reminded of the need for a supportive, inclusive, and human-centered approach to EdTech integration. Maintaining a focus on human agency and sociocultural factors is essential, particularly during an era in which technological determinism often takes precedence. This approach helps mitigate the risks of technological supremacy, labor alienation, and erosion of human subjectivity. EdTech integration's ultimate goal must be to enhance student growth and development, aligning with the fundamental purpose of education. As TVET institutions worldwide contemplate integrating EdTech into their curricula, the lessons from SZPU provide valuable insights. By adopting a systemic, inclusive, and reflective approach to EdTech integration, these institutions can foster a digital TVET ecosystem that is robust, equitable, and centered around learners' needs and future workforce demands.

Limitations and further research

This study's primary limitation is its reliance on qualitative case studies, which, while providing in-depth insights into EdTech integration within a specific context, restricts the findings' generalizability to other TVET institutions with different contexts and resources. Furthermore, the lack of diverse quantitative data—including detailed feedback from students on their perceptions and acceptance of EdTech, success rates, satisfaction levels, and employment outcomes—limits our ability to quantify EdTech's impact comprehensively. The case studies we analyzed also focused on short-term impacts without examining EdTech practices' long-term effects and sustainability, with an emphasis on specific EdTech applications and practices at SZPU, potentially omitting relevant technologies and methods beneficial in other contexts.

Future research should incorporate data from various channels to understand the whole picture on EdTech integration at the institutional level. Longitudinal studies are necessary to evaluate EdTech integration's sustainability and evolving impact on TVET, offering insights into enduring effects and potential areas for improvement. Finally, comparative studies across different TVET institutions and regions would help identify best practices and common challenges, allowing for broader recommendations and adaptable strategies.

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Author contributions

Pan LC: Conceptualization, Data curation, Analysis of case studies, Writing—Original draft. Filippova A: Writing—Review and Editing. Both authors have read and approved the final version.

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