Comparison and Implications of Digital Training Models for Vocational Education Teachers from an International Perspective

——Based on Experiences from Germany, Australia, and Singapore

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ABSTRACT Digitalization has become a new way to promote the professional development of vocational education teachers. It is necessary and reasonable to promote the development of digitalized training by taking advantage of the adaptability of both the industrial system and the educational system. Currently, Germany, Australia and Singapore are in the leading position in the digital training of vocational education teachers, and have already formed an adaptive system to cope with the complexity of the industrial environment. Among them, online courses, digital certification and virtual training constitute the detector, rule set and effector of the complex adaptive system, which can quickly and accurately collect digital information of the industry and make timely behavioral responses. Based on the theory of complex adaptive systems, a comparative study of digital training in three countries found that Germany's synergistic model of "convergence to practice, multiple certifications and spatial simulation", Australia's articulation model of "competence-based, qualification-based and virtual and real", and Singapore's model of "multiple synergies, vertical and horizontal", are the most important factors in the development of digital training in three countries. The cross-border model of "multiple synergies, vertical integration and two-way interaction" of Australia and Singapore has effectively enhanced the organic linkage of adaptive subjects. In view of this, it is suggested that the digital training system should be constructed on the basis of demand detection, rule articulation and effect transformation, so as to realize the digital training of vocational education teachers from "individual adaptation to complex emergence".

INDEX TERMS digital training; VET teachers; international comparison

I. INTRODUCTION

Digital teacher training is a key initiative for implementing educational digital transformation (Mukul and Büyüközkan, 2023). Digital training transcends temporal and spatial constraints, offering significant flexibility and intelligent advantages. It serves not only as a driving force for high-quality educational development but also as essential preparation for enhancing the knowledge and skills of in-service teachers (Saiti and Saitis, 2006). However, vocational education teacher training in China has yet to establish a robust digital training framework; three critical issues—imprecise demand identification, delayed evaluation feedback, and disconnection from the workplace context—have placed it at a disadvantage (Avis et al., 2012; Zhang et al., 2018). Previous research has primarily focused on analyzing how online courses facilitate teacher development needs through multi-stakeholder discussions and collaborative learning (Vilppu et al., 2019). Yet relying solely on single online training programs often results in insufficient digital training effectiveness and suboptimal application outcomes of digital technologies (Gudmundsdottir and Hatlevik, 2018). Recently, scholars have begun paying attention to digital certification. For example, some scholars emphasize that digital certification facilitates refined assessment, and a stack-based evaluation system grounded in micro-skills can progressively enhance competencies and capabilities (Wang and Li, 2024). Some researchers even argue that micro-certifications have a more positive impact on teachers' professional development than degree certificates (Altindag, 2022). However, the practical implementation pathways for micro-certification remain unclear, and the lack of understanding and consensus regarding it is regarded as a core challenge in teacher digital training (OECD, 2021). Other scholars have begun focusing on digital training models

at the instructional practice level, highlighting the importance of sustained interaction between practical settings and digital technologies (Grollmann, 2008; Chan, 2021). Undeniably, however, traditional training models often lack substantial hands-on experience due to the absence of virtual training components (Carmo and Franco, 2019).

It is evident that while previous studies have highlighted the effectiveness of online courses, digital certificates, and virtual training in enhancing the digital training models for vocational education teachers, they lacked a comprehensive, integrated approach. In contrast, research on teacher digital training in Germany, Australia, and Singapore leads the field, each with distinct strengths. Germany's dual-system collaboration in developing online courses, Australia's integration of formal and informal certification systems, and Singapore's cross-sectoral school-enterprise virtual training programs have proven to be key strategies for effectively adapting to digital transformation. A thorough analysis of these models can help optimize teacher development and promote high-quality growth in vocational education. Based on this, this study compares online courses, digital certificates, and virtual training approaches across Germany, Australia, and Singapore, aiming to provide guidance for establishing a well-rounded digital training framework for vocational education teachers in China.

II. DEMAND IDENTIFICATION: COMPARISON OF COLLABORATIVE MODELS AND DIFFERENCES AMONG ONLINE COURSES FOR VOCATIONAL EDUCATION TEACHERS IN GERMANY, AUSTRALIA, AND SINGAPORE

Online courses form the foundation of digital training models for vocational education teachers and significantly enhance the effectiveness of teacher training (Means et al., 2013). As a product of deep integration between information technology and educational practice, online courses not only embody the ideals of convenient knowledge acquisition and lifelong learning in the information age but also serve multiple functions such as dialogue and reflection, knowledge construction, and self-assessment.

A. FORWARD-LOOKING STRATEGY: A FUTURE-ORIENTED COLLABORATIVE MODEL FOR ONLINE COURSES

German vocational education's online courses emphasize alignment with industry needs. The design, content development, and teaching evaluation of these courses are designed to prepare instructors for future curriculum requirements. Firstly, the design of German online courses is rooted in the digital demands of Industry 4.0. Educational institutions involve industry practitioners in the design and development of professional courses to proactively address evolving industry needs.

Secondly, course content focuses on adapting to future skill structures (see Table 1), ensuring flexibility in responding to industry changes and complex teaching scenarios (Federal Ministry of Education and Research, 2016). The "Digital Teacher Training" (DiBS) project implemented by the Technical University of Braunschweig enhances vocational educators' digital competencies through online courses.

Finally, timely and interactive feedback has become a key driver in online course development, facilitating continuous refinement of digital training models for vocational educators.

The development of online courses in Australia is essential preparation for vocational education teachers to adapt to the "digital education revolution." Firstly, short-term courses dominate this approach. Australia designs these short-term online programs through collaboration among industry stakeholders, training institutions, and experts. This multi-stakeholder partnership not only provides substantial funding for Technical and Further Education Colleges (TAFE) but also integrates cutting-edge technologies and methodologies from industries and training organizations, addressing the outdated nature of traditional training content.

Secondly, the focus lies on skills renewal. The government enhances teacher professional development frameworks to ensure teaching practices dynamically align with evolving industrial needs.

Thirdly, the model is demand-driven. Guided by a competency-based approach, the TAFE framework breaks down required competencies into independent online course modules in accordance with guidelines from industrial and skills committees as well as sector-specific reference bodies, thereby meeting evolving professional development demands.

The Ministry of Education in Singapore continues to advance reforms in the coherence of online courses, exhibiting new characteristics such as multi-stakeholder development, adaptation to complex environments, and evidence-based dynamic feedback. First, it overcomes limitations imposed by individual entities regarding resources, funding, and talent, fostering consensus among diverse stakeholders including industry employers, corporate experts, and teacher representatives.

Second, it enhances adaptability to complex environments and strengthens vocational education teachers 'digital resilience to meet evolving practical demands.

Third, course evaluation emphasizes dynamism, utilizing evidence-based feedback to dynamically monitor comprehensive indicators such as teachers' classroom performance, learning duration, and assessment outcomes.

In summary, online courses for vocational education teachers in the three countries demonstrate a forward-looking approach. Germany focuses on collaborating with industry stakeholders to guide vocational educators in optimizing their skill profiles for the future, though course development lacks flexibility. Australia's online course development incorporates input from industry players, training institutions, and experts, using short-term courses as a vehicle to continuously update teachers' digital competencies

TABLE I. German Teachers' Future Skills Framework (McKinsey and Company, 2019)

Category	Capability	Description
Technical Skills	Complex data analysis	Efficiently analyze large volumes of data to extract information, including advancements in artificial intelligence (AI).
	Intelligent hardware/robotic technology development	Develop physical components for the "intelligent" hardware and software system ("Internet of Things")
	Web development	Master the programming languages for both backend and frontend development of web applications, especially mobile applications.
	User-oriented design	Design products with optimized functionality and an intuitive interface to deliver an engaging user experience.
	Design and Management of Networked IT Systems	Establish complex IT infrastructure in the cloud, integrate it with other IT systems, and manage and develop it continuously.
	Blockchain Technology Development technical translation	Blockchain Technology Development: Utilizing blockchain technology to establish a decentralized database. Appropriate involvement of both technical experts and non-experts.
Basic digital Skills	Digital Literacy	Master basic digital skills, such as handling personal digital data carefully, using common software, and interacting with artificial intelligence.
	Digital Interaction	During online interactions, understand others and behave appropriately ("digital etiquette").
	Digital Learning	Building effective knowledge on specific topics from large amounts of numerical data.
	Digital Ethics	Critically question the impact of digital information and one's own digital behaviors, and make appropriate ethical decisions.

and adapt to evolving industry needs. Although Singapore is a small nation, its online course development leverages the contributions of diverse stakeholders—a characteristic closely tied to its modern governance model characterized by government leadership and broad societal participation. Under such governance conditions, online courses dynamically monitor the overall performance of vocational education teachers through interaction and collaboration among multiple stakeholders.

B. A THREE-DIMENSIONAL COMPARISON OF DIFFERENCES IN ONLINE COURSE TRAINING MODELS AMONG THE THREE COUNTRIES

Although Germany, Australia, and Singapore regard online courses as the foundation for digital training models for vocational education teachers, there are variations in curriculum development, content design, and assessment methods.

Firstly, in curriculum development, the fundamental differences between the three countries 'digital training models manifest in two aspects: development entities and development cycles. Regarding development entities, Germany's dual education system emphasizes integrating real-world cases and challenges from frontline production into online courses. Australia utilizes the Safe Shared Digital Platform (Loop), developed by select universities, to facilitate data sharing, feedback collection, and course evaluation. Singapore engages diverse stakeholders—including public, private, and civil society organizations—in online course development, providing teachers with opportunities to collaborate with industry experts (Academy of Singapore Teachers, 2024). In terms of development cycles, Germany primarily designs online courses based on long-term needs; for instance, Siemens Digital Industries Software has consistently offered the Solid Edge online course to train instructors in basic operations and advanced features of 3D/CAD software (Siemens, 2023). Australia focuses on developing short-term courses ranging from 2 hours to 18 weeks, offering greater flexibility. Singapore adopts a four-year cycle for curriculum development strategy, ensuring systematic and stable online course structures. Vocational education teachers are selected by the Ministry of Education to pursue advanced training in online courses at the National Institute of Education (NIE) of Nanyang Technological University.

Secondly, regarding curriculum content, differences among countries manifest in two aspects: competency requirements and standard frameworks. In terms of teacher competence, Germany emphasizes training vocational education teachers in future-oriented skills such as complex data analysis and smart hardware development; Australia focuses on skill updates for educators, with Queensland's TAFE colleges offering rapid, adaptable, and cost-effective short-term digital skills programs; Singapore prioritizes real-time interaction, providing ICT application training courses through The Knowledge Academy. At the standard level, Germany uses the "Teacher Education Standards" issued and revised by the Joint Conference of Ministers for Culture and Education (KMK) to effectively guide, regulate, and assess the quality of digital training. Australia designs its framework based on the "Australian Teacher Professional Standards," covering three dimensions—professional knowledge, skills, and practice—with seven specific criteria. Singapore's National Institute of Education has developed the V3SK model as the primary standard for online teacher training, requiring educators to master self-knowledge, multicultural literacy, technical skills, and other competencies to become well-equipped learners for the future (Office of Education Research, 2017).

Thirdly, regarding curriculum evaluation, the differences among the three countries manifest in both evaluation content and assessment methodologies. In terms of evaluation content, guided by the fundamental principle of action-oriented teaching, Germany consistently employs cutting-edge technologies to create authentic learning scenarios, thereby enhancing the purposefulness and systematic nature of curriculum evaluation. Australia emphasizes improving teachers 'digital teaching reflection skills through project-based course data analysis. The Australian Curriculum, Assessment and Reporting Authority (ACARA) utilizes

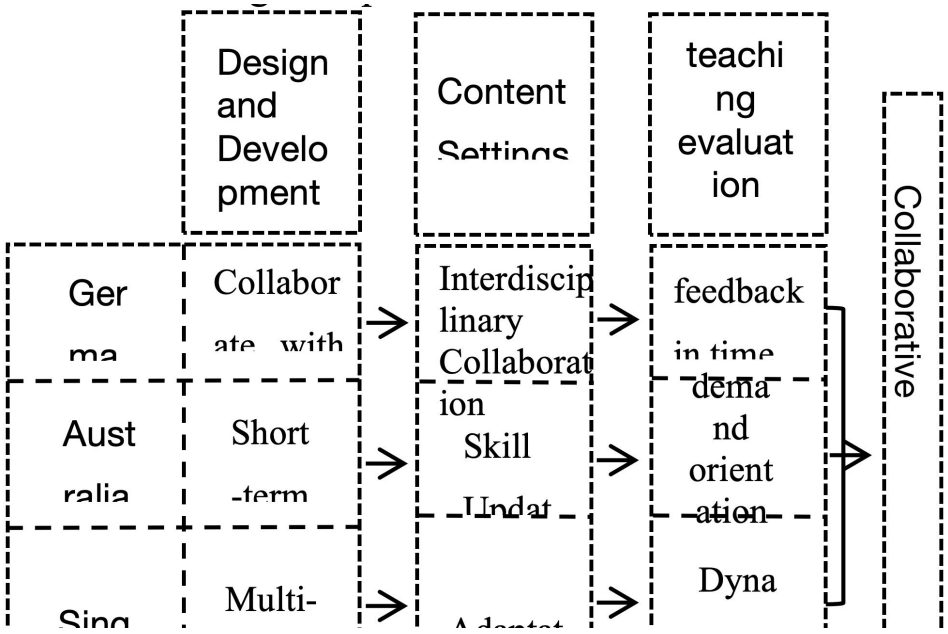

Fig. 1. Collaborative Development Model for Online Courses for Vocational Education Teachers in Germany, Australia, and Singapore

initiatives such as "Digital Technology Focus (DTiF)" and "High Achieving Teachers" programs to facilitate vocational education teachers' reflection on challenges in digital instruction based on relevant data (Australian Curriculum, Assessment and Reporting Authority, n.d.). Singapore's online course evaluations focus on cultivating teachers' ICT literacy and overall performance. Regarding assessment methods, Frankfurt University in Germany adopts a developmental curriculum evaluation approach, utilizing video analysis and expert discussions based on the Documentary Method to comprehensively assess the effectiveness of online training programs. Australia's teacher competency-based evaluation framework is particularly rigorous: the official Certificate IV program requires all participants to upload their assessment records to an online system under the supervision of the Skills Quality Management Agency. Singapore, meanwhile, employs the National Teacher Performance Management System (EPMS), which incorporates multi-source evaluations—including student feedback, supervisor assessments, peer reviews, and corporate certifications—to holistically evaluate teachers' core ICT competencies.

At its core, the differences in online course training among these three countries stem from their respective economic environments and educational philosophies. In Germany, with the advancement of Industry 4.0, the industrial sector has become characterized by data-driven operations, intelligent systems, and real-time responsiveness, necessitating that online courses be adapted and upgraded to align with technological innovations, industrial transformation, and trends toward digitalization. Australia, impacted by the pandemic, promptly updated its training content through short-term courses, promoted the internationalization of online programs, and mitigated the risk of a mismatch between teacher training supply and demand. Singapore, in response to emerging trends in industrial digitalization, places high importance on fostering ICT literacy and implemented three rounds of educational ICT initiatives in 1997, 2003, and 2009 respectively to ensure vocational education teachers can design courses incorporating ICT elements.

III. EVALUATION FEEDBACK: COMPARISON OF DIGITAL CERTIFICATION MODELS AND DIFFERENCES AMONG GERMANY, AUSTRALIA, AND SINGAPORE FOR VOCATIONAL EDUCATION TEACHERS

Digital certification serves as both an evaluation tool and a quality assurance mechanism for digital training models, and is regarded as one of their key priorities (Cisco and Optus, 2021). The digital certification systems for vocational education teachers in Germany, Australia, and Singapore employ multi-tiered certification processes, credential alignment mechanisms, and vertical integration approaches, emphasizing both top-down alignment with academic qualifications and bottom-up stack-based assessment frameworks.

A. CONTINUOUS IMPROVEMENT: A COHERENT INTEGRATED DIGITAL CERTIFICATION FRAMEWORK

Digital certification serves as a key metric for digital training models. Germany leverages digital certification to streamline evaluation processes, ensure educational quality, and facilitate teacher mobility. Firstly, certification bodies are primarily corporate entities, and certification standards are open and transparent. A professional standards committee composed of representatives from employers, employees, vocational education research institutes, and educators ensures openness and fairness in the digital certification process for vocational education teachers.

Secondly, certification content emphasizes digital literacy. In 2019, Germany introduced "Qualification Training 4.0," a customized digital certification program designed specifically for teachers, which significantly enhanced their digital knowledge as well as professional and social skills.

Thirdly, the certification models are diverse. Advances in digital technology have expanded the approaches to skill certification, giving rise to assessment tools such as digital badges, nano-degree certificates, and online certificates.

Unlike Germany's emphasis on corporate participation, Australia's digital certification framework for vocational education teachers is nationally mandated and prioritizes alignment between formal and informal qualification recognition. First, at the national level, microcertifications are strengthened through a "top-down" approach: in 2022, the Australian Department of Education, Skills and Employment issued the National Micro Certificate Framework (Department of Education, Skills and Employment, 2021), establishing nationwide implementation guidelines and positioning microcertifications as supplementary, alternative, or integral components of formal qualifications.

Second, at the individual level, efforts focus on integrating digital certification with the Australian Qualifications Framework (AQF) via a "stack-based" assessment model that enables cross-domain skill certification and alignment, while enhancing the diagnosis, evaluation, and personalized feedback of vocational education teachers' competencies.

Digital certification in Singapore is pivotal to achieving lifelong teacher development. The historical evolution of teacher certification demonstrates a clear trend toward lifelong progression (see Table 2), reflecting the seamless integration of certification bodies, content, and evaluation criteria. First, certification authorities are primarily led by the Ministry of Education, collaborating with entities such as the Private Education Board and the Cybersecurity Agency to align digital certification with qualification frameworks and academic credentials.

Second, certification content incorporates digitalization throughout the entire teacher training lifecycle, transforming educators from traditional knowledge transmitters into designers, facilitators, and lifelong learners of student learning.

Finally, certification standards are dynamically adjusted based on learning analytics data; the Education Technology Initiative (EdTech Program) emphasizes identifying student needs through educational data analysis and subsequently refining certification criteria accordingly.

Overall, Germany designates enterprises as the primary implementers of digital certification, with transparent certification criteria serving as a prerequisite for promoting diversified teacher certification. This model provides equal certification opportunities for vocational education teachers from diverse backgrounds and regions, helping to reduce regional training disparities. Australia's Government Micro-Certificate Framework establishes a foundation for integrating digital certification with qualification frameworks, enabling vocational education teachers to complete training flexibly according to their needs. Singapore's lifelong digital certification system is dynamically updated in response to technological advancements. Such continuous improvement integrates the latest technological developments and industry trends into teacher education, enhances the identification of emerging skills, and fosters sustainable professional development for vocational education teachers.

B. A THREE-DIMENSIONAL COMPARISON OF DIFFERENCES IN DIGITAL CERTIFICATION TRAINING MODELS AMONG THE THREE COUNTRIES

Although Germany, Australia, and Singapore all emphasize the alignment of digital certification with national qualification frameworks, they exhibit distinct priorities and differences in practical implementation. Overall, the digital certification programs for vocational education teachers across these countries not only focus on evaluating and providing feedback on the effectiveness of digital training but also maintain their unique characteristics in terms of certification bodies, content, and methodologies.

The extensive participation of German enterprises in digital certification authorities supports diversified accreditation for vocational education teachers. The dominant Technical Supervisory Authority (TUV) group, through its subsidiaries TÜV Rheinland, TÜV SÜD, and TÜV Norddeutschland, offers vocational educators various certifications including dual-qualified instructor certification, professional certificates from the Handwerkverband (HWK), and short-term vocational training certificates. These diverse digital credentials are widely adopted in Germany's vocational teacher training programs due to their flexible formats and multifaceted assessment methods. In Australia, national authorities lead digital certification efforts, ensuring transparency and consistency in micro-certifications. The National Micro-Certificate Framework establishes minimum learning requirements and issuance standards, aligning micro-certified credits and skills with the Australian Qualifications Framework (AQF) to enhance vertical alignment of training outcomes (Department of Education, 2019). Singapore's digital certification system for vocational educators is driven by the Ministry of Education, implementing initiatives such as the EdTech Program and the Future Skills for Educators Program (SFEd Program) to provide ongoing professional certification (see Table 3).

In terms of digital certification content, Germany's teacher digital certification focuses on digital knowledge as well as professional and social skills. During the second phase of implementation for the "Excellence in Teacher Education Programme," project guidelines published in the German Federal Gazette significantly enhanced teachers' ability to safely and effectively utilize digital media and design instructional activities. Australia employs micro-certifications in digital literacy to equip teachers with essential skills for the future, particularly in operating digital devices and analyzing student learning data. Singapore emphasizes ICT application capabilities in teaching; under

TABLE II. Historical Evolution of Teacher Training and Certification in Singapore

Time	1959–1978	1979–1999	2000–
Certification Orientation	Survival Orientation	Efficiency Orientation	Innovation-oriented approach
Authentication Method	A brief teacher skills certification program, along with an apprenticeship initiative.	Create a work environment on campus and collaborate with enterprises to conduct teacher certification programs.	Through part-time work-study programs, work-study initiatives, and degree programs, individuals can support their lifelong self-development.
Certification body	Career and Industrial Training Committee	College-industry cooperation	Future Skills Committee

TABLE III. Statistics on Types of Digital Certification Bodies for Vocational Education Teachers in Germany, Australia, and New Zealand

Country	Government Organization Assessment	Education Institution Evaluation	Third-party Evaluation
Germany	×	×	√
Australia	√	×	×
Singapore	√	√	×

the guidance of its Educational Technology Planning (MP1), teachers' ICT competencies have evolved to encompass comprehensive skills in designing, developing, utilizing, managing, and evaluating teaching resources, thereby facilitating effective certification of innovative teaching practices.

In terms of digital certification approaches, Germany employs various methods—including digital badges, online certificates, and nano-degree programs—to certify vocational education teachers, enabling flexible and rapid adaptation to the skill requirements of the digital era. In Australia, obtaining a digital badge typically involves submitting a website or digital portfolio URL, which includes steps such as self-assessment, evidence submission, and on-site evaluation (Lang, 2016). Singapore emphasizes the dynamic nature of its vocational teacher certification system. Nanyang Technological University offers diverse diploma conversion and teaching effectiveness certifications for in-service teachers through short-term course certification programs, continuously monitors their ICT competencies, and provides qualified teachers with collaborative mentors and peer coaches when necessary.

Overall, the differences in digital certification practices across the three countries are closely linked to their respective educational traditions, national strategies, and industry development needs. Germany's dual education system has consistently positioned enterprises as the primary stakeholders in providing digital training for vocational educators; digital certification for small and medium-sized enterprises thus creates conditions for addressing the shortage of digitally competent teachers and enabling timely, effective evaluation of training outcomes. Australia emphasizes the alignment between microcertificates and the national qualification framework, as while short-term courses can help teachers rapidly acquire new knowledge and skills, their authority and recognition require a nationally coordinated mechanism to ensure consistency. Singapore established a dynamic ICT competency certification system in line with its long-standing internationalization strategy, which urgently necessitates standards that provide fair and objective criteria for assessing competencies among both local and foreign teachers.

IV. VIRTUAL PRESENCE: A COMPARATIVE ANALYSIS OF CROSS-SECTORAL MODELS AND DIFFERENCES IN VIRTUAL TRAINING FOR VOCATIONAL EDUCATION TEACHERS IN GERMANY, AUSTRALIA, AND SINGAPORE

Maxine Greene emphasizes that technology holds the potential to transform education by eliminating the inherent limitations of experiential learning and enabling the acquisition of context-specific knowledge derived from practical application (Greene, 2016). Virtual training serves as a centralized practical teaching environment, forming the essential foundation for developing a digital training model that integrates virtual and real-world elements while fostering learner interaction (Radianti et al., 2020). In this context, what digital training truly requires is virtual presence that transcends institutional and organizational boundaries, thereby aligning vocational teacher training with genuine needs.

A. INTEGRATION OF VIRTUAL AND REAL: A PRACTICE-ORIENTED CROSS-DISCIPLINARY VIRTUAL TRAINING MODEL

Germany employs virtual simulation to enhance the practical teaching capabilities of vocational education instructors. Under the Industry 4.0 framework, Germany's "Learning Factory" adopts a modular design to facilitate virtual training for vocational educators. The University of Frankfurt provides teacher training through digital teaching solutions and learning spaces, thereby improving their proficiency in digital teaching practices (Federal Ministry of Education and Research, 2017). Building on this foundation, new technologies are continuously integrated to simulate complex production environments, enabling seamless, interconnected, and ubiquitous learning experiences.

Amid the COVID-19 pandemic, Australia has enhanced vocational education teachers 'adaptability and resilience by establishing virtual training environments. Building on this initiative, the country has redefined teachers' physical engagement through virtual training platforms, advancing the digitalization of sensory experiences to ensure stable progression of teaching practices. With government support, educational institutions regularly offer practical teaching

training programs, creating a cohesive training ecosystem that ensures seamless integration across various initiatives (Australian Institute for Teaching and School Leadership, 2023).

Singapore's innovative vocational training ecosystem leverages school-enterprise collaboration to deliver virtual training programs. First, vocational colleges and enterprises jointly develop virtual training platforms, inviting leading domestic and international companies to participate, thereby creating conditions for digital training to align with the global labor market.

Second, "teaching factories" establish virtual training environments by providing advanced technological equipment and virtual "production workshops" that simulate real-world tasks and projects.

Finally, the application of emerging technologies such as the metaverse significantly enhances vocational educators' immersive teaching experience and improves their practical skills.

Overall, the advancement of virtual training for vocational education teachers in Germany, Australia, and New Zealand is primarily reflected in two aspects: first, enhancing their practical teaching capabilities, particularly their adaptability to virtual learning environments; second, providing hardware and software support for virtual training, such as establishing virtual workshops aligned with real-world production scenarios and integrating metaverse technology into practical learning settings. The virtual training models promoted by these three countries involve the interactive integration of complex environments, practical projects, and virtual spaces. In other words, against the backdrop of increasing intelligence and virtualization in vocational teacher training, the development of virtual training environments has become a significant advantage of their digital training approaches.

B. A THREE-DIMENSIONAL COMPARISON OF DIFFERENCES IN VIRTUAL TRAINING MODELS AMONG THE THREE COUNTRIES

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Virtual training for vocational education teachers extends beyond school boundaries, representing a mutually beneficial collaboration across organizational frontiers. Although educators from Germany, Australia, and Singapore all advocate cross-sector collaboration, significant differences exist in their practical implementations.

Firstly, there are differences in the entities responsible for virtual training. Under Germany's dual education system, small and medium-sized enterprises undertake 70% of virtual training tasks (Wieland and Thies, 2017). Schools leverage enterprise resource planning (ERP) systems to enhance teachers' adaptability to intelligent work environments. In Australia, the primary stakeholders are the government and educational institutions; the government provides policy support and funding to enable educational institutions to regularly deploy vocational education teachers onto virtual training platforms, helping them stay attuned to emerging industry trends. Singapore's vocational colleges place great emphasis on teachers' practical experience gained at enterprises—80% of teachers have previously served as managers or key business personnel in companies such as KPMG, Singapore Telecommunications, and Fullway Insurance—providing teachers with diverse virtual training environments.

Secondly, there are differences in virtual training content. Germany's "Smart Learning Factory" utilizes the CPS platform to facilitate interaction between teachers and students, positioning teachers as facilitators and supporters in students' skill development. Australia leverages virtual training to enhance equitable access to professional development opportunities for vocational education teachers. The Victorian government has specifically designed "Enterprise Internship Programs" for vocational educators; these 12-week hands-on programs effectively improve digital industry knowledge and skills among vocational teachers in remote areas. Singapore employs the "Teaching Factory" to simulate real-world business tasks for developing training programs, providing teachers with a fully digital virtual training environment by simulating actual challenges encountered in corporate production.

Thirdly, there are differences in virtual training environments. German vocational education teachers 'virtual training focuses on "work-object-oriented" virtualization, designing the environment as a "Tutorial Working System" to assist instructors in completing training tasks tailored to specific work domains, environments, and conditions (Bonz, 1999). Australia has pursued the development of virtual training spaces that replicate real-world work scenarios. The Advanced Welder Training Centre established by South Australia's TAFE College provides simulation-based operational skills training for vocational educators using visual effects and tactile feedback closely resembling actual working conditions, thereby enhancing their teaching practice capabilities. Singapore employs metaverse technology to create more interactive training environments, while some universities have set up "metaverse laboratories" to facilitate immersive engagement with practical learning contexts for vocational educators.

The above analysis reveals that virtual training approaches vary significantly across Germany, Australia, and New Zealand. In Germany, a guided work system provides vocational education teachers with production-line training covering the latest industry technologies and processes, making virtual training more aligned with actual workplace needs. Australian virtual training emphasizes consistency with real-world work environments, freeing vocational educators from the spatial and temporal constraints of traditional training facilities and thereby enhancing its timeliness and accessibility. Singapore's vocational teacher training program leverages metaverse technology and the "Teaching Factory" professional development initiative to create effective virtual training spaces supported by large enterprises, enhancing

teachers' immersive learning experience.

V. DISCUSSION AND IMPLICATIONS

The aforementioned digital training practices concerning online courses, digital certification, and virtual practical training constitute fundamental prerequisites for achieving world-leading standards in vocational education teacher training across Germany, Australia, and New Zealand. During this critical phase of advancing educational digital transformation, China urgently needs to implement digital training models. First, develop online courses by accurately identifying industry development needs and updating training content promptly through short-term programs.

Second, strengthen digital certification mechanisms to enable real-time evaluation of online training outcomes, thereby reducing reliance on rigid qualification certification systems.

Finally, implement virtual practical training by deeply integrating it into corporate work environments.

A. HORIZONTAL COLLABORATION: DEVELOPING ONLINE COURSES TO ACCURATELY IDENTIFY INDUSTRY NEEDS

Germany, Australia, and Singapore have developed online courses based on precise identification of industry demands, ensuring the quality of digital training. Germany aligns its programs with the future skill structures required by Industry 4.0, effectively bridging vocational education teachers 'skills development with practical needs; Australia collaborates with multiple stakeholders to create short-term courses that regularly update teachers' competencies; Singapore integrates the "Four Lifelong Learners" concept into digital training, fostering lifelong learning among vocational educators. In contrast, China's online courses for vocational education teachers lag behind labor market demands, relying predominantly on expert-led lectures, which results in inaccurate demand identification and insufficient scientific rigor or flexibility (Huang et al., 2015). At its core, the limited diversity of developers for these courses remains a major weakness in China's digital training initiatives. Long-term challenges include courses primarily developed by educational institutions without effective collaboration among industry partners, educational experts, and teacher representatives, leading to rigid content that fails to adapt promptly to evolving industry needs.

To address this, it is imperative to deepen industry-education integration at the curriculum development level and strengthen partnerships with industries, industry associations, and vocational education institutions. First, identify cutting-edge industry trends and shorten training cycles by proactively addressing demands for strategic emerging industries and future-oriented sectors that are in high demand yet hold significant potential, thereby establishing a "Future Skills Demand Database." Based on evolving industry needs, online training programs should be condensed to within three months, enhancing flexibility, foresight, and adaptability to new challenges.

Second, develop tailored training content by creating digital profiles of corporate engineers and expert instructors to design specialized training programs and deliver personalized courses.

Third, establish a dynamic improvement mechanism: leverage big data for resource integration, enhance collaboration between industries, educational institutions, and training providers in developing flexible course materials such as micro-videos and online courses, and create digital communities for vocational educators to foster communication, interaction, and collaboration.

B. VERTICAL INTEGRATION: STRENGTHENING DIGITAL CERTIFICATION AND REAL-TIME EVALUATION OF ONLINE TRAINING OUTCOMES

The digital certification systems in Germany, Australia, and Singapore not only emphasize alignment with the national qualification frameworks from a "top-down" perspective but also incorporate supplementary certifications provided by industry practitioners through a "bottom-up" approach. Germany's dual education system offers diverse certification pathways for vocational teacher training; Australia's micro-certification framework effectively promotes vertical integration of qualifications; Singapore's dynamic ICT competency assessment system creates sustainable development opportunities for vocational educators. In contrast, China's vocational education sector faces challenges: teacher qualification certifications (e.g., national examinations) exhibit low content validity, while certification requirements for subject teachers and internship supervisors remain ambiguous. Data shows that 36.56% of secondary vocational school subject teachers also serve as internship supervisors, yet only 7.49% hold valid certifications (Zha and Zhang, 2010). Additionally, the absence of standardized certification criteria leads to inconsistent evaluation quality, making it difficult to ensure adequate competence among vocational educators.

Drawing on the experiences of digital certification systems in Germany, Australia, and New Zealand, China urgently needs to enhance the validity and recognition of its digital certification framework. First, at the national level, it is essential to strengthen top-level design, improve the credibility of micro-certifications, and align teacher competency standards with internationally recognized frameworks. Based on the Ministry of Education's industry standard "Teacher Digital Literacy" (covering areas such as digital awareness and digital technology knowledge/skills), certification criteria should be refined. For instance, by incorporating UNESCO's "Teacher AI Competency Framework" released in September 2024 (UNESCO, 2024),specifically breaking down digital awareness into human-centered AI values. China can drive continuous upgrades to digital certification standards and precisely define minimum requirements for digital training programs.

Second, at the corporate level, collaboration between educational institutions and enterprises should be strengthened. In China, leading companies 'vocational skill certification standards enjoy high social acceptance; these can serve as a foundation for establishing digital certification standards for vocational education teachers. For example, project-based micro-certifications and developer certifications offered through Huawei Cloud's micro-certification system across fields like cloud computing and software development could become key components of digital certification for vocational educators.

Based on this, small and medium-sized enterprises should be mobilized to participate in the development, supervision, and maintenance of the micro-certification platform for vocational education teachers, providing them with more certification opportunities.

Thirdly, educational institutions should promptly document and track certification outcomes while enhancing the systematic exchange of certifications. On one hand, collaboration with the Education Quality Assessment Center of the Ministry of Education, domestic teacher-training universities, and higher education institutions should be strengthened to establish digital training "portfolio systems" for storing, managing, and sharing training achievements, enabling comprehensive recording, feedback, and evaluation throughout teachers 'entire career lifecycle. For example, the online teaching competency micro-certification program developed by East China Normal University assesses vocational education teachers' abilities in delivering concise lectures, interactive instruction, and assessment tasks. On the other hand, a competency certification exchange mechanism should be established through credit accumulation and redemption, creating a "stack-based" feedback system for professional skills development. Specifically, leveraging professional certification bodies such as Jinhua Vocational and Technical University, an exchange mechanism should be implemented according to the Ministry of Education's "Notice on the List of Professional Programs Subject to Certification and Mid-term Review for Teacher Training Programs in Regular Higher Education Institutions," thereby establishing a continuous quality improvement framework.

C. CROSS-DOMAIN INTEGRATION: IMPLEMENTING VIRTUAL TRAINING AND DEEP INTEGRATION INTO CORPORATE WORK ENVIRONMENTS

Cross-domain integration is fundamental to engaging vocational education teachers in virtual training programs and enhancing their practical teaching capabilities. The significance of virtual training for digital education lies in its alignment with cutting-edge information technologies, providing educators with authentic corporate training experiences. However, China's vocational education system still faces significant challenges in integrating teachers' training with real-world workplace contexts, as evidenced by the low participation rate of teachers in corporate internships and specialized operational skill training. Key reasons include: First, teachers' corporate engagement remains superficial—long-standing requirements mandate "at least six months of cumulative frontline enterprise or production service experience every five years," yet practical training often consists of formalized activities like site visits, lectures, and presentations rather than substantive industry immersion.

Second, technological infrastructure for virtual training lags behind expectations: data shows utilization rates of virtual training platforms and generative AI tools stand at merely 19.24% and 4.34%, respectively, with most educators unable to fully grasp metaverse-based teaching applications—a clear manifestation of challenges posed by outdated smart equipment (Tsinghua University, 2024).

Education cannot thrive without cross-sector collaboration. The virtual training experiences of vocational education instructors from Germany, Australia, and New Zealand offer valuable insights for China. Firstly, in terms of stakeholder engagement, China urgently needs to involve small and medium-sized enterprises in building virtual training ecosystems. This includes collaborating with governments, industries, and universities to establish virtual training bases that closely replicate real-world production environments, thereby enhancing vocational educators 'adaptability to digital teaching methods. Partnering companies should receive tax incentives or priority recognition as industry-education integration enterprises.

Secondly, regarding content development, leveraging innovative organizational frameworks for industry-education integration can strengthen teachers' practical skills. By utilizing cross-sector partnerships such as industry-education alliances and municipal-level collaborative networks, virtual training platforms can be developed to deeply integrate practical training into corporate production environments.

Thirdly, spatially, virtual environments should be created using hardware and software solutions. Adopting a centralized resource development approach combined with virtual simulation technologies enables the integration of interdisciplinary training resources, establishing comprehensive process-based training environments comprising virtual scenarios, configuration software, and simulated training workbenches – creating an immersive blend of theoretical knowledge and practical application.

VI. CONCLUSION

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The digital training models for vocational education teachers in Germany, Australia, and Singapore represent world-leading standards. Germany's modular curriculum design, diversified certification systems, and platform-based practices enhance the foresight and flexibility of digital training. Australia's short-term courses, transferable certifications, and project-based learning improve the adaptability and effectiveness of digital training. Singapore's cross-sector integration, dynamic certification mechanisms, and interactive platforms foster lifelong engagement and continuity in digital training, serving as key reference points for this

comparative study. Addressing core challenges in China's digital training for vocational educators—including inaccurate needs identification, delayed evaluation feedback, and disconnection from workplace contexts—the study draws on Germany's collaborative approach, Australia's transferable standards, and Singapore's cross-sector integration advantages to develop a comprehensive training model characterized by "horizontal collaboration, vertical alignment, and cross-sector integration." This framework holds significant academic value for domestic scholars who have yet to establish robust research frameworks in teacher digital training. Furthermore, it is essential to fully explore the practical applications of these models, identify potential issues during their adaptation to local contexts, and promote systematic integration of digital training into China's vocational education teacher development programs to enhance both its efficacy and quality.

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