VTE VOCATION, TECHNOLOGY & EDUCATION

ORIGINAL ARTICLE

Implementing digital pedagogy in TVET: A Connectivist perspective

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ABSTRACT

This study explores the application of digital pedagogies in technical and vocational education and training (TVET) from the perspective of Connectivism, focusing on five widely adopted methods: blended learning, simulation-based learning, game-based learning, flipped classroom, and precision teaching. By analyzing curriculum standards and case studies from Shenzhen Polytechnic University, the research examines how TVET educators implement these methods across various contexts, highlighting their common characteristics and advantages. It evaluates their effectiveness in promoting autonomous learning, providing technical support, and enhancing educational collaboration, integrating them into the core principles of Connectivism. The findings indicate that, under Connectivism, digital pedagogies significantly enhance TVET's flexibility and effectiveness, offering richer and more personalized learning experiences. However, challenges such as disparities in technological resources, fragmentation of knowledge, and the need for teachers to enhance their digital literacy persist. The study proposes potential strategies and recommendations to address these issues, providing valuable insights for future educational practices and research.

Key words: Connectivism, digital pedagogy, digital transformation, technical and vocational education and training

INTRODUCTION

The rapid evolution of digital technologies is profoundly reshaping educational paradigms across various sectors, including technical and vocational education and training (TVET). Enhancing the deep integration of digital technology with TVET and improving the level of digital transformation in TVET are inevitable trends for the high-quality development of higher TVET in the future.[1] This transformation is driven by the need to enhance the relevance, accessibility, and effectiveness of TVET training in a digital age. As digital tools and platforms become integral to educational methodologies, TVET institutions face the critical challenge of aligning their pedagogical strategies with the technological advancements that characterize modern workplaces. Innovative digital teaching models can effectively improve both student learning outcomes and teaching quality, providing innovative approaches and strategies for the digital transformation in TVET.[2] In this context, exploring the application of digital pedagogy in TVET, particularly from the perspective of Connectivism, holds significant theoretical and practical implications.

Connectivism, as an emerging learning theory, emphasizes that knowledge is distributed and dynamically changes through networks and that learning is a process built on various connections.[3] Unlike traditional learning theories, Connectivism places particular emphasis on the construction of learning

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Received: 10 May 2024; Revised: 14 June 2024; Accepted: 17 June 2024
https://doi.org/10.54844/vte.2024.0595

networks and the pivotal role of digital technology in education.[4] Through digital technology, learners can access a broader range of knowledge resources and connect with other learners and experts, thereby facilitating the sharing and innovation of knowledge.[5] Connectivism offers a novel perspective for understanding and designing digital pedagogies.

Shenzhen Polytechnic University (SZPU), a leading institution in China's TVET sector, has actively embraced and implemented various digital pedagogical methods in its pursuit of digital transformation to enhance educational quality and student learning experiences. This study focuses on five digital pedagogical methods employed by SZPU: blended learning, simulation-based learning (SBL), game-based learning (GBL), flipped classroom, and precision teaching. Through detailed analysis of these methods, this paper aims to explore their application in the TVET context and their common characteristics from a Connectivist perspective.

This research aims to provide theoretical support and practical insights for digital transformation in TVET by analyzing the implementation effects and practical experiences of these digital pedagogies. Additionally, the study will address the main challenges encountered during their implementation and offer suggestions for improvement to promote continuous innovation and development in the TVET field.

THEORETICAL FOUNDATIONS OF CONNECTIVISM

Overview of Connectivism

Connectivism, a learning theory introduced by George Siemens and Stephen Downes in 2004, represents a significant departure from traditional learning theories such as Behaviorism, Cognitivism, and Constructivism. As an emergent theory designed for the digital age, Connectivism posits that learning occurs within extensive networks of social and technological interactions, rather than being confined to individual cognitive processes.[6] Unlike traditional theories that focus on individual learners, Connectivism highlights the importance of learning as a dynamic process that is facilitated through connections with external networks. These connections allow learners to continuously update and expand their knowledge bases.[4]

Connectivism underscores the importance of open courses, the role of teachers as facilitators of learning, and the notion of learners as active creators of knowledge. It also emphasizes the critical role of personal learning environments and the construction of learning networks. This perspective fosters an understanding of learning as a participatory process, deeply integrated with digital technologies and social networks, which supports the ongoing development of an individual's knowledge system.[7,8]

Application of Connectivism in TVET

Since the theory was proposed, Connectivism has rapidly evolved to become a critical theoretical foundation for networked learning and open education, gaining significant attention and debate within the academic community. Siemens' perspectives on Connectivism are academically oriented and widely accepted, whereas Downes' views are more philosophical, liberal, and thought-provoking.[5] Connectivism emphasizes the importance of connections. It proposes that learners can better adapt to the rapidly changing knowledge landscape through connections with diverse resources and networks.[4,9]

In the realm of TVET, the principles of Connectivism have been applied to support digital and networked teaching methodologies. For instance, Boitshwarelo introduced a comprehensive research framework to facilitate the application of Connectivism across various educational contexts. This framework integrates concepts such as online communities of practice, design-based research, and activity theory, aiming to help scholars understand the learning ecosystem of Connectivism and enhance local practices.[10]

Fournier *et al.* explored how digital tools and methods in massive open online courses (MOOCs) can support knowledge construction and interaction among learners. They found that by connecting nodes within a network, learners can leverage diverse resources and expert networks to improve learning outcomes, reflecting the core principles of Connectivism.[11]

Madimabe and Omodan examined the effectiveness of using e-learning for course delivery in rural TVET colleges, finding that this approach aligns with Connectivist principles by requiring teachers to adapt to new learning methods and design spaces and structures that fit contemporary learning models.[12]

These studies emphasize the importance of applying Connectivism in TVET, particularly in supporting continuous learning and knowledge construction through networks and technological means. Connectivism provides a useful theoretical foundation for understanding how learning occurs in the digital age by fostering the development of networks and connections that facilitate the acquisition and application of knowledge.[12,13] TVET programs are progressively incorporating Connectivist principles to address the challenges posed by digital transformation and globalization.

Despite the widespread attention and discussion, the status of Connectivism as an independent learning theory remains a topic of debate.[14] As a modern learning theory, Connectivism has found extensive application and validation in the TVET sector, playing a crucial role in supporting the digital and networked transformation of TVET.[15] The increasing application of Connectivism in networked learning environments underscores its importance as a theoretical foundation in both research and practice.

Core principles of Connectivism

The core principles of Connectivism can be summarized as follows.

Knowledge distribution

Connectivism emphasizes that knowledge is distributed across various nodes within a network rather than being confined to individuals or single sources[3]. These nodes encompass people, organizations, and technological systems such as databases, search engines, and online repositories.[16] In the modern educational context, learners can access the distributed knowledge resources through networks and establish connections with diverse knowledge sources.[17] This distribution requires learners to effectively integrate and utilize this dispersed knowledge to enhance the acquisition and application of information.[12] Different from traditional methods where knowledge is primarily transmitted through teachers and textbooks, Connectivism advocates for learners to actively explore and connect with these diverse knowledge nodes, constructing personalized knowledge networks.[18] Educators should focus on helping students develop networked learning skills to navigate and learn effectively within complex knowledge networks.[19]

Networked learning

Networked learning is a central concept in Connectivism, claiming that learning is achieved through interactions with others, resources, and technology.[20] Learners gain knowledge not only from personal experiences but significantly through network platforms such as social media, online communities, and learning management systems, facilitating exchanges and collaborations with other learners and experts.[21] In this networked environment, learning is no longer an isolated activity but a dynamic, interactive process where learners share resources, discuss problems, and collaboratively solve challenges, thereby building and expanding their knowledge systems.[22] Networked Learning fosters widespread dissemination and deep understanding of knowledge, encouraging collaboration and innovation. Educators should encourage students to actively participate in networked learning communities, using online platforms and resources to enhance their knowledge and skills. This approach not only improves learning efficiency but also broadens the scope and depth of learning.

Importance of connections

The effectiveness of learning in Connectivist theory relies on the quality and diversity of connections. Siemens noted, "the pipe is more important than the content within the pipe",[3] underscoring the importance of a well-connected network over mere content. This perspective expands learning from individual efforts to broader community engagement, enriching it through diverse viewpoints. A robust network provides access to varied information, requiring critical thinking to navigate effectively. Connections extend beyond interpersonal links to include information resources and technology systems, facilitating quick access to up-to-date knowledge.[8] Educators should foster students' ability to create broad connections, building extensive knowledge networks and driving innovation.[10] Effective connections enable learners to navigate the knowledge landscape, enhancing learning outcomes.

Technology as support

Connectivism highlights the role of digital technology in supporting modern learning. Digital technology serves not only as a tool for knowledge transmission but also as a crucial medium for knowledge construction and sharing.[23] Through the internet, social media, and various online platforms, learners can access a wide range of knowledge resources at any time and interact with learners and experts globally. The use of technology makes learning more flexible and personalized, allowing students to select content and pathways based on their interests and needs.[16] Technology also facilitates the updating and dissemination of knowledge, enabling learners to quickly acquire the latest information and research findings.[24]

Dynamic knowledge

Connectivism posits that knowledge is dynamic and constantly evolving with the influx of new information.[9] Connectivism claims that learners need to adapt and update their knowledge to navigate rapidly changing environments.[18] Continuous learning and maintaining connections with diverse knowledge sources help learners stay responsive to new information.[22] Educators should promote an open learning attitude, lifelong learning habits, and critical thinking, enabling students to refine their knowledge systems as the knowledge landscape evolves.

Autonomous and non-linear learning

From a Connectivist perspective, autonomous and non-linear learning emphasize learner agency and flexibility in constructing knowledge through dynamic networks and interactions. Autonomous learning encourages active exploration and self-management, requiring continuous updating of knowledge systems.[18] Non-linear learning allows flexible adjustment of learning paths and access to diverse information sources, facilitating the expansion and reconfiguration of knowledge networks.[25] This approach enhances adaptability and innovation, enabling efficient acquisition and integration of information in an evolving knowledge environment.

These core principles constitute the foundation of Connectivism, offering critical guidance for modern education. By understanding and applying these principles, educators can design and implement more flexible, interactive, and personalized teaching methods, helping students better adapt to the learning demands of the digital age.

DIGITAL PEDAGOGY

With the continuous advancement of digital technologies, the field of TVET is progressively advancing towards the digital transformation of its teaching methodologies. Through the utilization of digital technology, education adopts a meta-connective pedagogical approach that mirrors the ecological and transformative characteristics of our digitally networked society.[26] Digital pedagogy plays a crucial role in this transition. From the perspective of Connectivism, digital pedagogy shows significant advantages in facilitating learners' continuous learning and knowledge construction through networks and technologies. This study focuses on five digital pedagogical methods: blended learning, SBL, GBL, flipped classroom, and precision teaching, exploring their application and effectiveness in TVET.

Blended learning

Blended learning arises from the strategic integration of various instructional modes, teaching models, and learning styles, aimed at creating an interactive and engaging learning environment.[27] This approach combines online digital media with traditional classroom teaching methods, maximizing the strengths of each to enhance educational outcomes.[28] Blended learning has garnered increasing attention, especially in higher education and TVET, due to its flexibility and the critical role of technology integration.[29] It combines in-person teacher-led sessions with online discussions, digital assignments, and multimedia resources, allowing learners to access educational materials and engage with teachers and peers anytime and anywhere.

Blended learning has been widely adopted in TVET. This method accommodates different learning preferences by providing a dynamic learning environment, allowing students to access learning materials at their own pace.[28] Through data-driven analysis, educators can tailor educational pathways, thereby enhancing personalized learning outcomes[30]. The use of digital tools not only increases the interactivity of learning but also supports continuous feedback through online assessments and forums, helping students track their progress and receive timely assistance.[31]

From a Connectivist perspective, blended learning effectively realizes the concept of knowledge distribution and resource connectivity through networks. It bridges the gap between traditional education and modern digital needs, creating a networked learning environment that allows learners to fully leverage resources for a richer learning experience.

SBL

SBL employs advanced technologies like virtual reality (VR) and augmented reality (AR) to replicate real-world environments for educational purposes. It provides an experiential learning platform where learners tackle complex problems in a controlled environment, acquiring knowledge and practical skills through virtual interactions.[32] The immersive aspects of SBL, such as role-playing and interaction with virtual objects, offer a realistic yet risk-free learning experience, allowing students to practice extensively before facing real-world scenarios.[33]

SBL is particularly advantageous in TVET fields like healthcare, engineering, and aviation, where practical skills are crucial.[34] It addresses the educational need for hands-on skills and overcomes the limitations of traditional training methods.[32] By using simulation technologies, students can repeatedly practice tasks until they master them, avoiding the high costs and impracticalities of physical training. SBL also supports personalized learning paths, allowing educators to adjust content and difficulty based on students' progress, enhancing teaching effectiveness and learning efficiency.[35]

Aligned with Connectivism, which emphasizes dynamic knowledge flow within networks, SBL uses advanced technology to create an interactive and collaborative learning environment. This approach integrates theoretical concepts with practical applications, reinforcing learning through teamwork, problem-solving, and immediate feedback, thereby fostering a more effective and comprehensive learning experience.

GBL

GBL, or gamification, is an innovative educational approach that integrates game elements such as points, badges, leaderboards, and tasks into the learning process.[36] This approach leverages game mechanics and thinking to engage students, motivate action, and enhance learning and problem-solving skills.[37,38] By transforming traditional knowledge transmission into an interactive and enjoyable experience, GBL significantly increases student engagement and retention of learning materials, thereby improving educational outcomes.

In the 21st century, the education sector is transforming from traditional learning to digital learning, with GBL gaining prominence, particularly in TVET area.[39] This method incorporates game design elements into educational settings, enhancing learner engagement and interest. It aligns closely with the practical aspects of vocational training by simulating real-world tasks and processes, creating an engaging learning environment.[40] GBL is widely used in fields such as engineering and healthcare, not only serving as an external training and engagement tool but also enhancing productivity and bridging the gap between theory and practice.

From the perspective of Connectivism, GBL enhances networked connections through gamification, creating a highly interactive and immersive learning environment. This approach boosts student engagement and motivation, not only sparking interest in learning but also effectively bridging the gap between theoretical knowledge and practical application.

Flipped classroom

The flipped classroom is an innovative teaching model that reverses traditional instructional sequences by having students independently learn foundational content through video lectures, podcasts, and e-books before class.[41,42] Class time is then dedicated to higher-order cognitive activities like critical thinking and problem-solving, allowing for a deeper understanding of the material and personalized attention to student needs. This approach shifts the responsibility for learning to students, ensuring they remain proactive and engaged.

In TVET, the flipped classroom optimizes learning by requiring students to grasp theoretical knowledge beforehand, freeing class time for practical exercises and skill training, which are crucial for TVET. Pre-class autonomous learning prepares students for problem/project-based and work-based learning during class, enhancing engagement and promoting a learner-centered approach.[43]

From a Connectivist perspective, the flipped classroom redefines learning by leveraging networks and technology for knowledge distribution and acquisition. Students engage in autonomous online learning and participate in peer discussions, aligning with Connectivism's emphasis on building knowledge through network connections and enriching learning experiences through interaction and collaboration.

Precision teaching

Precision teaching, introduced by Lindsley in the 1960s, is grounded in Skinner's behavioral learning theory and was initially aimed at elementary education.[44] Its core principle involves monitoring students' learning performance and providing data-driven decision support, placing "scientific control in the hands of students and teachers".[44,45] With advancements in technology, precision teaching has evolved into a framework for evaluating the effectiveness of teaching methods, ensuring precision in goal setting, content selection, assessment of learning outcomes, and the application of educational processes.

In TVET, precision teaching enhances skill acquisition efficiency and meets diverse occupational needs. Artificial intelligence (AI) technologies facilitate personalized educational experiences by analyzing learner data to develop custom learning paths, providing real-time feedback and continuous teaching optimization.[46]

From a Connectivist perspective, precision teaching is a dynamic, interconnected educational approach. It uses big data and AI to adjust learning paths in real time, emphasizing the dynamic distribution and constant updating of knowledge. Both precision teaching and Connectivism leverage technology to connect learners with diverse resources, fostering personalized knowledge and skill development for efficient and adaptive education.

Modern digital pedagogies are closely aligned with the principles of Connectivism, which emphasizes the distribution and dynamic updating of knowledge through networks. Digital pedagogies use technological tools such as online learning platforms, VR, and data analytics to facilitate the broad acquisition, real-time updating, and personalized application of knowledge throughout the learning process, embodying the core principals of Connectivism. As illustrated in Figure 1, this study aims to analyze from a Connectivist perspective how its six core principles are interwoven into these digital pedagogical approaches.

METHODS

This study adopts a qualitative research methodology, which includes text analysis, questionnaires, and interviews, to investigate five representative courses at SZPU. The courses examined are "Java Programming Basics", "MYSQL Technology Practical", "Building Construction", "Surgical Nursing", and "Enterprise

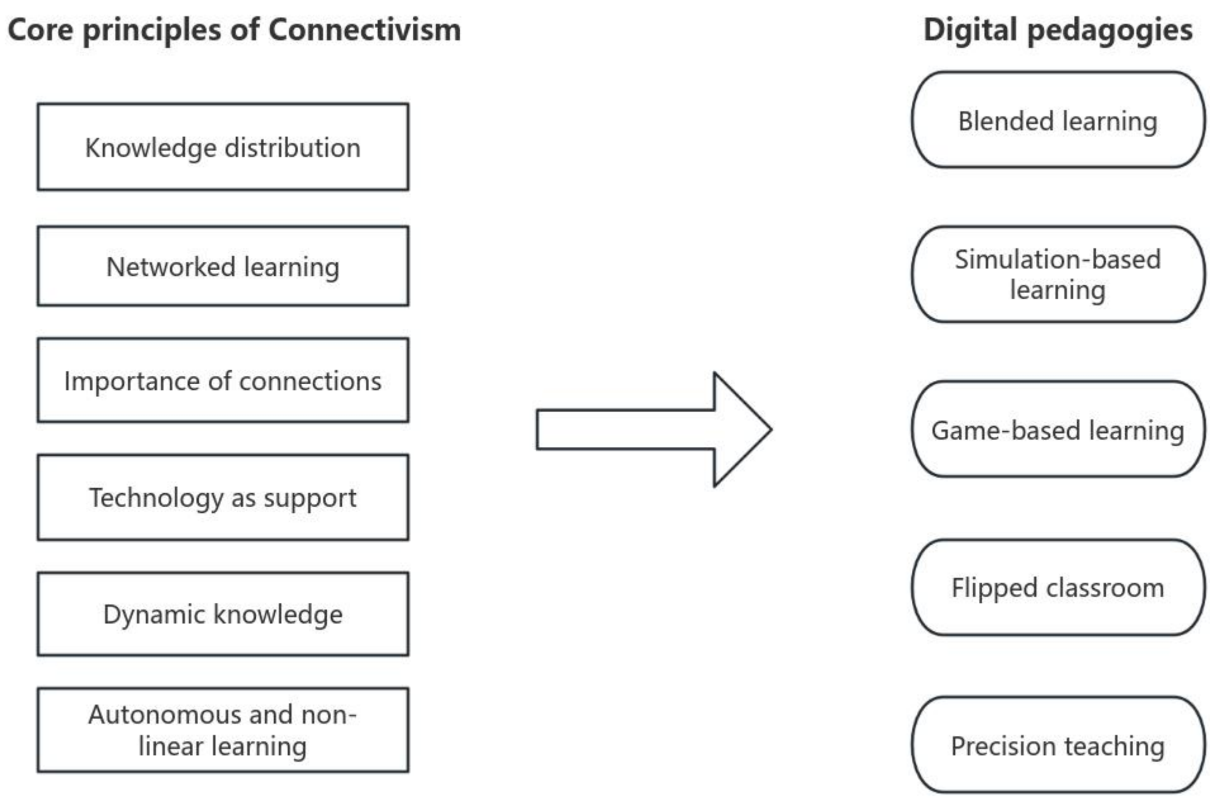

Figure 1. Mapping core principles of Connectivism to digital pedagogies in TVET. TVET, technical and vocational education and training.

Management Innovation". Each course employs multiple digital pedagogies. This study focuses on analyzing the most representative digital pedagogy in each course.

Case selection criteria

The criteria for selecting these courses are based on several key considerations.

Institutional excellence

SZPU is a nationally recognized exemplary higher TVET institution in China. It leads in the digital transformation of TVET. Its curriculum design and innovative teaching practices are highly representative and provide significant value for broader application.

Diverse disciplines

The selected courses span various fields, including applied sciences, information technology, engineering, medical sciences, and business management. This demonstrates the diverse application of digital pedagogy across different disciplines.

Outstanding performance

These courses have received widespread acclaim for their excellent performance in student satisfaction, employment rates, and the development of practical skills. This makes them highly representative and exemplary in TVET.

Data collection and analysis methods

This study adopts qualitative analysis methods, including text analysis, questionnaires, and interview records. The collected data are organized and classified to identify themes and concepts related to Connectivism. It aims to extract the characteristics and commonalities of digital pedagogy across different courses, particularly how they reflect the core principles of Connectivism. By analyzing these cases in detail, the study examines the practical application of digital pedagogy in TVET and highlights its common features from a Connectivist perspective. This provides theoretical support and practical guidance for the development of digital education.

Text analysis

The study analyzes relevant curriculum standards and internal teaching documents at SZPU. This helps to understand the specific applications and theoretical foundations of various digital pedagogies. These documents detail the implementation context for each course, including policy basis and specific implementation pathways, offering valuable data for the research.

Questionnaires

A total of 60 questionnaires were distributed among the curriculum development team members and students, comprising 10 teachers and 50 students. Out of these, 54 fully completed questionnaires were returned, providing a substantial amount of data for analysis. The questionnaire incorporated both open-ended and closed-ended questions to assess various aspects of the curriculum development process and its outcomes. The questions primarily focused on evaluating course content, teaching methods, learning resources, and overall satisfaction.

Interviews

Ten participants were selected for in-depth interviews. This group included 10 curriculum development team members and 10 students, ensuring a balanced representation of viewpoints. The purpose of these interviews was to delve deeper into the insights collected from the questionnaires, providing a nuanced understanding of the experiences and challenges related to digital pedagogy in TVET. Interviews with teachers focused on how they applied digital pedagogies in their teaching, assessed the effectiveness of these methods, and addressed challenges encountered during implementation. Student interviews concentrated on their experiences with the courses, feedback on various teaching methods, and expectations for future improvements. All interview data were coded and subjected to thematic analysis to summarize the characteristics and impacts of digital pedagogies in TVET.

Based on the available data and our research context, our study explores the following aspects: 1. How do teachers at SZPU adopt digital pedagogy in TVET? What are the effectiveness and limitations? 2. How are the core principles of Connectivism reflected in these digital pedagogies? 3. What are the main features of these digital pedagogies from a Connectivist perspective?

FINDINGS

Adoption of digital pedagogy in TVET at SZPU

MYSQL Technology Practical: blended learning

Implementation pathway

The course adopts a blended learning approach, integrating online and offline methods. Traditional content is digitized and broken down into detailed tasks like requirement analysis, database design, and development. These are presented as digital task chains that students complete on a digital platform, simulating a real work environment. The course provides rich digital resources such as knowledge maps, video lectures, e-handouts, and project texts. Students access these *via* an online platform for self-study and preparation. The course follows a three-stage model: pre-class video learning, in-class targeted teaching, and post-class assignments and reflections.

Outcomes and achievements

Blended learning has significantly improved students' self-study skills and digital competencies, enhancing their understanding and practical abilities in database development. Students excel in domestic and international database exams, increasing the number of Oracle certifications and boosting their employability. The introduction of digital resources and blended methods has enriched the course content, raising student interest and engagement. The course consistently receives positive feedback for aligning with job requirements and enhancing career prospects, with many students securing positions in well-known companies.

Challenges and limitations

Teachers and students face challenges such as the time and effort required to develop digital resources and course design. Teachers need strong digital skills and must continually update course content to keep pace with technological and industry changes. Students need good self-management skills, and some struggle to adapt to online learning, manage their time, and effectively use online resources. Issues like insufficient interactivity and immediate feedback in online learning, technical problems such as unstable internet connections, and unfamiliarity with platform features also affect learning outcomes.

Building Construction: SBL

Implementation pathway

This course uses SBL, optimizing content through digital environments and VR. It develops a detailed knowledge map and leverages school-enterprise collaboration and big data to ensure content meets industry needs. Rich digital resources are available on MOOC platforms for student self-study. AI-based digital virtual teachers provide personalized learning support and real-time assistance. VR classrooms simulate construction scenarios like excavation and foundation work, enhancing practical skills. Industry experts are involved to ensure students learn the latest technologies.

Outcomes and achievements

Digital teaching has significantly improved student learning outcomes and teaching quality. The certification pass rate has increased from 64.4% in 2020 to 95% in 2023, and student satisfaction with the course has also risen, maintaining a top 30 ranking in internal teaching quality evaluations. Teachers have received multiple national and provincial awards and obtained several patents and copyrights. Collaboration with enterprises in the Greater Bay Area has aligned course content with industry needs, producing skilled graduates.

Challenges and limitations

Introducing virtual simulation technology is challenging for both teachers and students. Students need time to adapt to this new interactive learning model and must learn to operate in virtual environments. Teachers must redesign course content and learn new teaching tools, requiring ongoing technical training. Developing high-quality digital resources and simulation environments is costly, necessitating collaboration with industry experts and significant investment. The rapid development of virtual technology requires schools to continually invest to stay current, posing financial challenges, especially for resource-limited TVET institutions.

Surgical Nursing: GBL

Implementation pathway

The "Surgical Nursing" course innovatively applies game-based learning to enhance student engagement and practical skills. Through Wisdom Tree, an online platform, the course combines 3D design and gamification elements, creating a hybrid learning model. The team developed game-based modules and virtual simulation projects with hospital experts, including training for brain, chest, and abdominal injuries and colon cancer patients, using AR and VR for immersive learning. Students engage in clinical scenarios, such as wound care and post-operative nursing, making real-time decisions in a virtual game environment.

Outcomes and achievements

Game-based learning has greatly increased student participation and practical skills in "Surgical Nursing". In an interactive environment simulating real clinical situations, students master complex nursing knowledge and skills. Performing nursing tasks and handling emergencies in a virtual setting boosts students' practical experience and adaptability. Over 95% of students report that this method makes it easier to understand and master complex nursing procedures. The course's innovative approach has won several teaching awards, and its digital resources have been widely adopted and positively received, extending its impact on TVET resources.

Challenges and limitations

Despite its advantages in boosting learning interest and motivation, game-based learning has limitations. Complex medical theories and precise nursing techniques are challenging to convey through gamification. Game-based learning suits simpler skills and knowledge but may not support deep understanding and long-term retention. Virtual environments cannot fully replicate the complexities and unpredictability of real surgeries, affecting the practical application. Evaluating real skills through game environments is also challenging, as external rewards like points might undermine intrinsic motivation and professional responsibility. Different students respond to gamification differently, with some potentially overlooking essential content. To ensure thorough skill mastery, game-based learning must be combined with traditional methods and hands-on training.

Enterprise Management Innovation: flipped classroom

Implementation pathway

The "Enterprise Management Innovation" course uses the flipped classroom method, focusing on enhancing teachers' digital competencies with tools like AI. Teachers develop and manage digital resources, creating personalized content and facilitating classroom interactions. The course offers multimedia materials, interactive videos, and online tests for pre-class self-study. In class, emphasis shifts to discussion, teamwork, and case analysis. Students simulate business decisions, working in teams to manage a virtual company, using AI for data analysis and market predictions. They complete project-based tasks, analyzing and reporting on virtual and real business innovations.

Outcomes and achievements

The flipped classroom shifts knowledge acquisition to pre-class activities, allowing deeper in-class discussions and engagement. Surveys show over 90% of students are satisfied, finding it enhances understanding and practical skills. Teachers effectively use AI tools to create and manage digital resources, improving teaching efficiency and reducing manual grading. The course's application has led to a 30% increase in learning outcomes and a 10% improvement in average grades. The course's reach and impact have expanded through shared platforms, engaging over 4500 participants and achieving significant viewership and interaction.

Challenges and limitations

The flipped classroom demands high self-discipline and time management from students. Failing to complete pre-class tasks affects in-class discussions and overall learning outcomes. Diverse backgrounds and abilities among students can lead to uneven knowledge acquisition, particularly for those with lower self-discipline or learning capacity. Effective classroom management to ensure active participation is challenging, especially in large classes, increasing the complexity of maintaining student engagement.

Java Programming Basics: precision teaching

Implementation pathway

The "Java Programming Basics" course focuses on precision teaching with digital tools and resources. An online judgment system (OJ system) provides real-time programming exercises and automated grading, helping students quickly identify and correct errors. The system generates personalized learning reports using big data analysis, allowing teachers to offer targeted guidance. The course uses an interactive video and online assessment system, with AI dynamically adjusting content difficulty and teaching pace to match student needs.

Outcomes and achievements

The introduction of the OJ system and interactive videos has significantly improved students' programming skills and learning outcomes. Evaluation data shows a 20% reduction in programming errors and a 30% increase in learning efficiency. Over 90% of students are satisfied with the immediate feedback and personalized learning support, finding it deepens their understanding. Teachers can adjust teaching content and pace in real time, enhancing teaching efficiency and reducing manual grading. The course team has created high-quality teaching videos and interactive content, receiving support for various teaching research projects.

Challenges and limitations

Teachers face challenges in data interpretation. While learning data provides basic insights into student attitudes and engagement, it lacks depth in identifying specific learning issues. Teachers need significant time to analyze data for useful information, but limited time and resources make detailed analysis difficult. Future technology needs to improve data mining capabilities to aid teachers in understanding and interpreting data for precise guidance. Current data is insufficient for exploring deeper aspects like student competence, affecting teaching decisions. There is a need to improve teachers' data literacy and interpretation skills, requiring further research on enhancing knowledge and abilities in this area.

Digital pedagogies from a Connectivist perspective

Table 1 provides a detailed overview of the various digital pedagogies employed across different courses at SZPU. It highlights how these practices align with the core principles of Connectivism. This section provides a specific analysis of the manifestation of these principles within each course and pedagogy.

Blended learning

In the "MYSQL Technology Practical" course, a blended learning approach was employed, integrating core principles of Connectivism. This method combines online resources with traditional classroom teaching, allowing students to access a wide range of learning materials beyond traditional textbooks and lectures. This integration facilitates the wide distribution of knowledge across network platforms, enabling students to access these resources as needed.

Networked learning is a key aspect of this pedagogy. Students interact with peers and instructors through online discussion platforms and collaborative projects, forming a learning network. This network serves as a medium for knowledge exchange and provides opportunities for mutual learning and collaboration, reinforcing the importance of connections between pieces of knowledge.

Technology as support plays a crucial role in this course. The introduction of online learning platforms and tools makes it easier for students to access resources and engage in practical exercises. Technology becomes the backbone of knowledge distribution and the learning network.

Autonomous and non-linear learning is also emphasized in this blended approach. Students can choose their learning content and pace according to their progress and needs, creating a flexible and personalized learning process that aligns with their learning habits and interests.

SBL

The "Building Construction" course uses SBL, highlighting Connectivist principles. The course employs a network learning platform and online collaboration tools to create an interactive learning community where students can simulate construction projects and work in teams. This approach exemplifies networked learning in Connectivism.

Using advanced simulation software, students engage in complex construction operations within a highly realistic virtual environment. Technology as support provides students with a real-world practice experience, helping them develop essential skills for the workforce.

The dynamic knowledge aspect is well represented in this course. The curriculum is continuously updated to reflect current trends and industry standards in construction technology. Through SBL, students interact with the latest building materials and techniques in a VR setting, keeping up with technological advancements. The continuous update of teaching resources on the online platform allows students to access the latest

Table 1: Connectivist principles in digital pedagogies at Shenzhen Polytechnic University

Course	Digital pedagogy	Core principles of Connectivism involved
MYSQL Technology Practical	Blended learning	Knowledge distribution Networked learning Technology as support Autonomous and non-linear learning
Building Construction	Simulation-based learning	Networked learning Technology as support Dynamic knowledge
Surgical Nursing	Game-based learning	Knowledge distribution Networked learning Technology as support
Enterprise Management Innovation	Flipped classroom	Knowledge distribution Networked learning Importance of connections Technology as support Autonomous and non-linear learning
Java Programming Basics	Precision teaching	Networked learning Technology as support Dynamic knowledge Autonomous and non-linear learning

industry information and technology developments, enhancing their knowledge and skills.

GBL

In the "Surgical Nursing" course, game-based learning integrates theoretical knowledge into gaming contexts. Various digital resources and game modules distribute knowledge across multiple nodes. Students engage with knowledge from diverse professional fields and practical environments through virtual communities, simulated surgeries, and nursing tasks. This knowledge is embedded in virtual patient records, nursing protocols, and operation guides. Students connect different knowledge nodes through autonomous learning and collaborative discussion, gradually building a comprehensive nursing knowledge network.

Networked learning is fostered through the creation of virtual learning communities and interactive platforms, enhancing student engagement and cooperation. Using AR and VR technologies, combined with online discussion and collaboration tools, students simulate real clinical nursing scenarios in a virtual environment and complete nursing tasks within the game. This relies on modern technology as a support tool.

Flipped classroom

Connectivism emphasizes that knowledge is distributed across various network nodes, rather than being concentrated in a single source. In the "Enterprise Management Innovation" course, students access digital resources such as multimedia presentations, interactive videos, and industry reports through an online platform, gaining knowledge of enterprise management and innovation. The course breaks the traditional one-way knowledge transfer, allowing students to interact with digital resources and real-world cases to build a diverse knowledge network, enhancing their understanding and application of business management concepts.

The course employs project-based learning, where students analyze data resources and collaborate on simulations of real business operations. This multi-layered connection enables students to navigate complex knowledge networks effectively, enhancing their ability to integrate and apply knowledge.

Connectivism underscores the importance of technology in modern learning and promotes autonomous and non-linear learning. The course team utilizes digital platforms and AI tools like iFlytek Smart, Wenxin Yige, and ChatGPT to provide students with rich learning resources and personalized guidance, improving the interactivity and practicality of learning. Students use these tools for autonomous learning, data analysis, and decision-making simulations, allowing them to flexibly manage their learning progress and content. Through classroom discussions and project practice, students adjust learning paths and goals, gaining a deeper understanding of complex business knowledge and skills. The diverse learning resources and real-time feedback provided by teachers enhance teaching efficiency and help students continuously update and refine their knowledge systems, strengthening their competitiveness and adaptability in the digital era.

Precision teaching

Networked learning is widely applied in precision teaching. Students collaborate and discuss on online platforms, forming a learning community that enhances the sharing and application of knowledge. Technology as support plays a crucial role in precision teaching. The introduction of OJ systems and interactive platforms allows students to engage in real-time practice and receive immediate feedback. The use of technology increases learning efficiency, allowing students to monitor their learning progress and identify areas for improvement.

Dynamic knowledge and autonomous learning are fully represented in precision teaching. Course content is continuously updated and adjusted based on student feedback and progress, ensuring the relevance and timeliness of knowledge. Students can select learning paths and content according to their personal needs, enhancing the personalization and flexibility of learning. This mode of dynamic knowledge updating and autonomous learning enables students to adapt to rapidly changing technological environments, maintaining sensitivity to new knowledge and fostering continuous learning capabilities.

Common features of digital pedagogies

Network-connected resource sharing system

Connectivism emphasizes the importance of distributed knowledge and networked learning.[5] In these courses, learners access a wealth of resources and data through online platforms. For instance, the "Enterprise Management Innovation" course uses diverse online materials to facilitate pre-class autonomous learning. Meanwhile, the "Java Programming Basics" course employs an online coding system, enabling students to access and apply programming knowledge in real time. The blended learning approach in the "MYSQL Technology Practical" course integrates online and offline resources, enhancing accessibility and diversity. This resource-sharing system not only increases educational flexibility and accessibility but also promotes extensive knowledge exchange and collaboration, aligning with Connectivism's principles of knowledge distribution and networked learning.

Collective intelligence in teaching models

Connectivism posits that learning is a social process formed through diverse connections and interactions,[21] a principle well-reflected in digital pedagogies. For example, the "Surgical Nursing" course uses game-based learning to simulate real-life nursing scenarios, encouraging teamwork and knowledge sharing among students. Similarly, the "Building Construction" course, through SBL and VR, creates a collaborative learning environment where students solve problems together in simulated settings, demonstrating the power of collective intelligence. These courses, driven by projects and team collaboration, enhance student interaction and cooperation, fostering the co-creation and sharing of knowledge, which embodies the Connectivist idea of group intelligence and socially constructed knowledge.

Learner-centered learning pathways

Connectivism supports personalized learning pathways, emphasizing that learners construct knowledge networks based on their needs and interests. Digital pedagogies in these courses highlight a learner-centered approach through personalized and self-paced learning. In the "Enterprise Management Innovation" course, the flipped classroom model allows students to choose their learning content and pathways flexibly according to their interests and needs. The "Java Programming Basics" course uses precision teaching with big data analysis to provide personalized learning reports and real-time feedback, enabling students to adjust their learning strategies autonomously. This personalized and self-paced approach enhances learning flexibility and efficiency, reflecting Connectivism's core principles of autonomous and non-linear learning.

Technology-supported learning environments

From a Connectivist perspective, technology is a crucial tool for connecting knowledge nodes and facilitating learning.[18] In these courses, technology-supported learning environments are central to digital pedagogy. For instance, the "Surgical Nursing" course uses AR and VR technologies to create an immersive virtual learning environment where students perform hands-on tasks and skill training in simulated scenarios. The "Building Construction" course employs SBL through VR to replicate the latest construction technologies and scenarios, allowing students to practice in a virtual setting, which enhances skill acquisition. The application of technology enriches learning resources and methods, improves interactivity and practicality in teaching, and enhances students' understanding and application of knowledge. Technology-supported learning environments foster the dynamic growth and evolution of knowledge networks, reflecting the Connectivist principle of technology as support.

In conclusion, these course cases from SZPU demonstrate the core principles of Connectivism through digital pedagogies. These pedagogies not only increase the diversity and flexibility of knowledge acquisition but also enhance interaction and personalization through extensive use of technology. Digital pedagogies make knowledge transmission and application more efficient, enabling learners to better grasp and apply knowledge within this dynamic and connected network environment. This transformation represents a forward direction in educational technology and offers new possibilities and higher standards for modern education. These teaching practices reveal the immense potential and value of digital pedagogies in improving educational quality and meeting the learning needs of the new era.

DISCUSSION: CHALLENGES AND RECOMMENDATIONS

Despite the significant value of Connectivist principles in guiding digital pedagogies, educators encounter numerous challenges when implementing these methods. The previous section analyzed course cases, highlighting the specific challenges and limitations associated with each teaching method. This chapter delves into these issues further, based on data collected from questionnaires and interviews. We discuss the various challenges that may arise during the implementation of digital pedagogies and propose feasible strategies and recommendations to address these challenges.

Challenges

Technological resource disparity

The successful implementation of digital pedagogies from a Connectivist perspective requires extensive technological infrastructure to enhance connectivity and the development of learning networks. However, uneven distribution of technological resources, particularly in low- and middle-income countries, significantly limits this. The *2022 EDUCAUSE Horizon Report* highlighted that blended learning demands substantial infrastructure investment. In these regions, economic pressures have led to educational budget cuts in two-thirds of countries since the COVID-19 pandemic, exacerbating educational resource disparities.[47,48] In SZPU's course cases, despite the provision of advanced digital platforms, resource allocation disparities persist. For instance, during the pandemic, some students faced limitations due to geographical and economic factors, lacking access to high-quality equipment and stable internet, which impacted their online learning effectiveness.

High maintenance costs

In courses such as "Building Construction" and "Surgical Nursing", the use of virtual simulation technologies encounters significant challenges due to high maintenance costs. Developing and maintaining digital resources and simulation environments require substantial expertise and technical support. This involves collaboration with industry experts and continuous updates and maintenance to keep the content and technology current. These costs include purchasing advanced hardware, compensating technical staff, and ensuring long-term technical support and updates. High maintenance costs limit the widespread application of these technologies and impose significant demands on institutional budget management.

Fragmentation of knowledge

In the digital age, the rapid update and proliferation of information resources increase the difficulty for learners to integrate and comprehend knowledge cohesively.[49] Students often struggle to systematically organize and understand vast amounts of fragmented information, leading to loose knowledge networks and decreased learning effectiveness. Although digital platforms provide abundant resources, students may experience confusion and information overload, finding it challenging to identify logical connections and build a comprehensive knowledge framework. This can result in a disconnect between theory and practical application, affecting their future innovative and applied skills in their careers. While Connectivism emphasizes integrating knowledge through networks, the challenge of managing fragmented information in actual teaching requires educators to assist students in developing coherent knowledge networks and enhancing course design and teaching strategies.

Increased demands on teachers' digital literacy

Connectivism advocates for open, networked teaching models where teachers transition from knowledge transmitters to facilitators and knowledge connectors. In SZPU's course cases, the implementation of digital pedagogies demands higher levels of digital literacy from teachers, requiring proficiency not only in subject matter but also in advanced digital skills. For instance, the "Java Programming Basics" course's use of an online coding system and discussion platforms requires teachers to analyze data and provide personalized guidance. However, inadequate adaptation to and training in new technologies have constrained teacher performance, especially during COVID-19 when many were forced to use unfamiliar tools. As education and industry continue to digitize, teachers must acquire advanced information and communication technology (ICT) skills to achieve digital transformation in teaching.[50] Supporting teachers' digital development and providing adequate resources and training is a significant challenge in implementing digital pedagogies.

Lack of student motivation for autonomous learning

Digital pedagogies, particularly flipped classrooms, require substantial pre-class autonomous learning and preparation by students. However, many students lack effective time management skills and the habit of autonomous learning, failing to utilize online resources effectively. This results in a disjointed learning process, negatively impacting class discussions and practical activities. This is particularly challenging for TVET students who often need to balance study with work responsibilities, making it difficult to dedicate sufficient time and effort to autonomous learning. A lack of motivation and drive for autonomous learning makes it challenging for students to maintain consistent learning engagement and effectiveness in a digital teaching environment.

Recommendations
In light of the challenges and successes observed in the digital pedagogy practices at SZPU, and aligning with the core principles of Connectivism, this study proposes the following recommendations to enhance the implementation of digital pedagogy in TVET.

Enhance technological infrastructure
Prioritize the enhancement of digital infrastructure, including cloud computing upgrades and expanded broadband coverage, to ensure seamless access to educational resources. Invest in intelligent learning management systems for personalized learning and real-time feedback. Upgrade hardware, such as multimedia tools and virtual labs, to create an engaging, interactive learning environment and support the dynamic growth of knowledge networks.

Foster cross-sector collaboration
Break down barriers between education and industry by establishing a platform for collaboration with various stakeholders, such as industries, government agencies, and educational institutions. This collaboration will integrate educational content with practical applications, aligning with vocational needs and promoting continuous knowledge innovation and application.

Build resource-sharing platforms
Create an open platform for resource sharing using new media and big data technologies. This will provide wide access to educational materials, encourage interaction, and keep resources updated. Such platforms can reduce regional educational disparities, promote equity, and enhance TVET quality by offering more opportunities for practical application and innovation.

Promote teacher development
Enhance teacher training to improve digital competencies and adopt student-centered teaching. Encourage continuous professional development through internal training, workshops, and online communities for sharing best practices. This approach ensures teachers can guide and support students in a rapidly evolving digital learning environment, aligning with TVET's dynamic demands.

CONCLUSION

Summary
This study examines the application of digital pedagogy in TVET from the perspective of Connectivism. Focusing on five digital teaching methods at SZPU—blended learning, SBL, GBL, flipped classroom, and precision teaching—this research investigates how these methods are implemented in TVET and highlights their advantages in promoting autonomous learning, providing technological support, and enhancing educational collaboration. Blended learning combines online and offline resources, increasing flexibility and interactivity; SBL enhances students' practical skills and problem-solving abilities through virtual simulations; GBL improves learner motivation and engagement through gamified elements; the flipped classroom redefines the allocation of time inside and outside the classroom, promoting autonomous learning and deep engagement; precision teaching offers personalized learning support and real-time feedback through big data and AI.

The study reveals that the core principles of Connectivism are well reflected in these digital teaching methods and play a crucial role in improving teaching effectiveness and student learning experiences. However, challenges such as unequal distribution of technological resources, fragmented knowledge, the need for improving teachers' digital literacy, and insufficient student motivation for pre-class learning are identified. Addressing these challenges requires optimizing resource distribution, enhancing teacher capabilities, fostering multi-stakeholder collaboration, and motivating students.

This study highlights the potential and practical benefits of applying Connectivism in digital pedagogy within TVET and offers valuable insights for the future development of TVET. In the digital age, Connectivism provides a new perspective for understanding and applying digital teaching methods. By integrating the core principles of Connectivism, this study demonstrates how technology-driven digital pedagogy can enhance teaching quality and learning experiences. Through thorough exploration and practice, we can build an educational system that meets future demands, promotes continuous development and innovation in global TVET, and responds proactively to the ever-changing social and economic landscape.

Limitations and further research
This study focuses primarily on the implementation of digital pedagogy from a Connectivist perspective in China and does not delve into the diverse needs of students from different cultural and national backgrounds. The access to technology and learning habits of students may vary significantly due to regional and economic differences, affecting their acceptance and use of digital teaching tools. Moreover, the study only uses SZPU as a case for analysis, which may not adequately reflect the different responses and adaptations to digital pedagogy across various

educational institutions and cultural contexts. These factors may limit the generalizability of the findings and do not fully represent the practice of TVET in different regions and schools.

Future research should explore the application of Connectivism in diverse cultural and economic contexts to understand how digital pedagogy can be tailored to meet the needs of varied student groups. Especially in low-income countries and regions with limited technological resources, research should focus on optimizing digital pedagogy to address the unique needs and challenges in these environments. In-depth studies in these areas will help uncover the global applicability of Connectivism in TVET and provide robust references for the development of TVET worldwide.

DECLARATIONS

Author contributions

Xueying Chen: Data curation, Writing—Original draft. Sokmeng Chan: Writing—Review and Editing. All authors have read and approved the final version.

Source of funding

This research received no external funding.

Ethical approval

Not applicable.

Conflict of interest

The authors have no conflicts of interest to declare

Data availability statement

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

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