International Journal for Research in Vocational Education and Training (IJRVET)
2026, Early Access, 1–23
https://doi.org/10.13152/IJRVET.14.1.1

Digital Competency Profiles for Brazilian Vocational Educators and Professionals: Toward Digital Sustainability

Laura Visintainer Lerman*[1,2], Paolla Polla Pontes do Espírito Santo[1], Camila Costa Dutra[1], Maria Auxiliadora Cannarozzo Tinoco[1]

[1]*Universidade Federal do Rio Grande do Sul, Department of Industrial Engineering, Organizational Engineering Group, Av. Osvaldo Aranha, 99 Centro Histórico, Porto Alegre RS, 90035-190, Brasil*
[2]*Technical University of Munich, TUM School of Management, Arcisstraße 21, 80333 Munich, Germany*

Received: 18 June 2025, Accepted: 11 March 2026

Abstract

Context: The concept of digital sustainability has gained attention in recent years, driven by the rapid advancement of digital transformation. Vocational education and training (VET) plays a crucial role in equipping individuals with the digital competencies necessary for advancing digital sustainability. VET not only supports the development of competences among students but also fosters the professional growth of educators, which is vital for achieving sustainable development goals. This study aims to facilitate the transition to digital education while addressing sustainability challenges by offering a comprehensive vision for vocational education and training.

Approach: We conducted an exploratory, qualitative multi-case study in four stages. To strengthen the proposed competencies, the first three stages involved literature reviews and validation workshops with experts. In the final stage, a program was designed around five mentoring cycles, incorporating project management methodologies such as Agile and Design Thinking, along with instructional design strategies like Active Learning, Backward Design, and Formative Assessment. This program was implemented in four vocational education institutions in Brazil to pilot the development of these competencies.

*Corresponding author: laura.visintainer-lerman@tum.de

ISSN: 2197-8646
https://www.ijrvet.net
© Laura Visintainer Lerman, Paolla Polla Pontes do Espírito Santo, Camila Costa Dutra, Maria Auxiliadora Cannarozzo Tinoco[1]

Results: Our study presents a digital competency profile for VET professionals and teachers. The profile for VET professionals encompasses competencies in sensing technologies, digital communication, data processing and analysis, as well as operational and managerial skills. It also includes socio-emotional competencies and specific knowledge of technologies and practices linked to sustainable development. VET teachers should align their digital competencies with digital teaching technologies.

Conclusion: Our study proposes a digital sustainability framework for VET, offering policy recommendations aligned with education, innovation, and sustainability pillars. The approach fosters hands-on learning, accelerates technology transfer, and enhances digital-sustainability competencies. It also emphasizes contingency planning to ensure learning continuity and attract co-investment. Prioritizing low-cost, scalable pilots and simplifying administration strengthens partnerships with startups and industries, advancing sustainable education models while fostering green innovation and reducing environmental impacts.

Keywords: Digital sustainability, Digital competencies profiles, Vocational Education and Training, VET

1 Introduction

Digital sustainability presents a new approach to managing sustainable development by harnessing digital transformation to address challenges such as waste management, renewable energy use, and water conservation (Schöggl et al., 2023). It integrates the digital transition's economic, environmental, and social goals to promote sustainable practices. As digitalization advances in sustainability contexts, professionals need new competencies, especially for technology transfer (Nikoloudakis & Rangoussi, 2024; Thunqvist et al., 2023). However, many lack the digital skills required to effectively apply these technologies (Lee & Meng, 2021). Although there is growing interest in Digital Competencies (DC) across education, politics, and media, scientific research on adult DCs-especially in work-related contexts-remains limited (Oberländer et al., 2020). For professionals to benefit from digital sustainability, it is essential to acquire competencies in digital technologies and transformation during vocational education and training (Fraile et al., 2018; Thunqvist et al., 2023). A key strategy is strengthening teachers' digital competencies, which is central to spreading knowledge on sustainability and digital innovation across classrooms, industries, and research institutions (Basilotta-Gómez-Pablos et al., 2022; Fraile et al., 2018).

In this scenario, to meet the current and future demands of corporate businesses, it is necessary to develop digital competencies in working professionals (Quintero, 2022; Vuorikari et al., 2022). The European frameworks serve as a reference for others when exploring

social, economic, and sustainable contexts of this evolution aligned with the United Nations 2030 Agenda. The most recent Digital Competences Framework for Citizens (DigComp 2.2; Vuorikari et al., 2022) provides valuable support for creating competency profiles for VET professionals, including sustainability-related competencies. However, it may not fully address the specific technical skills required for certain professions. Other frameworks, such as the Digital Competences Framework for Educators (DigCompEdu; Redecker & Punie, 2017) and the Information and Communication Tools Competency Framework for Teachers (ICT CFT; UNESCO, 2018), also contribute to the development of digital competencies for VET teachers. The ICT CFT uniquely connects digital skills development to the United Nations' Sustainable Development Goals (SDG)[1]. Quintero's (2022) research on digital competencies for digital industrial engineers highlights essential VET technical, interpersonal, and socio-emotional skills, aligning with the broader digital transformation needs. However, it falls short in addressing specific digital competencies for technical and sustainability roles. Finally, GreenComp (Bianchi et al., 2022) focuses on equipping students with the knowledge, competencies, and values needed for sustainability, but it does not incorporate technology as a tool for promoting sustainability. While these frameworks support lifelong learning and digital adaptation, they are often too general and fail to address the specific needs of VET (Cattaneo et al., 2022).

In this sense, developing digital and sustainable competencies in professionals is crucial for understanding the integration of technologies, basic waste management concepts, use of renewable resources, and sustainable inventory management. VET teachers should also develop digital competencies to effectively incorporate digital technologies and digital transformation concepts into their teaching practices (Shamzzuzoha et al., 2022). Several educational policies focus on teachers' digital competence (TDC), primarily concerned with organizing teacher training and enabling them to integrate technology into their teaching practice effectively (Cattaneo et al., 2022). These policies also aim to identify a set of sustainability competencies for education programs to help students develop the necessary knowledge, competencies, and attitudes (Bianchi et al., 2022; Nikoloudakis & Rangoussi, 2024). However, most conceptual frameworks have been developed to clarify digital competence, focusing on preservice teachers (Cattaneo et al., 2022) and presenting digital and sustainable competencies disaggregated. Recent contributions highlight the need to explore other educational contexts, noting that no current framework considers the particularities of VET teachers (Cattaneo et al., 2022; Lucas et al., 2021). Therefore, our study aims to establish a digital competencies profile (DCP) for teachers and professionals of Brazilian vocational education and training, contributing to the transition to digitalized and environmentally engaged education with sustainable objectives. To this end, we propose the following research question: *How digital competencies should professionals and teachers in vocational education and training possess to effectively contribute to digital sustainability?*

1 Data/information can be requested from the author.

To address the research question, we conducted a one-year exploratory multiple case study, conducting workshops to validate the two profiles and a program with pilot projects in Brazilian VET institutions. Our main contribution is to assist the development of educational practices in digital sustainability within the VET context focusing on developing new policies. This study contributes by integrating digital competencies within the broader concept of digital sustainability.

2 Research Method

To identify the DCP required for VET in Brazil, we conducted a one-year exploratory, qualitative multi-case study in four stages. First, we conducted a comprehensive literature review to identify reference models for DCP relevant to professionals and teachers. In the second stage, we outlined the market-required DCP for VET professionals by conducting interviews with representatives from technology companies in sustainability sectors and VET institutions. The third stage focused on identifying the key competencies needed by teachers in VET. Finally, we designed and piloted a competency development program across four Brazilian VET institutions. Figure 1 provides a systematic overview of the study's design.

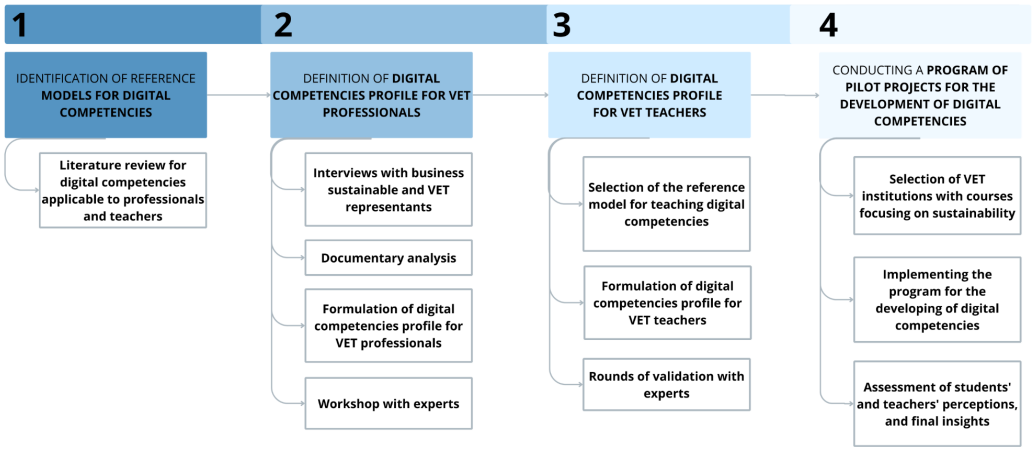


Figure 1: Steps of the Research Method

2.1 Identification of Reference Models for Digital Competencies

The development of the DCP for VET was based on skills-based training models traditionally used in higher education and on digital competency training for educators across various educational levels (Fraile et al., 2018). It also draws on key European frameworks that outline

digital competencies for teachers, such as the *ICT Competency Framework for Teachers* (UNESCO, 2018), and for citizens and professionals through the DigComp framework (Bianchi et al., 2022; Quintero, 2022; Vuorikari et al., 2022).

The selection of these models is grounded in their origins within organizations and institutions with established expertise in the social, ethical, economic, and environmental domains. As a result, they have achieved widespread recognition and adoption across educational institutions at all levels worldwide, providing a foundation for the development of innovative curricula. Furthermore, these models focused on creating assessment tools for evaluating teaching competencies and assessing existing skills (Cruz et al., 2020; Lucas et al., 2021).

2.2 Definition of Digital Competencies Profile for VET Professionals in the Digital Sustainability Context

First, we identifed the DCP required by Brazilian VET professionals within the current digital sustainability landscape. This involved 15 interviews with digital technology companies, businesses and institutions operating in sustainability sectors, representing stakeholders from government, the private sector and academia, reflecting the triple helix (TH) model, crucial for fostering sustainability innovation (Lerman et al., 2021). This approach allowed us to gain a broad perspective. We sought professionals from diverse backgrounds to ensure a comprehensive understanding of the problem. Participants were selected based on relevant experience and influence within TH. Interviews were recorded (with permission) and supplemented with notes[2].

Interviews with experts led to the identification of digital technologies. The classifications include: i) Sensing technologies (e.g., IoT for material efficiency); ii) Communication technologies (e.g., blockchain for supply chain traceability); iii) Data processing and analysis technologies (e.g., Big Data for real-time energy monitoring); iv) Operation and management technologies (e.g., ERP systems for sustainability performance) (Table 1). The decision to adopt this classification model systems from its greater compatibility with the context.

2 Data/information can be requested from the author.

Table 1: Profile of the 15 Experts

Triple Helix Actor	*Company | Entity*	*Position | Role*
Academia	Federal VET Institution	Innovation Project Coordinator
		Director of Extension, Research, Postgraduate, and Innovation
	Private VET Institution	Industrial Development Specialist
	Federal University	Researcher and professor in the field of Bioeconomy
	Federal University	Renewable energy Expert Professor
	Private VET Institution	Industrial Development Analyst
	Federal VET Institution	2 experts in VET and digital technologies
Private Entity	Smart Energy company	Sales Director
	Circular Economy and Closed Loop Supply Chain Company	Executive Director
	Bioeconomy company	Executive Director
	Automation and Industry 4.0 Company	CEO
	Union of Metallurgical Industries Workers	Director
	International Cooperation for Sustainable Development	Coordinator of Digitalization and Business Partnerships
Government	International Cooperation for Sustainable Development	Coordinator of Inputs for Professional and Technological Education Guidelines
	Socio-Environmental Institute of the Amazon	Forestry Engineer of Socio-Environmental Institute of the Amazon focused on Amazon Supply Chains
	Ministry of Education of Brazil	Special Advisor to the Core of Innovation Policy
	Ministry of Education of Brazil	General Coordinator of Planning and Evaluation of Professional and Technological Education

Guided by the indicated technologies and their practical applications, we formulated digital competencies to VET professionals. The development of these competency profiles was adapted from the framework of digital competencies, as proposed by Vuorikari et al. (2022) and Quintero (2022). The writing of competency profiles followed structuring elements: Verb + Object of Knowledge + Purpose + Condition (Kennedy, 2006; Tinoco et al., 2023). A two-hour workshop involving different TH actors was conducted to validate the DCP, which involved 16 experts in VET and digital transformation[3], and partners from the Ministry of Education in Brazil. After conducting a workshop, a DCP was developed for VET, aligning the profile with sustainable development goals (section 4.1).

3 Data/information can be requested from the author.

2.3 Definition of Digital Competencies Profile for VET Teachers

The ICT Competency Framework for Teachers (ICT CFT) based the definition of teaching competencies, as it incorporates key elements of current technological advances within the scope of the UN 2030 Agenda (UNESCO, 2018). Beyond acquiring and teaching ICT skills, it outlines 18 ICT-related competencies across three levels of professional development and six educational aspects. For this study, we focused on the second level, knowledge deepening, which aims to enhance teachers' ability to help diverse learners apply knowledge and use digital tools to solve complex real-world problems. We selected three framework aspects most relevant to VET teaching: Curriculum and assessment, pedagogy, and the use of digital resources. These align with the realities and goals of VET education. Other aspects, such as institutional policy and educator professional development, were not prioritized in this phase. As with the professional competency profile (Section 2.2), teacher competencies were structured using cognitive, psychomotor, and affective taxonomies (Kennedy, 2006; Krathwohl et al., 1964), and verbs were chosen accordingly (Tinoco et al., 2023). To validate the proposed teacher competency profile, experts were consulted (Table 2). Each expert independently assessed whether the competencies aligned with VET and digital technology usage. This step ensured external validation for refining the competencies before planning professional development programs.

Table 2: Profile of the Experts

Company / Entity	*Position / Role*
Ministry of Education of Brazil	1 General Coordinator of Planning and Evaluation of Professional and Technological Education
Federal University	1 Specialist Professor in competencies for education
Federal VET Institution	1 Specialist in VET and Digital Technologies
Private VET Institution	1 Industrial Development Analyst

2.4 Conducting a Program of Pilot Projects for the Development of Digital Competencies

This stage was specifically developed in collaboration with the project Professionals of the Future: Skills for the Green Economy, a partnership between GIZ Brazil and the Brazilian Ministry of Education (MEC), funded by Germany's Federal Ministry for Economic Cooperation and Development (BMZ). The project aims to enhance employment prospects in Brazil's green sectors, addressing a shortage of qualified labor with a focus on digital sustainability.

To ensure effective implementation of the program, the MEC selected participant institutions through a public call for pilot projects, choosing schools based on: i) Sustainability-related courses, ii) digital technology initiatives, and iii) teacher availability for training. The program was implemented in four VET institutions, labeled A, B, C, and D in Table 3. It was structured around five mentoring cycles, incorporating project management methodologies such as Agile and Design Thinking, as well as instructional design strategies like Active Learning, Backward Design, and Formative Assessment (Tinoco et al., 2023). This program focused on: i) Defining the scope of pilot projects, ii) developing a DCP for teachers, iii) establishing partnerships between pilot projects and digital technology companies, iv) introducing new technologies, and v) evaluating the scalability potential of pilot projects. At the conclusion of the mentorship, an assessment of perceptions from both students and teachers was conducted (Steppacher et al., 2019).

Table 3: Lesson Plan for Developing Students' Digital Competencies

Aspects	*Pilot A*	*Pilot B*	*Pilot C*	*Pilot D*
Professional digital competency	Recognize the potential use of inventory management technology in transforming data into real information about the system, integrating socio-environmental aspects into digital sustainability context.	Traceability concept (e.g., QR code) to gather information about the apparel supply chain in the Amazon region.	Ability to integrate different digital technologies for monitoring and intelligent control in developing sustainable activities.	Ability to plan and design photovoltaic plants considering technical, economic, and environmental factors with digital technologies.
Learning outcomes	Students should be able to input and interpret product entry and exit data in the WMS system to suggest appropriate stock levels	Students should be able to define and collect information for the traceability of products generated from textile industry waste in the region	Students should be able to set up and use IoT sensors for real-time process monitoring and control, applying this knowledge in practical simulations of environmental monitoring	Students should be able to use design software to determine the number of photovoltaic modules and inverters required for a plant to meet a specified monthly generation capacity
Assessment Method	Spreadsheet report containing data analysis and product restocking level	Electronic form containing the information to be collected from partners in the textile supply chain for the traceability of sustainable products	Final project containing the configuration and integration of IoT sensors for a school garden monitoring system	Report with specifications of the designed plant, project configurations, consumption, and module positioning

Pedagogical Practice	Flipped classroom Project-based learning in conjunction with green logistics challenges in partner companies	Project-based learning for the production and traceability of a sustainable collection generated from textile industry waste	Experiential-based learning in laboratory for IoT sensor configuration and collaborative learning	Experiential-based learning in laboratory and collaborative learning
Technologies and resources	Office applications, WMS software, task management software.	Office applications, electronic forms	Temperature and Humidity Sensor, Light Sensor, Soil Moisture Detection Sensor, Rain and Humidity Sensor with Relay Activation, Channel Relay Module	Office application, Design software for photovoltaic plant projects, task management software.

3 Results

This section presents the main results obtained from the implementation of the pilot projects (A–D) in VET institutions. The findings are organized around the key dimensions of the study, including the development of digital competencies, pedagogical practices, and the application of digital resources in the context of digital sustainability. Tables and figures are used to summarize the outcomes of each pilot and to highlight the main trends observed across the evaluated criteria.

3.1 Digital Competencies Profile for VET Professionals

To ensure the internationalization of DCP (Quintero, 2022; Vuorikari et al., 2016), we included the relevance of using digital technologies, communication through digital means, data protection and security, social inclusion and well-being, integration of socio-environmental-economic aspects, problem-solving using digital technologies, and innovation of processes and products using digital tools (Quintero, 2022). A DCP for VET professionals was established after conducting a workshop to validate the digital competencies of professionals (2.2) and make adjustments in collaboration with experts from the private sector, academia, and the VET sector. The profile (Table 4) applies to the context of digital sustainability.

Table 4: Profile of Digital Competencies for VET Professional

Professionals' Digital Competencies	*Knowledge*	*Competencies*	*Attitudes*
Apply sensing technologies to capture information about equipment, employees, material, or processes, in the context of digital sustainability.	Apply sensing technologies to gather information about equipment, employees, materials or processes. It is important to assess the relevance of the technology to the digital sustainability context.	Manipulate sensing technologies to gather information about equipment, employees, material or processes, judging the relevance of the technology to the digital sustainability context.	Value the relevance of sensing technologies for capturing information about equipment, employees, materials, or processes that should be acknowledged, while also considering ethical and data security aspects in the digital sustainability.
Apply communication technologies enabling interaction and sharing of information in different ways, in the context of digital sustainability.	Apply communication technologies for interaction and sharing of information in different ways (horizontal and vertical integration), considering the security and integrity of the data and the digital sustainability context.	Manipulate communication technologies to interact and communicate with others, considering cultural and generational aspects of the digital sustainability.	Respond appropriately using communication technologies to collaborate with colleagues in professional activities, considering cybersecurity and digital sustainability.
Apply processing and analysis technologies enabling the processing and transformation of data into real information about the system, in the context of digital sustainability.	Apply processing and analysis technologies to process and transform data into real information about the system, judging the relevance of the technology to the digital sustainability context.	Articulate and adapt processing and analysis technologies to transform data into real information about the system, considering the protection of personal data and privacy in the digital sustainability context.	Value the relevance of processing and analysis technologies to transform data into real information about the system, integrating socio-environmental aspects into the digital sustainability context.
Apply operation and management technologies that help control systems and mechanisms for conducting daily activities, in the context of digital sustainability.	Recognize the potential use of operation and management technologies to transform data into real information about the system, integrating socio-environmental aspects into the digital sustainability context.	Articulate and adapt operation and management technologies to solve real problems, considering technological advances in the digital sustainability context.	Organize operation and management technologies to improve and innovate processes and products, considering aspects of social inclusion and social well-being into the digital sustainability context.

Apply sensing technologies to capture information about equipment, employees, material, or processes in the context of digital sustainability. Intelligent lighting systems with motion and occupancy sensors can reduce energy use and support communication networks (Füchtenhans et al., 2021). Sensors like QR codes, Radio-Frequency Identification (RFID), and georeferencing improve traceability and optimize transportation in supply chains (Agusdinata et al., 2023).

Apply communication technologies enabling interaction and sharing of information in different ways in the context of digital sustainability. Digital technologies ensure reliable and secure data integration enhance business decisions and drive sustainability. Investing in

cybersecurity (Melnyk et al., 2022) enables secure communication with suppliers, encouraging resource allocation to strategies that reduce supply chain carbon footprints and support environmentally and socially responsible practices.

Apply processing and analysis technologies enabling the processing and transformation of data into real information about the system in the context of digital sustainability. Data analytics is critical in helping companies understand customer needs and preferences through advanced systems. Companies can tangibly assess the social impact of their products and services, wich enables members of a community of practice to decide collectively, act collaboratively, and co-create solutions for sustainability and climate change (SDG 13; Bianchi et al., 2022).

Apply operation and management technologies that help control systems and mechanisms for conducting daily activities in the context of digital sustainability. Companies use technologies to enhance inventory and administrative processes, supporting sustainable purchasing (Tong et al., 2023). These tools boost efficiency, enable accurate tracking, and improve decision-making. When combined with horizontal data integration, they foster more sustainable, integrated supply chain management.

Finally, the DCP presented for VET professionals can help them solve sustainable issues related to their field of activity based on digital technologies through the competencies acquired during their training.

3.2 Digital Competencies Profile for VET Teachers

We examined the ICT CFT (UNESCO, 2018) at the 'knowledge deepening' level (second level) concerning the context of VET teachers' competencies. Based on this, we can align our DCP with some SDG 4 goals. By 2030, the aim is to substantially increase the number of youth and adults with relevant skills, including technical and vocational competencies. VET demands that teachers explore the potential of digital technologies to transform the teaching-learning process and develop the digital competencies required of professionals from vocational institutions. This requires aligning the DCP level with the demands and reality of the education system. According to the ICT CFT, these aspects include the teacher's ability to design and implement a curriculum that integrates digital technologies, assess students' digital competencies, and adapt teaching strategies accordingly. Furthermore, teachers should employ active learning practices that effectively leverage digital technologies, fostering collaboration, personalized learning, and the development of critical and creative skills (UNESCO, 2018). Table 5 presents the competency profile for vocational education teachers, broken down into knowledge, competencies, and attitudes.

Table 5: Profile of Digital Competencies for VET Teachers

Aspect	*Teacher's Digital Competencies*	*Knowledge*	*Competencies*	*Attitudes*
Curriculum and Assessment	1. Integrate digital technologies into subject content, teaching and assessment processes to promote digital sustainability, creating a learning environment enhanced by digital technologies.	Identify and incorporate knowledge about digital technologies into the curriculum to promote digital sustainability within the vocational professional context.	Create and implement assessment tools to evaluate digital competencies in students, considering formative and summative assessment, considering the digital sustainability context.	Demonstrate the applicability of digital technologies in various learning and assessment processes, considering the digital sustainability context.
Pedagogy	2. Design learning activities based on projects and the resolution of complex problems supported by digital technologies.	Design collaborative learning activities to engage students in reasoning and solving digital sustainability real-world problems using digital technologies.	Implement project-based learning activities using digital technologies and guide students in digital sustainability projects.	Evaluate the role of digital technologies in solving digital sustainability real problems in the context of the vocational professional, considering aspects of feasibility.
Applications of Digital Resources	3. Combine digital tools and resources to create an integrated digital learning environment, assisting students in developing high-level problem-solving and reflection competencies and developing digital sustainability.	Select appropriate digital technologies to promote the studied thematic areas, considering feasibility, accessibility aspects and promoting digital sustainability.	Operate (create and modify) digital technologies suitable for the studied thematic areas to encourage higher-order thinking in students, fostering active learning and student engagement.	Assess the effectiveness of digital technologies in supporting and developing the digital sustainability, considering aspects of accessibility and inclusion.

The Competency Profile for VET teachers supports educators in incorporating digital technologies into their routines, fostering a profile aligned with the digital sustainability context. For example, teachers can design curricula emphasizing digital technologies for sustainable development, such as real-time tracking systems, and train professionals to implement sustainable solutions in supply chains by applying data analytics, automation technologies, and sustainable practices. By promoting interdisciplinary collaboration and personalized learning, teachers can prepare professionals to integrate advanced technologies into sustainable development strategies. In doing so, VET teachers help build a workforce capable of driving smarter, sustainable solutions that address modern challenges, preparing their students.

3.3 Program of Pilot Projects for the Development of Digital Competencies in VET Education

The program for the development of digital competencies was implemented through pilot projects across four Brazilian VET institutions. The program was conducted through five mentoring cycles, which are outlined below.

The *first cycle* involved defining the scope of pilot projects for the four selected VET institutions. The following premises were considered in this definition: The inclusion of digital technologies in courses related to sustainability sectors; the level of student engagement in the courses; female participation in the teams; contribution to sustainability; and the implementation of active learning methodologies. The scope of each pilot is presented in Table 6.

Table 6: Scope of Pilot Projects

VET Institution	*Scope*
Pilot A	The objective was to optimize processes, improve waste management, and develop digital competencies by promoting the implementation of digital technologies to optimize various logistical processes, thereby reducing environmental impacts and contributing to the digital sustainability of organizations.
Pilot B	The primary goal is to develop sustainable business models for apparel and accessory products by reusing solid waste from the Amazon river supply chain. The case prioritizes the environmental aspect of the supply chain by creating a green supply chain management.
Pilot C	The primary goal is to implement digital sensing technologies based on a real case of small-scale smart and sustainable agricultural cultivation, observing climatic conditions through robotics and automation, and using energy generation systems with solar panels.
Pilot D	The aim is to train students to use digital tools for sizing photovoltaic plants and regulations on the country's current energy matrix. The case prioritizes renewable energy generation by promoting digital sustainability practices among VET professionals and promoting SDG7.

The *second cycle* focused on developing the DCP of VET teachers working in sustainability-related. Using the Backward Design approach, four training sessions were conducted to promote active learning and competency-based instruction. Teachers developed digital competencies (Quintero, 2022; Vuorikari et al., 2022) related to sensing, communication, processing, analysis, and operational management in sustainability sectors.

The *third cycle* fostered partnerships between pilot projects and 17 technology companies in Brazil. Matchmaking meetings (Katzy et al., 2013; Manotungvorapun & Gerdsri, 2015) led to six formal partnerships and over 10 technologies adopted. Implementation starts by defining target subjects and areas, followed by establishing learning outcomes to develop digital competencies. Pedagogical practices and assessment methods are set (Cruz et al., 2020; Ferreira & Canedo, 2020). Technology providers supply tutorials or training for teachers, who then execute the planned activities and evaluate the results of the technology integration.



Figure 2: Proposal for a Program for Developing Digital Competencies in VET Teachers

Once the proposed program (Figure 2) was implemented, VET teachers could acquire knowledge on developing digital competencies that can enhance the competencies of VET professionals. They integrate active learning practices and introduce digital technologies into training programs for digital sustainability. The planned activities aim to implement elements that support the modernization of professionals and teachers in professional education

through digitalization and education in the 4.0 world of Brazilian VET institutions efficiently. This includes assisting in the organization of curricular units using new teaching tools to enhance the learning process.

In the *fourth cycle*, these technologies were implemented through teacher training sessions focused on lesson planning and competency-based instruction. Teachers defined learning outcomes, assessment methods, and active learning strategies. Technology providers also supported the process with materials and training. Implementation was evaluated over one academic semester.

The *fifth cycle* assessed the scalability of each pilot. Pilot D demonstrated high replication potential in 34 schools with no additional cost. Pilot C could reach over 2,000 students at low cost. Pilots A and B, though impactful in terms of sustainability outcomes, involved higher costs and bureaucratic complexity. These results inform potential program expansion across Brazilian VET institutions.

Table 7: Scalability Potential of Pilot Projects

Evaluated Criteria	*Pilot A*	*Pilot B*	*Pilot C*	*Pilot D*
Brazilian Region of potentially impacted schools	Midwest	North	Midwest	Southeast
Number of potentially impacted schools	12	8	12	34
Number of potentially impacted teachers	84	40	96	102
Number of potentially impacted students	780	160	2040	1224
Number of digital technologies to be implemented	5	7	5	4
Technology costs (US$/year)	20,727.69	7,030.77	265.38	0.00
Bureaucracy level for establishing partnerships with suppliers	High	High	Medium	Low
Degree of positive impacts on long-term sustainability	High	High	Medium	Medium

At the end of the pilot projects program, an online questionnaire was utilized to assess students' and teachers' perceptions regarding the digital competencies developed. These competencies were assessed in terms of applications of digital resources, pedagogical tools and practices, and curricular and assessment development A total of 221 students and 15 teachers participated in the study. The perceptions of the two groups are illustrated in Figures 3 and 4.

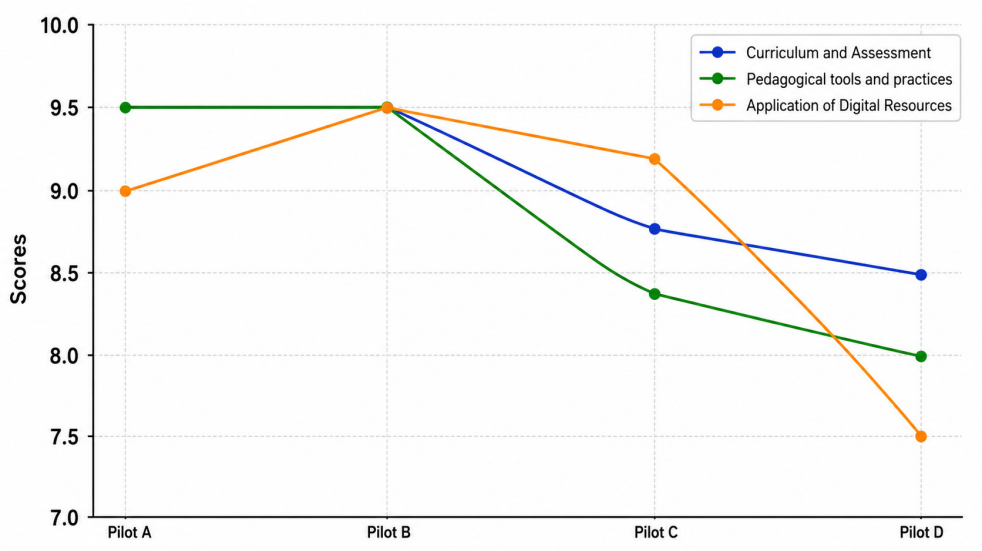


Figure 3: Students' Perception

After analyzing the dimensions evaluated (Figure 3), it was observed that teachers expressed high levels of satisfaction with the curriculum and assessment aspect and were satisfied with the activities and pedagogical tools used. In the four pilot projects, the "Application of Digital Resources" dimension obtained scores above 7.5, converging with the positive reports of more engaging activities and modernization of content reported in the questionnaire. Although the pilots received positive evaluations overall, it is important to note that Pilot D garnered the lowest scores in the assessment. This was likely due to the challenges faced in implementing the technologies during a strike at the institution while the project was underway.

Analysing Figure 4, some students specifically noted that exposure to digital technologies in their course subjects was highly beneficial, which can be seen, for example, by the score obtained in pilot B. Nevertheless, there is a necessity to enhance the practical implementation phases of these plans. For example, some students of the pilots C and D reported difficulties with specific digital tools, primarily due to the limited time allotted for practical applications in their projects. This observation indicates that the allocated duration for the use of digital technologies in teaching practices should be extended.

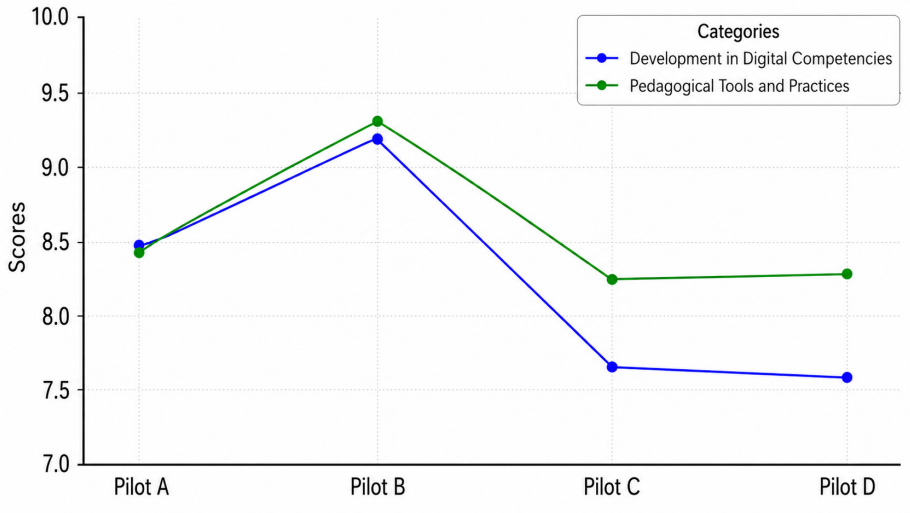


Figure 4: Student's Perception

In general, all respondents highlighted the importance of digital resources in the classroom, emphasizing their applicability in academic and professional contexts. All teachers involved in the pilot projects expressed great satisfaction with their participation in the study, underscoring the quality of the developed mentorship cycles. These results reinforce our proposed program. Therefore, based on the programme's outcomes, four priority actions are advised: (1) Expand hands-on learning time so that students can master advanced digital tools; (2) establish robust contingency protocols to keep instruction running during strikes, pandemics or similar disruptions; (3) launch the national-and subsequently international-roll-out with the lowest-cost, highest-reach pilots (C and D), particularly in peer emerging economies; and (4) streamline administrative workflows and implement cost-sharing mechanisms to reduce the financial and bureaucratic issues that currently limit the scalability of Pilots A and B.

4 Discussion and Conclusion

The operational recommendations are analyzed through three-pillar policy agenda-education, innovation and sustainability as articulated in recent government frameworks and on digital-competency gaps. The programme can also serve to broaden the hands-on sessions devoted to digital tools. From an educational perspective, this expansion enables more teachers to acquire *digital-sustainability* competencies, advancing VET up-skilling. On the innovation view, transforming classrooms into laboratory-style environments improves co-creation with industry partners, accelerating technology transfer to the productive sec-

tor while cultivating new competencies. Finally, by ensuring practical, the initiative reduces wasted time and materials, including sustainability dimension and reducing waste management.

> P1: New digital-sustainability education programmes should incorporate hands-on sessions to reinforce digital-sustainability competencies, accelerate technology transfer, and enhance sustainable efficiency.

The programme should also foster the development of contingency plans to mitigate institutional disruptions. Such plans ensure learning continuity, safeguard progress in closing digital and environmental skills gaps, and simultaneously reduce perceived risk for investors by attracting co-investment and enlarging partnerships. Developing business-continuity protocols guarantees that sustainability- and digitalisation-related learning outcomes are preserved even during shocks.

> P2: New digital-sustainability education programmes should create contingency plans that preserve learning continuity, attract co-investment, and guarantee the achievement of sustainability competencies – even during institutional shocks.

Prioritise low-cost, high-reach pilots-such as C and D-can be replicated in other emerging economies. This strategy democratises access to digital-sustainability education, sends strong demand signals that invite start-ups, like Edtechs, and institutional research centres to co-develop affordable solutions, and promotes partnership-driven, low-cost business models for both public and private education systems. Savings generated can be reinvested in green upgrades and energy-efficient infrastructure, further amplifying sustainability gains.

> P3: New digital-sustainability education programmes should prioritise low-cost, high-reach pilots by facilitating access to digital-sustainability education, developing partnerships with start-ups, and promoting low-cost business models.

Simplify administration and introduce cost-sharing for Pilots A and B. Reducing bureaucratic barriers makes it easier for VET teachers to access training and acquire new digital-sustainability competencies. These measures can attract private co-investment to develop new digital programmes, distribute investment burdens, and embed sustainability metrics within procurement and reporting processes. Such co-investment will strengthen the VET innovation and technology ecosystem.

P4: New digital-sustainability education programmes should streamline high-impact pilots burdened by bureaucracy by removing educational barriers, co-funding initiatives with private institutions, and aligning new investments with sustainable principles.

Table 8: Operational Recommendations

Operational recommendation	*Education policy lens*	*Innovation policy lens*	*Sustainability policy lens*
Extend practical sessions to deepen students‘ mastery of digital tools	Expands continuous teacher professional development programs that build digital sustainability competences, aligned with upskilling goals in EPT/VET (Lahn & Berntsen 2023; Cattaneo et al. 2020; Siegel & Fischer 2021)	Lab-format sessions catalyze co-creation with industry partners and accelerate technology transfer (Garcia-Peñalvo et al. 2019; Taylor & Newton 2022)	Hands-on practice ensures efficient resource use, reducing waste from trial-and-error
Create contingency plans to mitigate institutional disruptions	Protects learning continuity and safeguards progress in closing the digital skills gap	Business continuity protocols reduce pilot risks and attract private co-investment (Bonoli & Cattaneo 2023)	Ensures sustainability learning outcomes even during strikes or other shocks (Bonoli & Cattaneo 2023)
Prioritize low-cost, high-reach pilots	Democratizes access to digital sustainability education (Haase et al. 2024)	Startups enable rapid iteration of affordable solutions (Siegel & Fischer 2021)	Low-cost models free up budget for „green“ improvements and energy-efficient infrastructure
Simplify administration and explore co-financing for highly bureaucratic pilots	Removes bureaucratic barriers that inhibit teacher participation in continuous professional development (Müller & Schmidt 2022)	Cost-sharing with industry expands the EPT/VET innovation and technology ecosystem (Müller & Schmidt 2022)	Shared investment guided by sustainability metrics (Siegel & Fischer 2021)

5 Limitations and Future Research

Our study determined a profile of teaching and professional digital competencies. In the future, creating a TDC self-assessment instrument based on the DCP and training program developed in our study can extend to other aspects besides implementing digital competencies. Lucas et al. (2021) identified that teachers' digital competence comprises various dimensions, such as social, cultural, pedagogical, ethical, and attitudinal. Our study's profile of teachers' digital competencies is based on market demands gathered through a survey of companies, interviews with VET experts in the country, and an analysis of the current VET curricula. So, next studies can include more dimensions.

Acknowledgement

This work was supported by the Alexander von Humboldt Foundation, the Brazilian National Council for Scientific and Technological Development (CNPq), and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Ethical Statement

All data were anonymized before analysis, and access was restricted to the research team only. The authors declare no conflicts of interest. The study was conducted in accordance with the applicable national guidelines.

AI Statement

We employed AI tools-ChatGPT, DeepL, and Grammarly-to refine their manuscript's wording and coherence, then personally reviewed the output and accept full responsibility for the final content.

References

Agusdinata, D. B., Eakin, H., Darnall, N., Jiang, B., & Romero, H. (2023). Advancing recognition justice in telecoupled critical mineral supply chains: The promise of social media. *Energy Research & Social Science, 104*, 103264. https://doi.org/10.1016/j.erss.2023.103264

Basilotta-Gómez-Pablos, V., Matarranz, M., Casado-Aranda, L. A., & Otto, A. (2022). Teachers' digital competencies in higher education: A systematic literature review. *International Journal of Educational Technology in Higher Education, 19*(1), 1–16. https://doi.org/10.1186/s41239-021-00312-8

Bianchi, G., Pisiotis, U., & Cabrera Giraldez, M. (2022). *GreenComp - The European sustainability competence framework.* Publications Office of the European Union. https://doi.org/10.2760/13286

Cattaneo, A. A., Antonietti, C., & Rauseo, M. (2022). How digitalised are vocational teachers? Assessing digital competence in vocational education and looking at its underlying factors. *Computers & Education, 176*, 104358. https://doi.org/10.1016/j.compedu.2021.104358

Cruz, M. L., Saunders-Smits, G. N., & Groen, P. (2020). Evaluation of competency methods in engineering education: A systematic review. *European Journal of Engineering Education, 45*(5), 729–757. https://doi.org/10.1080/03043797.2019.1671810

Ferreira, V. G., & Canedo, E. D. (2020). Design sprint in classroom: Exploring new active learning tools for project-based learning approach. Journal of Ambient Intelligence and Humanized Computing, 11(3), 1191–1212. https://doi.org/10.1007/s12652-019-01285-3

Fraile, M. N., Peñalva-Vélez, A., & Mendióroz Lacambra, A. M. (2018). Development of digital competence in secondary education teachers' training. *Education Sciences, 8*(3), 104. https://doi.org/10.3390/educsci8030104

Füchtenhans, M., Grosse, E. H., & Glock, C. H. (2021). Smart lighting systems: State-of-the-art and potential applications in warehouse order picking. *International Journal of Production Research, 59*(12), 3817–3839. https://doi.org/10.1080/00207543.2021.1897177

Katzy, B., Turgut, E., Holzmann, T., & Sailer, K. (2013). Innovation intermediaries: A process view on open innovation coordination. *Technology Analysis & Strategic Management, 25*(3), 295–309. https://doi.org/10.1080/09537325.2013.764982

Kennedy, D. (2006). *Writing and using learning outcomes: A practical guide*. University College Cork. https://hdl.handle.net/10468/1613

Krathwohl, D., Bloom, B., & Masia, B. (1964). *Taxonomy of educational objectives: The affective domain*. David McKay. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/43808/11217_2004_Article_BF00373956.pdf?sequence=1/

Lee, J. J., & Meng, J. (2021). Digital competencies in communication management: A conceptual framework of readiness for Industry 4.0 for communication professionals in the workplace. *Journal of Communication Management, 25*(4), 417–436. https://doi.org/10.1108/JCOM-10-2020-0116

Lerman, L. V., Gerstlberger, W., Lima, M. F., & Frank, A. G. (2021). How governments, universities, and companies contribute to renewable energy development? A municipal innovation policy perspective of the triple helix. *Energy Research & Social Science, 71*, 101854. https://doi.org/10.1016/j.erss.2020.101854

Lucas, M., Bem-Haja, P., Siddiq, F., Moreira, A., & Redecker, C. (2021). The relation between in-service teachers' digital competence and personal and contextual factors: What matters most? *Computers & Education, 160*, 104052. https://doi.org/10.1016/j.compedu.2020.104052

Manotungvorapun, N., & Gerdsri, N. (2015). Matching partners for open innovation practice. In *Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET 2015): Management of the Technology Age* (pp. 718–727). IEEE. https://doi.org/10.1109/PICMET.2015.7273262

Melnyk, S. A., Schoenherr, T., Speier-Pero, C., Peters, C., Chang, J. F. & Friday, D. (2022). New challenges in supply chain management: Cybersecurity across the supply chain. *International Journal of Production Research, 60*(1), 162–183. https://doi.org/10.1080/00207543.2021.1984606

Nikoloudakis, N., & Rangoussi, M. (2024). Introducing green, eco-friendly practices and circular economy principles in vocational education through a novel analysis-synthesis method. *International Journal for Research in Vocational Education and Training, 11*(3), 429–459. https://doi.org/10.13152/IJRVET.11.3.5

Núñez-Canal, M., de Obesso, M. M., & Pérez-Rivero, C. A. (2022). New challenges in higher education: A study of the digital competence of educators in Covid times. Technological Forecasting and Social Change, 174, 121270. https://doi.org/10.1016/j.techfore.2021.121270

Oberländer, M., Beinicke, A., & Bipp, T. (2020). Digital competencies: A review of the literature and applications in the workplace. *Computers & Education, 146*, 103752. https://doi.org/10.1016/j.compedu.2019.103752

Quintero, W. R. (2022). Digital competences of the industrial engineer in Industry 4.0: A systematic vision. *Production, 32*, e20220028. https://doi.org/10.1590/0103-6513.20220028

Redecker, C., & Punie, Y. (2017). *European framework for the digital competence of educators: DigCompEdu*. Publications Office of the European Union. https://doi.org/10.2760/159770

Reynolds, H. L., & Kearns, K. D. (2017). A planning tool for incorporating backward design, active learning, and authentic assessment in the college classroom. College Teaching, 65(1), 17–27. https://doi.org/10.1080/87567555.2016.1222575

Schöggl, J. P., Rusch, M., Stumpf, L., & Baumgartner, R. J. (2023). Implementation of digital technologies for a circular economy and sustainability management in the manufacturing sector. *Sustainable Production and Consumption, 35*, 401–420. https://doi.org/10.1016/j.spc.2022.11.012

Shamzzuzoha, A., Chavira, P. C., Kekäle, T., Kuusniemi, H., & Jovanovski, B. (2022). Identified necessary skills to establish a center of excellence in vocational education for green innovation. *Cleaner Environmental Systems, 7*, 100100. https://doi.org/10.1016/j.cesys.2022.100100

Steppacher, D., Tinoco, M. A. C., ten Caten, C. S., & Marcon, A. (2019). Assessing administrative service quality in higher education: Development of an attribute-based framework (HEADSQUAL) in a Brazilian university. *Studies in Higher Education, 46*(9), 1785–1800. https://doi.org/10.1080/03075079.2019.1706076

Thunqvist, D. P., Gustavsson, M., & Halvarsson Lundqvist, A. (2023). The role of VET in a green transition of industry: A literature review. *International Journal for Research in Vocational Education and Training, 10*(3), 361–382. https://doi.org/10.13152/IJRVET.10.3.4

Tinoco, M. A. C., Nodari, C. T., Rabelo, L., Kvitko de Moura, P., Marcon, A., & Danilevicz, A. M. F. (2023, June). *Proposition of a method to monitor higher education students' competence development through assessment rubrics*. In Proceedings of the ASEE Annual Conference & Exposition, Baltimore, Maryland. https://doi.org/10.18260/1-2--43992

Tong, Q., Ming, X., & Zhang, X. (2023). Construction of a sustainable digital factory for automated warehouse based on integration of ERP and WMS. *Sustainability, 15*(2), 1022. https://doi.org/10.3390/su15021022

UNESCO. (2018). *ICT competency framework for teachers* (Version 3). UNESCO Publishing. https://www.unesco.org/en/digital-competencies-skills/ict-cft

Vuorikari, R., Kluzer, S., & Punie, Y. (2022). *DigComp 2.2: The Digital Competence Framework for Citizens with new examples of knowledge, skills and attitudes*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/50c53c01-abeb-11ec-83e1-01aa75ed71a1/language-en

Vuorikari, R., Punie, Y., Carretero, S., & Van den Brande, L. (2016). DigComp 2.0: The digital competence framework for citizens. Publications Office of the European Union. https://doi.org/10.2791/11517

Biographical Notes

Laura Visintainer Lerman, PhD is a Humboldt Research Fellow and postdoctoral researcher at the Technical University of Munich (TUM). She holds bachelor's, master's, and doctoral degrees in Industrial Engineering from the Federal University of Rio Grande do Sul (UFRGS), Brazil. Laura has worked as a consultant and professor supporting start-ups and digital-transformation initiatives, and was a visiting scholar at Technische Universität Berlin and Fraunhofer IPK. Her research focuses on digital transformation, supply-chain management, and sustainability.

Paolla Polla Pontes do Espírito Santo is a PhD candidate in Industrial Engineering at the Federal University of Rio Grande do Sul (UFRGS), Brazil, where she also earned her bachelor's and master's degrees. A research fellow in the Organizational Engineering Group (NEO-UFRGS), she consults on Education 4.0 and designs open-data business models. Her work advances data-driven decision-making, virtualization technologies, and frameworks for real-time decisions.

Camila Costa Dutra is a Professor in the Department of Industrial Engineering at the Federal University of Rio Grande do Sul (UFRGS), Brazil. She earned her M.Sc. (2003) and PhD (2012) degrees in Engineering from UFRGS. Her research interests include digital transformation, innovation and technology management, project portfolio management, and the optimization of products and processes.

Maria Auxiliadora Cannarozzo Tinoco is a Professor in the Industrial Engineering Department at the Federal University of Rio Grande do Sul (UFRGS), Brazil. She received her M.Sc. (2004) and PhD (2011) degrees in Engineering from UFRGS. Her research focuses on engineering education, digital transformation, service management, and product and service innovation.