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DIGITALIZATION AND DIGITAL PEDAGOGICAL LEADERSHIP: DRIVING TVET PROGRAM EFFECTIVENESS IN DIVERSE CONTEXTS

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Abstract
This study investigates the impact of digitalization and digital pedagogical leadership (DPL) on the effectiveness of Technical and Vocational Education and Training (TVET) programs in Pakistan, using the Technology-Organization-Environment (TOE) framework. Despite ambitious national initiatives like NAVTTC's Skills for All, Pakistan's TVET sector continues to face challenges such as limited institutional capacity, outdated pedagogies, and regional disparities. A cross-sectional survey of 120 TVET institutions across Punjab, Sindh, Khyber Pakhtunkhwa, and Balochistan was conducted using systematic random sampling and regression analysis to test five hypotheses. The findings reveal that digitalization significantly enhances TVET program effectiveness, with this relationship being strongly positively mediated by DPL. Furthermore, contextual barriers were found to significantly moderate negatively the relationships between digitalization and program effectiveness, digitalization and DPL, and DPL and program effectiveness. This suggests that higher levels of contextual barriers (e.g., infrastructure limitations, socio-economic challenges) weaken the positive impact of digitalization and leadership on program outcomes. The study extends the TOE framework by incorporating DPL as a mediating factor in the relationship between digitalization and program effectiveness in the context of developing countries. Practically, the research highlights the need for policymakers and institutional leaders to not only invest in digital technologies but also focus on leadership development and overcoming contextual challenges to maximize the effectiveness of TVET programs in Pakistan. The study calls for rethinking digital reform strategies in Pakistan's TVET sector, emphasizing institutional readiness and human capacity development to address regional disparities.

INTRODUCTION

Digital technologies have emerged as one of the most important elements in the changes of the learning experience in the world over the last few years. The fast development of digital tools and e-learning platform has transformed most sectors of education, such as Technical and Vocational Education and Training (TVET) - an important sector in developing a pool of skilled employees.

The implementation of digital learning has received interest in terms of improving the quality of vocational training through digital pedagogical leadership, which encompasses approaches to leading the use of digital tools in teaching. However, the adoption of digital technologies in TVET programs is a very complicated issue, particularly in the developing world, like in Pakistan. The institutions of TVET in Pakistan play a crucial role in employing and developing the skills of youth, however, they face serious challenges of digitalization, management, and environmental issues (Ali et al., 2020).

In Pakistan, the percentage of the total population constituted by the youth is almost 64 (UNDP, 2020). The increasing unemployment rate in the country is 10.6 percent as of 2021, which is a significant problem that has to be addressed by reinforcing the TVET systems (Pakistan Bureau of Statistics, 2021). Less-developed and rural regions have worse unemployment rates and access to digital tools. The deployment of digital strategies is problematic because of the inability to utilize digital pedagogical leadership and various challenges in the region, which are viewed as a solution to the problem by encouraging the use of TVET institutions. Each region (Punjab, Sindh, Khyber Pakhtunkhwa (KPK)) and Balochistan has a different socio-economic and infrastructural environment, which influences the delivery of digital education. Although digitalization in education has been considered on a global level, the precise effect of digitalization on the TVET programs, especially in the framework of disparities that exist in Pakistan, has not been studied extensively (Khan et al., 2019).

The gap in research is considerable. The abundance of the studies is on digital tools in general education (Ali et al., 2020), and there is a gap in research on the role of digital pedagogical leadership in the effectiveness of TVET in the developing world. There is a limited number of studies that cover the impact of the infrastructure, social-economic factors and access to technologies on the adoption of digital strategies in TVET institutions. Even though the literature examines digital leadership in higher education (Zhang and Li, 2021), the challenges and strategies of leadership that are specific to TVET are hardly investigated (Khan and Memon, 2021).

It is well-known that leadership is the key towards educational success, and there is a lack of awareness about how digital educational leadership can be effectively implemented in Pakistani TVET institutions. Such leadership is not only about the integration of technologies, but also about the development of a culture of innovation, professional growth of teaching personnel, as well as the ability to guarantee that the digital tools contribute to improvement of the learning process. Digital initiatives are hampered by the shortage of trained leaders and established integration strategies, particularly in the areas such as Balochistan and KPK where digital infrastructure is worse than Punjab or Sindh (Pakistan Telecommunication Authority, 2020).

The study aims to fill this gap by examining the connection between digitalization, digital pedagogical leadership, effectiveness of TVET programs, and contextual constraints in Pakistan. It will discuss the role played by leadership in implementing digital tools in the various provinces of the country taking into consideration the differences in infrastructure, socio-economic and educational policies. The research will consider the role of contextual challenges in the effective implementation of the digital strategy in the vocational education sector by targeting Punjab, Sindh, KPK, and Balochistan. It will also provide a platform of designing specific leadership strategies in these regions.

This study is important as it could help to improve TVET program efficacy in Pakistan. Through analyzing the interpersonal nature of digitalization, leadership, and contextual constraints, the policymakers and educators will acquire an understanding of how to overcome the digital integration problems. Also, the research will be important to the worldwide discourse of digital pedagogical leadership by providing a case study in Pakistan that can be

adapted in other contexts of related developing countries.

Finally, the study will give some practical recommendations that can be used to enhance the quality and accessibility of TVET in Pakistan. It will help fill the gap between the digital pedagogical leadership and the actualities of putting digital education strategies into practice in various locations. The study aims at creating a more inclusive, effective and digitally enhanced TVET system that is more equipped to equip the Pakistani youth to meet the requirements of the modern workforce.

2. Literature Review

2.1. Digitalization in TVET

The concept of digitalization is essential in improving effectiveness and flexibility of global education system, including that of Pakistan. The implementation of digital technologies in TVET institutions is critical to enhancing the quality of education and changing the curricula according to the requirements of the modern labor market (Grech & Camilleri, 2020). Digital tools enhance flexibility, access and efficiency in the learning process particularly where there is a wide range of resources. The shift to the digital environment is not easy. Othman, Omar, and Abd Majid (2025) also mention insufficient infrastructure and technology tools as the main obstacles. Although in cities, there is improved internet and various advanced systems, in rural areas, there are usually poor connections creating a limiting effect in the extent of digitalization. This is an overwhelming digital divide to the policy makers who are in need of inclusive education. Digitalization in TVET is not just about the availability of technology. Teachers should have a digital skill so that they can incorporate the use of technology in their instructions. According to Razak and Noordin (2022), digital competence of instructors determines the success of digital education. In the absence of training, teachers will not be able to use digital tools to the maximum, which will decrease the effectiveness of the programs. Online pedagogical leadership is also essential. TVET leaders should promote the digital culture that would facilitate the learning and adapting processes. They ought to lead teachers through a transformation process in a way that ensures both the teachers and students enjoy the available technologies (Hani, Ismail, & Razali, 2024). This encompasses providing careers development and making sure that students are ready to work with digital workforces.

Digital TVET is also affected by contextual factors. The socio- economic differences, the cultural differences, and the level of support of the government in Pakistan can be of help or hindrance in adoption of technology. Yang and Wu (2024) clarify that one should take context into account when developing digital initiatives. Regionalized programs (like the use of local languages) stand a higher chance of success as opposed to blanket solutions.

The effects of digitalization on learning outcomes can be distinguished. Research indicates that online tools lead to improved learning through interactive learning (Douse & Uys, 2019). The ability to be flexible in both time and place also means that the digital environment is more accessible to students who have logistical and financial constraints.

Digitalization is, however, also an issue of depersonalization. Ismail, Shaikh Ali, and Mohd Sharifuddin (2023) caution that technology must not extend to the interpersonal aspect of teaching. Complex concepts are still being guided, have feedback provided on, and mentor students by teachers in ways that cannot be completely replicated by digital tools.

To summarize, the digitalization of TVET is very promising, yet the success will be determined by the availability of infrastructure, competency of educators, and sensitivity to the context. To achieve the full potential of digitalization and train students according to the requirements of the digital economy, TVET institutions need to implement new technologies, increase teacher training, and solve regional challenges.

2.2. Digital Pedagogical Leadership

Digital Pedagogical Leadership (DPL) is essential to do not be left behind in digital transformation in education, particularly in TVET where digital

integration plays a central role. DPL is defined as the capacity of leaders to lead, mentor, and motivate teachers to employ digital tools in order to enhance the teaching and learning results. Such leadership promotes the culture of continuous improvement and makes educators have the required skills and resources. Visionary thinking is one of the major components of DPL. Digital leaders do not provide a technology-additional environment but facilitate and integrate technology. According to Hani, Ismail, and Razali (2024), leaders of TVETs need to come up with ways of integrating technology, equipping educators with digital literacy, and developing supportive infrastructure. This vision makes the tools to coordinate with the educational objectives to add value to learning instead of making it tricky. DPL needs to deal with different levels of digital skills of educators. Because educators are not equally technologically comfortable, leadership involves delivering specific professional training and support. As noted by Razak and Noordin (2022), it is critical to create a culture of lifelong learning that prompts the educator to acquire more digital expertise. The leaders must also deal with the barriers to adoption like insufficient training, resources, or infrastructure. DPL involves collaboration and the best practices. Yang and Wu (2024) state that the leader who is good fosters educator cooperation, emerges as a community of practice by sharing their experiences. The strategy reinforces the use of digital tools and forms a culture of peer learning, which diminishes opposition and lack of support. The significance of DPL in Pakistan is increased by the context diversity. Being a developing nation, Pakistan has inequitable access to digital infrastructure, access to limited resources, and unequal digital capabilities within the country (Othman et al., 2025; Cheema & Jamal, 2022). Leadership should be environmentally aware and change strategies based on the rural and underserved regions where connectivity, access, and digital literacy may be lower. Liberality and emphasis towards universal accessibility are needed. In addition to the mastery of technology, DPL should learn the pedagogical connotations. Ismail, Shaikh Ali, and Mohd Sharifuddin (2023) affirm that leaders need to help educators adopt technology so that they can achieve advanced learning, interaction, and critical thinking. Introducing technology alone does not ensure better results, it is essential to use it deliberately, with a solid pedagogical foundation. DPL is also supported by distributed leadership. The promotion of shared aids among faculty members, students, and administrative bodies equips the stakeholders in the area of digital transformation. Hani et al. (2024) claim that distributed leadership improves ownership and initiative, which are not only top-down but also makes a collective change. DPL must be in line with expectations of future work particularly in TVET where graduates are introduced into the workforce. The leaders are expected to predict the labor market tendencies and align digital tools and pedagogies to industry competencies (Razak and Noordin, 2022). This active attitude makes the graduates prepared to meet the changing demands of the jobs.

In short, DPL is a complex concept that includes vision, professional growth, teamwork, pedagogical orientation, and contextual awareness. DPL is essential in Pakistan in its diverse terrain, where barriers to infrastructure, resources, and skills are overcome and finally lead to someone successful digital transformation in TVET.

2.3. TVET Program Effectiveness

The effectiveness of TVET programs is a critical issue of concern to the world and policy makers and educators. Such programs prepare students with skills that are required in career achievement and economic development in the country. It is measured by the relevance to the industry, the quality of teaching, and adjustment to the contextual and technological change. It is imperative to match the labor market requirements with the curriculum. Grech and Camilleri (2020) emphasize the necessity of aligning the TVET curriculum with the industry requirements and making sure that graduates have the competencies requested by the employer. Good programs rest on both technical

training and soft skills like communication, work in a team and problem solving. TVET is improved with the help of digital tools. The use of simulations, virtual laboratories, and web-based platforms creates physical experiences that are not limited to the classroom setting (Hani, Ismail, and Razali, 2024). Technology helps in connecting the old ways of doing things to the new demands in the workforce and this is more so as industries are relying more on digital solutions. The quality and qualification of teachers determine the success of the program a lot. Othman, Omar and Abd Majid (2025) discover a direct relationship between digital competence of instructors and digital learning effectiveness. Qualified educators involve students and utilize instruments with purpose. Professional growth is essential because it ensures that educators are abreast with pedagogical practices and technology. Leadership is a key factor. According to Razak and Noordin (2022), effective institutional leadership contributes to the implementation of digital tools, facilitates innovation, resources and teacher development. Leaders are also involved in facilitating cooperation among TVET, industry and the stakeholders to ensure that the curricula remain relevant.

The contextual barriers can be poor infrastructure and this influences program effectiveness. Such issues as inadequate facilities, poor connectivity, and inadequate teacher training are some of the problems that rural or underserved areas can experience (Yang and Wu, 2024). Such differences in Pakistan do not favor the TVET programs as they prevent awareness of modern technologies and good training. To tackle contexts, strategies are required to be different. Disparities can be achieved by adapting the curricula to the needs of the region, focusing on disadvantaged areas, and providing access to digital tools. Leaders should be aware of the challenges of the region and come up with solutions to address the issue of quality and access to education to every student. Continuous improvement requires a regular evaluation. An evaluation of student performance, employment rates, and employer satisfaction has information on strong and weak sides of the programs (Douse & Uys, 2019; Saleem & Cheema, 2025). Actionable changes that enhance the relevance and quality of the programs should be motivated by the feedback loops.

To sum up, the effectiveness of TVET depends on its correspondence to the needs of the labor market, digitalization, quality of teaching, leadership, and situational sensitivity. Through challenges and evaluation, institutions of TVET can keep the programs relevant and equip the students with the modern labor market.

2.4. Contextual Barriers as Moderator

The contextual barriers are a major determinant of the effectiveness of the TVET in geographic, socio-economic, and cultural environments. They generate disparities in quality, access, and outcome and thus it is necessary to know their effect particularly in diverse environments such as those found in Pakistan. Some of these obstacles are infrastructure constraints, socio-economic, cultural and disparities in access to technologies. One of the major barriers is infrastructure inequalities. Rural and less developed areas do not have well-equipped classes, workshops, and laboratories to restrict the quality of training (Grech & Camilleri, 2020). Without proper facilities, the hands-on training that people need to be job-ready is low; this influences the employment opportunities. There is unequal access to digital technology. Quality digital education requires quality internet and up to date equipment. Most of the Pakistani rural regions are not connected and do not have access to devices (Yang and Wu, 2024). This disparity increases educational inequality, since students in areas with poor internet access are not able to access the use of e-learning resources which are a part of contemporary TVET. The socio-economic aspects are also an impediment to the effectiveness of TVET. Students with low-income backgrounds are also usually restricted in their enrolment and completion due to their financial limits (Othman, Omar, and Abd Majid, 2025). The expensive nature of education, inadequate family support, and opportunity costs force high

numbers to drop out minimizing the impact and the reach of programs.

Participation is also influenced by cultural perceptions. In other areas, vocational education is perceived as the least prestigious choice compared to academic degrees and, thus, it does not encourage enrollment (Hani, Ismail, and Razali, 2024). Gender normality can also limit access by women particularly in the rural regions restricting them to work in the skilled sectors. Relevance is affected by industry collaboration or lack of the same. TVET programs in regions where industries are not very active find it difficult to establish meaningful employer relationships, which leads to skills mismatches and decreased job placement (Douse & Uys, 2019; Cheema & Baruch, 2024). The problem is compounded by the teacher training disparities. Teachers in low-income communities do not get access to professional development, which restricts their digital and pedagogical competence development (Razak and Noordin, 2022; Cheema et al., 2021). Lacking constant training, teachers are not able to interact with students and provide them with high-quality training, making the contextual differences worse. In order to improve the effectiveness of TVET, the interventions should address these barriers. The policies must be concerned with development of infrastructure, technology accessibility and financial aid to the students and gender policies. Connecting industries, growing teacher training, and encouraging local partnerships will deal with local problems.

In sum, contextual obstacles, including infrastructure and financial limitations, cultural beliefs, and so forth, determine the results of TVET in Pakistan. Their defeat should be achieved through direct, geographically-oriented policies that facilitate an equal access, industrial appeals and the quality of education. These challenges will be addressed and this will help TVET to equip students to embrace the modern workforce.

3. Theory, Hypotheses and Framework

This research paper uses Technology-Organization-Environment (TOE) Framework (Tornatzky and Fleischer, 1990) in examining innovation adoption in institutional environments. The TOE model is an analysis of the impact of technological, organizational, and environmental factors on the success of innovation. Technological context is the availability and the nature of technology, organizational context comprises of resources, processes and leadership and environmental context encompasses the external factors like competition, regulation and infrastructure.

In this study, digitalization is theorized as a technology configuration, which involves digital platforms, e-learning systems, virtual classrooms, and digital literacy tools in the institutions of TVET. Digitalization plays a significant role in Pakistan during the transition of policies and the trends in the global industry particularly in the light of Industry 4.0, which compels institutions to digitize teaching and administration (Ahmed et al., 2022). Nonetheless, the implementation of digital technology is still not uniform in all areas, which makes questions of successful implementation and influence on the effectiveness of TVET.

Digital Pedagogical Leadership (DPL) is a representation of the organizational context. DPL can be defined as leadership behaviors contributing to the digital transformation and learning within institutions. Leaders are agents, who can transform external innovations into internal strengths and encourage stakeholders to change (Abdullah et al., 2021). DPL is a mediating variable in the TOE framework where digitalization is transformed into specific physical outputs like the effectiveness of TVET. Researchers focus on the fact that DPL helps develop innovation and digital proficiency (Chen and Chan, 2024; Jamil et al., 2023).

Contextual Barriers are the environmental context and moderate the digitalization- TVET outcomes relationship. The inequity in infrastructure, socio-economic status, implementation of policies, and human resources endowed with skills influence the ability of a TVET institution to embrace technology. Situations in urban regions where there is a well-developed infrastructure can be less problematic

than in rural communities where essential facilities are missing (Ali et al., 2024; Cheema et al., 2024). TOE framework highlights the fact that the speed, magnitude, and sustainability of innovation adoption are dependent on the environmental factors and the reason of inclusion of contextual barriers as a moderator. Fairuz and Masek (2025) emphasize that digital pedagogical approaches are directly dependent on the socio-economic and infrastructural disparities in the ways of winning (Naeem, 2020).

The dependent variable is TVET Program Effectiveness, which is measured by the graduate employability, stakeholder satisfaction, and curriculum responsiveness. In the TOE framework the success of innovation is measured in respect to the performance and goal realization of the institution. Digitalization (technology), organizational support (leadership), and environmental compatibility (context) alignment also increases the chance of positivity of TVET programs (Zhong and Juwaheer, 2024).

Based on this conceptualization, the following hypotheses are proposed:

H1: Digitalization (Technology) has a significant positive effect on TVET Program Effectiveness.

H2: Digitalization has a significant positive effect on Digital Pedagogical Leadership (Organization).

H3: Digital Pedagogical Leadership has a significant positive effect on TVET Program Effectiveness.

H4: Digital Pedagogical Leadership mediates the relationship between Digitalization and TVET Program Effectiveness.

H5: Contextual Barriers (Environment) moderate the relationship between Digitalization and TVET Program Effectiveness, such that the relationship is stronger with better infrastructure and socio-economic support.

H6: Contextual Barriers (Environment) moderate the relationship between Digitalization and Digital Pedagogical Leadership, such that the relationship is stronger with better infrastructure and socio-economic support.

H7: Contextual Barriers (Environment) moderate the relationship between Digital Pedagogical Leadership and TVET Program Effectiveness, such that the relationship is stronger with better infrastructure and socio-economic support.

The triad of TOE is summed up in the research framework as shown in a visual way. Digitalization has a direct impact on TVET Program Effectiveness and an indirect one on it via Digital Pedagogical Leadership. The effect of digitalization on effectiveness is also conditioned by the Contextual Barriers with a focus on the fact that the institutional outcomes depend on the situation. This TOE informed framework offers a better insight into the interaction between internal enabling factors (leadership) and external facts (differences in context) and technological innovation to generate mixed effects in the TVET sector.

Through the use of the TOE framework, the paper does not only add value to the theoretical discussion regarding the adoption of innovation within the education sector of developing countries, but also provides practical suggestions to the policymakers and institutional leaders. It recommends that the internal leadership development and external infrastructure investment should support the digital initiatives in TVET so that they can reach their full potential. Further, this study can be useful in the empirical research in educational settings by operationalizing all three TOE dimensions using constructs that can be measured.

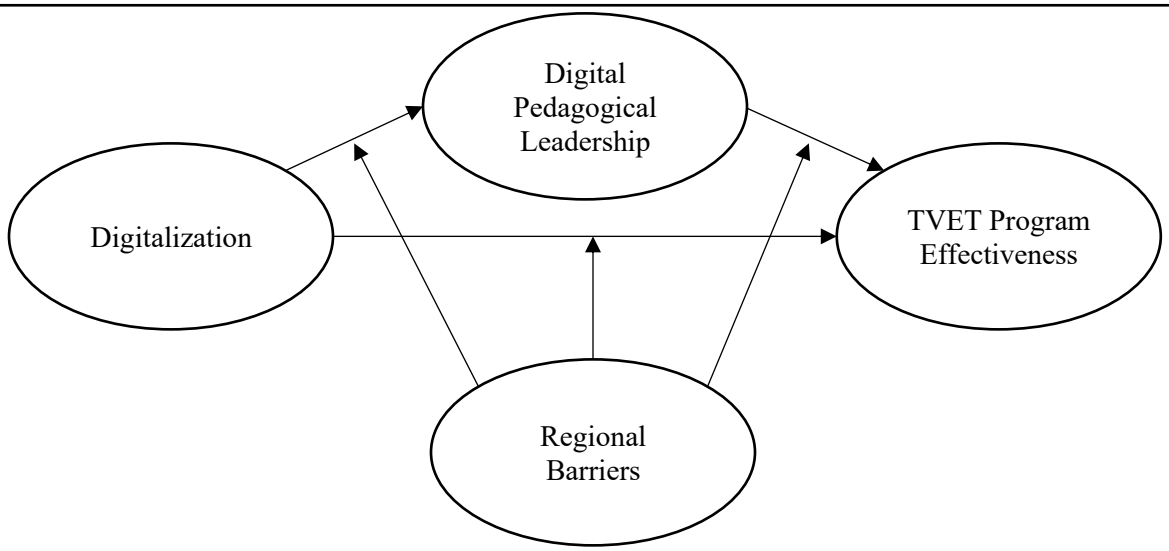

Figure-1: Research Framework

4. Research Methodology

The study research methodology is based on a quantitative research design with deductive approach which starts with the theory and the hypothesis based on the framework Technology-Organization-Environment (TOE). This method is appropriate to test theoretical assumptions and cause-effect relations with empirical data. Cross-sectional design implies that data were gathered on one occasion only, which permitted the study to capture institutional, leadership processes, and digital integration on a representative sample of Technical and Vocational Education and Training (TVET) institutions in Pakistan.

The study group included the entire known TVET institutions in the four largest provinces in Pakistan, which included Punjab, Sindh, Khyber Pakhtunkhwa (KPK), and Baluchistan. These areas were chosen in order to have a wide range of institutional capabilities, digital infrastructure and contextual realities. The study was also capable of assessing the nature of using context as a moderating factor in the relationship between digitalization and program effectiveness by incorporating institutes across different regions because the research design supported this hypothesis by the TOE framework (Tornatzky and Fleischer, 1990).

Sampling method used was systematic random sampling that gave all the institutions within the sampling frame equal opportunity of being selected but geographically distributed and institutions distributed. One hundred and twenty institutions were chosen with an equal distribution in the four provinces with both urban and rural representation. The institution of interest was the TVET institution and respondents were institutional leaders (principals, in-charges, and department heads) who are in the best position to give informed views on strategic leadership practices as well as technological integration. This sampling technique is consistent with the existing body of empirical research that relied on senior administrative personnel as a proxy of organizational wisdom and decision-making within education reform situations (Abdullah et al., 2021; Khalid and Noor, 2025).

A structured questionnaire, including valid scales measuring four main constructs, namely digitalization (independent variable), digital pedagogical leadership (mediator), contextual barriers (moderator), and TVET program effectiveness (dependent variable), was used to collect data. Each of the scales used a five-point Likert format with anchors of strongly disagree to strongly agree. The individual measures of every construct were established by assessing multiple items that were created or modified according to earlier research, and the reliability of the

instrument was verified by the values of Cronbach alpha, all above 0.90 which denotes excellent internal consistency (Hair et al., 2019; Fornell and Larcker, 1981).

The analysis of data used multiple regression analysis to test direct, mediating, and moderating effects based on the hypotheses of the TOE framework through the SPSS and the PROCESS macro developed by Hayes. To begin with, direct relationships between the digitalization, leadership, and the effectiveness of the programs were measured by conventional regression methods. This was because it was followed by mediation analysis through Model 4 in PROCESS that verified the importance of innovative leadership practices as a mediating variable. Lastly, the context moderation analysis involving Model 1 of PROCESS was conducted to determine the presence of the significance of context in moderation process of digitalization and effectiveness.

In general, this methodological framework gave an opportunity to conduct a rigorous analysis of the impact of digitalization on TVET effectiveness mediated by leadership and possibly moderated by the contextual conditions. It gave an appropriate empirical approach to testing theoretical constructs in a policy sensitive, resource constrained context such as Pakistan.

5. Results and Discussion

5.1. Reliability and Validity

As the analysis of reliability and validity presented in the table shows, the constructs applied in this study, which are Digitization (DIGT), Digital Pedagogical Leadership (DPL), Contextual Barriers (CTB), and Program Effectiveness (PREF), possess strong psychometric characteristics and can be used in a more sophisticated statistical analysis that involves regression and mediation/moderation testing. It is determined by Principal Component Analysis (PCA) with Varimax rotation, which is the popular method of assessing the construct validity of the social science studies (Hair et al., 2019).

To begin with, the items loading of all the four constructs exceed the traditional acceptable factor loading of 0.70, which is an indicator of convergent validity (Fornell and Larcker, 1981). In the case of Digitalization, the items were loaded between 0.730 and 0.810 with a significant representation of the construct. The lowest loading (DIGT5 = 0.730) is still within acceptable limits, which proves that the items in question are successful in their purpose to measure the desired digital constructs including technology use, e-learning, and digital infrastructure in TVET environments (Ahmed et al., 2022).

On the same note, there are five items under the category of Innovative Leadership Practices that have a loading of between 0.775 and 0.823. Such values are coherent constructs that assess adaptive, transformational, and visionary leadership practices that are important to facilitate change in institutional settings (Abdullah et al., 2021). The concept of leadership is commonly gauged as being multidimensional and these loadings justify the operationalization of DPL when it comes to technology adoption in TVET institutions (Khalid and Noor, 2025).

The table has the highest loadings of the Constructual Barriers construct, which is 0.835 to 0.888. This implies that the items are good to reflect the feature of the regions including its infrastructure, enforcement of policies, cultural norms, and socioeconomic status that shape the implementation of TVET in Pakistan. The high internal consistency (Cronbachs alpha = 0.920) is also aligned with the literature, which highlights the large role of the contextual disparity in determining the results of the national-level education reform policies (Ali et al., 2024; Guoliang, 2025).

The psychometric properties of the Program Effectiveness scale are also high with items loading that lies between 0.807 and 0.864. The construct contains such crucial outcome measures as graduate employability, stakeholder satisfaction, and curriculum responsiveness, which are highly identified in the literature as the indicators of the quality of TVET institutions (Asad et al., 2023; Dianawati et al., 2025). This construct alpha is 0.941, which indicates a high internal consistency.

Moreover, the total Kaiser-Meyer-Olkin (KMO) value of 0.918 proves the fact that the data is the most appropriate to be analyzed through factor analysis, which is greater than the minimum qualifying value of 0.60 (Kaiser, 1974). The test of Sphericity Bartlett gave a Chi-square value of 2023.511 with a significance level of $p < 0.001$ meaning that correlation matrix is not identity matrix and therefore, factor analysis is suitable. The two measures together confirm the appropriateness of the data to be analyzed using multivariate analysis.

The most interesting statistic is the total variance explained that is 78.860. It implies that the extracted components explain almost 79 percent of the difference in observed variables, which is far beyond the 60 percent threshold typically regarded as satisfactory as social science constructs (Hair et al., 2019). Such an explanatory power indicates that the constructs employed in the instrument are holistic and empirical.

The combination of these results has a good evidence of reliability and construct validity of the measurement tools used in this research study. The analysis supports the belief in the findings of further regression and mediation/moderation assessments because it allows concluding that all the constructs are measured correctly and consistently. Further, the high psychometric performance of these variables increases the theoretical relevance of using Technology-Organization-Environment (TOE) framework to explain digital transformation within the Pakistani TVET institutions.

Table-1: Reliability and Validity Analysis

Variable	Code	Items	Factor Loadings	Reliability
Digitalization	DIGT	DIG1	.808	0.942
		DIG2	.798	
		DIG3	.799	
		DIG4	.810	
		DIG5	.730	
Digital Pedagogical Leadership	DPL	DPL1	.821	0.920
		DPL2	.820	
		DPL3	.823	
		DPL4	.795	
		DPL5	.775	
Contextual Barriers	CTB	CTB1	.852	0.920
		CTB2	.835	
		CTB3	.848	
		CTB4	.868	
		CTB5	.888	
Program Effectiveness	PREF	PREF1	.849	0.941
		PREF2	.864	
		PREF3	.819	
		PREF4	.821	
		PREF5	.807	
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. KMO = 0.918 Bartlett's Test, Chi-square = 2023.511, Sig < 0.000 Total Variance Explained = 78.860%				

5.2. Regression Analysis

In Table-2, direct path coefficients are presented, where the three major relationships have all been found to be having strong and significant effects. The direction between DIGT and PREF (β = 0.580, t = 8.394, p <.001) proves that TVET program effectiveness is positively and significantly forecasted by digitalization. This finding is consistent with the prior empirical evidence that indicates that the incorporation of digital devices, learning management systems and digital literacy programs can significantly improve the educational outcomes including curriculum responsiveness and graduate employability (Ahmed et al., 2022; Asad et al., 2023; Gill et al., 2021). The fact that this path has R2 =.376 shows that the effect of digitalization on its own explains about 37.6 percent of the variance in program effectiveness, a moderate to strong impact in the academic context (Hair et al., 2019).

The relationship between DIGT and DPL (β = 0.534, t = 9.144, p < .001) is even more significant and the R2 is 0.417, which means that more than 41 percent of the innovative leadership practices can be explained by the level of digitization. This finding confirms the argument of the TOE framework that technological innovations affect the internal organizational capabilities (Tornatzky and Fleischer, 1990). It also argues that, the digital transformation efforts do not just demand infrastructure but also, inspire or demand a change in the behavior of leadership. This aligns with the literature that states that technology-enabled environments are more likely to support more collaborative, adaptive, and innovation-driven leadership (Abdullah et al., 2021; Khalid and Noor, 2025).

The third positive relation - DPL to PREF (β = 0.554, t = 5.996, p < .001) shows that innovative leadership is an important factor affecting TVET performance. The value of R2 is 0.235, which means that it has a moderate explanatory power, and leadership style and institutional agility are major factors influencing educational outcomes. This observation is reminiscent of research that has posited that in dynamic and resource-constrained settings such as Pakistan, leadership is one of the key processes that have a role to play in transforming innovation into performance (Guoliang, 2025; Dianawati et al., 2025).

Table-2: Regression Analysis for Direct Paths

Path	β	t-value	p-value	R^2
DIGT → PREF	0.580	8.394	< 0.001	0.376
DIGT → DPL	0.534	9.144	< 0.001	0.417
DPL → PREF	0.554	5.996	< 0.001	0.235

The mediation analysis shown in Table-3 indicates that there is a strong indirect influence of DIGT on PREF via DPL (effect =.1584, Boot SE= 0.0475, Boot LLCI= 0.0710, Boot ULCI=0.2639). The mediation is significant since the confidence interval excludes the value of zero (Preacher and Hayes, 2008). It means that some of the impact of digitalization on the effectiveness of a program is relayed via leadership. The result is the empirical confirmation of the organizational aspect of the TOE framework, which shows that technology in itself is not a significant contributor to the performance of the institution, and its effectiveness is further enhanced by combining it with strategic leadership. This confirms the thesis that leadership serves as an outlet of implementing the digital strategies into practical teaching, curriculum and administration enhancements (Bass and Avolio, 1994).

Table-3: Regression Result for Mediation

Path	Indirect Effect	Boot SE	Boot LLCI	Boot ULCI
DIGT → DPL → PREF (Indirect Effect)	0.1584	0.0475	0.0710	0.2639

The moderation analysis of the presented table focuses on the role of Contextual Barriers (CTB) in moderating the connection between Digitalization (DIGT), Digital Pedagogical Leadership (DPL), and TVET Program Effectiveness (PREF) in the context of Technical and Vocational Education and Training (TVET) institutions. The analysis shows that there are strong negative moderation effects and the degree of contextual barriers increases the negative effect of DIGT and DPL on PREF.

On the one hand, the relationship between DIGT and PREF is moderated by CTB, and the coefficient (-0.231) and t-value (-4.512) are noteworthy as negative and p-value is below 0.001, respectively. This result implies that Contextual Barriers diminish the power of digitalization to improve the program effectiveness. This finding is consistent with the research undertaken by Tornatzky and Fleischer (1990) who hold that the implementation of technological innovations can be hampered by organizational and contextual elements. In particular, in the context of TVET, the opportunities of digitalization can be constrained by such challenges as insufficient infrastructure, unwillingness to move over to digital, and insufficient resources (Ahmed et al., 2022). Therefore, it is important to overcome these obstacles to use digital tools to enhance the result of education.

The second path of moderation analyses the interaction of CTB and DIGT on DPL. This path has coefficient of 0.287, and t-value of -5.121 ($p < 0.001$) is significant. This finding indicates that Contextual Barriers reduce the effectiveness of digitalization on leadership practices. The more the CTB, the less the power of digitalization to affect leadership in TVET establishments. This observation confirms the claim by Khalid and Noor (2025) that digital transformation does not only necessitate technological infrastructure but also the need to have adaptive leadership that encourages innovation. But in environments where the barriers are significant e.g. inflexible institutional frameworks or unwillingness to embrace new leadership behaviors, the effects of digitalization on leadership development are reduced.

Lastly, the analysis shows that there is a high negative moderation of CTB on the association between DPL and PREF. The t-value of -5.378 ($p < 0.001$) and the coefficient (-0.309) indicate that Contextual Barriers lower the effectiveness of leadership in improving the outcomes of the programs. This aligns with the thesis that is presented by Bass and Avolio (1994) who point out that leadership plays a vital role in ensuring that technological innovations are converted into practical enhancements in the educational sector. Nevertheless, in the case of institutional obstacles like scarcity of resources, opposition to change, or insufficient training in leadership, the ability of leadership to influence the programs positively is diminished. This also highlights the significance of combating contextual hindrances in order to facilitate successful leadership and digitalization.

The results of the moderation procedure highlight the importance of contextual barriers (CTB) in the moderation of the effectiveness of digitalization (DIGT) and leadership (DPL) on TVET program effectiveness (PREF). These findings show that an increase in CTB undermines the correlations between DIGT and PREF, DIGT and DPL, and DPL and PREF, which supports the necessity to deal with the contextual issues when digital transformation takes place in TVET institutions. The discussion can be added to the accumulation of the literature emphasizing the necessity to eliminate contextual obstacles to the increased effect of digitalization and leadership in education (Hair et al., 2019; Abdullah et al., 2021).

The present paper reveals that digitalization and digital pedagogical leadership (DPL) play a major role in improving the efficiency of TVET

programs in Pakistan, and the importance of the contextual barriers (CTB) is critical. These findings can be of significance regarding the intricacies of the digital tool and leadership practice integration in developing nations, especially vocational education and training.

To start with, the beneficial effect of digitalization on the success of TVET programs corresponds to the available literature, which emphasizes the transformative nature of digital technologies within the educational process. It has been demonstrated that the introduction of digital tools and e-learning platforms into TVET could lead to increased access to learning resources, improved student interaction, and a more precise correspondence of the learning content to the demands of the job market (Grech and Camilleri, 2020). Digital education, like in most other developing countries, has been a critical component of national reforms in Pakistan to overcome the skills gap in the labor market. Through provision of flexibility in learning settings, digitalization has the potential to enhance the quality and accessibility of TVET programs, thereby enhancing the outcomes of programs, including employability and acquisition of skills.

Nonetheless, although digitalization is an essential facilitator of the educational enhancement, its potential can be achieved only when it is combined with the efficient use of digital pedagogical leadership (DPL). The leadership will play a key role in facilitating the process of adopting digital tools in the learning process and in supporting the educators and students during this process. This paper points out that leadership does not just facilitate the application of technology, but it also promotes a culture of life long learning, innovation and teamwork in institutions. This is consistent with the point of view by Bass and Avolio (1994) who indicate that leadership is a key mechanism that can be used to change education institutions via digital innovation. The problem of leadership capacity and digital preparedness is most likely to be encountered in Pakistan, where TVET institutions still struggle with these issues and need to be addressed through the DPL that will help to overcome the challenges and make certain that technology is utilized in order to facilitate teaching and learning.

Centrality of contextual constraints such as infrastructural constraints, socio-economic differences, and the level of access to digital resources also moderate the effects of digitalization and leadership on program outcomes. This observation is accompanied by other studies that have been carried out in the past that emphasized the importance of the context at which educational changes apply in ascertaining their effectiveness (Tornatzky and Fleischer, 1990). The unavailability of a stable internet, poor digital infrastructure, and social-economic factors are particularly problematic in Pakistan, which is where the realization of the strategies of digital education is involved. The contextual barriers preclude the potential of digital tools and leadership to make the programs as effective as possible since in such areas, students and educators lack resources and support that they need.

According to the results of the research, contextual impediments lower the relationship between digitalization and the efficacy of the TVET programs. This observation points to the weakness of digital solutions that do not take into account the regional peculiarities in infrastructures and socio-economic status. The most developed digital education programs may fail to fulfill their possibilities even in the rural and underserved regions where individuals lack access to technologies and digital resources in general. This point illustrates why policy makers ought to concentrate on context based policies that will defeat these hurdles and provide special aid to poor regions.

Moreover, the study found out that contextual barriers, which also hinder digitalization-digital pedagogical relationship of leadership, exist. The ability of the leadership to implement digital operation successfully is lower in those regions where situations of contextual problems are more frequent. This directs to the role of the leadership development not only to be digital competent but to be able to negotiate and respond to the challenges of the context. The

leaders of the TVET institutions are supposed to be empowered to manage digital change in different circumstances and establish a partnership with educators, students, and other stakeholders to assist them overcome the local barriers.

The fact that the negative moderation of contextual barriers and relationship between digital pedagogical leadership and effectiveness of TVET programs are also significant also adds to the importance of the consideration of the local issues in educational leadership. Leadership is the core of successful digital initiatives, and, most of the time, the contextual factors are what precondition the possibility or impossibility of transforming the digital strategies into meaningful educational outcomes under the impact of leadership. This fact is consistent with the research of Yang and Wu (2024) who believe that leadership must be localized and is dependent on the challenges and resources available in a specific region.

Table-4: Regression Analysis for Moderation

Path	β	t-value	p-value
CTB * DIGT → PREF	-0.231	-4.512	< 0.001
CTB * DIGT → DPL	-0.287	-5.121	< 0.001
CTB * DPL → PREF	-0.309	-5.378	< 0.001

Finally, the findings of this paper indicate that digitalization of TVET institutions can be a key to improving the effectiveness of different programs, yet the success of digitalization is largely affected by leadership and context. As much as digital tools have enormous potentials of transforming education, all these potentials can only be achieved with the presence of robust digital pedagogical leadership and an enabling environment. In such nations as Pakistan, where contextual differences in infrastructure and socio-economic situation are present, it is important to overcome these obstacles with specific policies and programs. This may involve enhancing the digital infrastructure, training professional development among the leaders and educators and coming up with region specific strategies that address the special needs of the regions.

6. Conclusion

The given paper provides a valuable discussion of the impact of digitalization and digital pedagogical leadership (DPL) on the effectiveness of TVET programs in Pakistan, which is outlined in terms of Technology-Organization-Environment (TOE). The findings demonstrate that the impact of digitalization on the quality of TVET programs is the most important, although it relies upon the digital pedagogical leadership and contextual barriers (CTB). The leadership practices are a critical mediating factor in the process of digitalization being transformed into the real changes in the teaching, curriculum, and student outcomes. In addition, digitalization and leadership have a positive effect on the quality of TVET programs, which is banned by contextual barriers (poor digital infrastructure and socio-economic differences). This finding also introduces the need to concentrate on the localized strategies that can be used to address the regional weaknesses, particularly in the undeveloped areas in Pakistan. The study fits into the broader discourse of the topic of digital transformation in higher education, which offers a clue of how the factors of leadership and context play out to either facilitate or hinder the acceptance and success of digital tools adoption in the TVET institutions.

6.1. Theoretical Implications

The article introduces some of the most important theoretical contributions to the TOE framework and digital education literature. Firstly, it expands the TOE framework with the addition of the position of the digital pedagogical leadership (DPL) as another intervening variable that has not previously been explored in the existing research on digital transformation in

education. Even though the TOE framework has historically been concerned with the technological, organizational, and environmental environment of the process of innovation adoption, the paper identifies leadership as the key factor in the process of transforming the digital initiatives into a more viable advance. Based on the analysis of DPL as a mediator, the research will provide a more informative contribution to the role of the leadership practices on the establishment of relationships between digitalization and the efficiency of TVET programs. This intervening variable is crucial in the learning institutions especially in the developing countries like Pakistan where leadership plays an important role in dealing with the challenges as far as technology incorporation is concerned.

Another contribution made by the study to the theory is the moderating effect of contextual barriers (CTB). Although the relevance of context in the adoption of technology has been taken seriously in past studies, this study offers empirical data that contextual factors like infrastructure, socio-economic differences, and access to digital resources play a significant moderating role on the efficacy of digitalization and leadership in TVET programs. This theoretical extension stresses the fact that technology integration should not be viewed in a vacuum of the environment within which it is being put into practice, particularly in resource-constrained settings such as Pakistan.

Besides, the research can be useful in terms of its contribution to the body of literature that requires more context-sensitive solutions to the educational reforms, as the research provides valuable insights into the influence of contextual barriers on the implementation of the digital strategies in the developing countries. The fact that the study was placed in Pakistan in a country where there exist great regional differences adds to the theoretical discussion of how contextual differences affect digital transformation in education because it provides a more specific view that can be applied to other nations in the Global South.

6.2. Practical Implications

The research has various implications on policy makers, institutional leaders and educationists in the TVET sector in Pakistan. These findings highlight the importance of digitalization as not being enough to enhance the effectiveness of a program without the help of leadership. Digital pedagogical leadership plays the critical role of leading the process of incorporation of digital tools into the teaching and learning activities and making sure that the educators are well prepared to use technology. Thus, TVET institutions need to consider leadership development programs as a priority in order to appreciate the culture of innovation, flexibility, and lifelong professional development. This is in line with what Bass and Avolio (1994) recommend when they amplify the importance of leadership in fueling digital transformation in learning institutions.

In addition, the results of the study indicate the necessity of context-specific policies that can be used to deal with a particular problem encountered by TVET institutions in this or that part of Pakistan. The effectiveness of digitalization is hindered by the contextual barriers, including the absence of digital infrastructure, low access to technology, and socio-economic differences. Hence, policymakers ought to pay attention to the closing of the digital divide by investing in digital infrastructure, especially in rural and underserved regions. This may involve the provision of affordable internet services, updating of facilities and also making the digital resources accessible to the educators and the students.

Also, according to the results, the existence of regional imbalances in socio-economic status and access to digital tools in accordance with specific interventions. Indicatively, the provision of financial assistance to rural institutions in terms of access to digital technologies, as well as the provision of training programs to educators in terms of developing their digital skills, can be examples of such measures. In this way, policymakers will be able to make certain that the advantages of digitalization will be extended to every part of the nation and eliminate

educational imbalances and enhance the performance of the programs.

Moreover, professional growth of the teachers is important to the effective implementation of the digital strategies. The research suggests that leadership is a key to establishing the environment in which the educators will be assisted in their digital path. The leaders of the institution should offer them continuous training opportunities in order to enhance their digital competencies hence enable them to incorporate the digital tools into their teaching methods more easily. This will make sure that the possible advantages of digitalization are achieved at classroom level and better educational outcomes will be achieved by students.

Last but not least, the results of the study indicate that cooperation among TVET institutions, government agencies, and industry stakeholders is necessary to make sure that digital transformation is in line with labor market requirements. Teamwork can be used to make sure that the curriculum is still updated to the needs of the industry and that the students acquire the necessary skills to be employed in the future. The reinforcement of the industry connection may also enhance students with better training opportunities and increase their employability, thereby increasing the overall efficacy of the TVET programs.

6.3. Research Limitations

Although the present study can contribute a lot to the understanding of the role of digitalization, digital pedagogical leadership (DPL), and contextual barriers to the improvement of the effectiveness of TVET programs in Pakistan, it has numerous limitations that should be considered.

Possibility of common method bias is one of the main constraints of the present research. As the data were gathered using self-reported questionnaires with institutional leaders (e.g., principals, department heads), it is possible that they did not give fully objective judgments and might have answered as they wanted to sound socially acceptable or because of their own personal biases. This would compromise the validity of the data particularly when quantifying subjective constructs such as leadership practices and contextual barriers. To address this weakness, the next study should consider multiple sources of data or triangulation, i.e. both leaders and teachers should be gathered to collect information and increase the results validity and reliability.

The other weakness of this study is that it is cross-sectional and is used to gather data at a single point in time. Although this design is practical in analyzing the relationship between the variables, it fails to provide the opportunity of exploring the relationship between variables in terms of causation. A longitudinal research would give a better idea of the changes in digitalization and leadership practices over time and their effect on the effectiveness of the TVET programs in the long run. Longitudinal studies would also enable researchers to measure the dynamics of contextual barriers, and how they concur with digital strategies and leadership over time, which will give more information about the dynamics of digital transformation in education.

The research is based on the sample of 120 TVET institutions in four Pakistani provinces. Although this sample size is adequate to do preliminary analysis, it can be rather small to represent the entire diversity of TVET institutions in the country. The sample might not be a complete representation of the huge socio-economic and infrastructural variations that exist in urban and rural regions. Moreover, the uniqueness of the study to Pakistan restricts its generalizability to other nations or regions with varying socio-economic statuses, educative systems and digital preparedness. The study can be improved in the future by increasing the sample size and considering more geographical areas to improve the external validity of the results. Also, it would be possible to conduct comparative research in different countries or regions with varying degrees of digitalization that would allow seeing the effect of contextual factors on the success of the digital transformation in TVET.

The research is based on cross-sectional data, which implies that the research provides a picture

of the present-day situation in digitalization, leadership, and effectiveness of programs in the TVET institutions in Pakistan. Although this method is useful in explaining the relationship between variables on a short term basis, it fails to consider the changes in time or how these factors will change with time. As the digital technologies and pedagogical practice keep developing, a longitudinal study would be able to give stronger findings regarding the long-term effects of digital strategies and leadership on the outcomes of TVET programs.

Although the research has taken into consideration the contextual barriers, the sample size of 120 institutions in four provinces may not be representative of the regional differences in terms of digital infrastructure, socio-economic differences, and cultural orientation towards vocational education. Pakistan has significant disparities in urban and rural regions, especially regarding access to digital resources and education opportunities. A more sophisticated strategy may include considering the sub-regional variations in every province since they may considerably influence the adoption and implementation of digital strategies and leadership practices in TVET institutions.

The research was also based on self-reported data of institutional leaders, which could subject the findings to subjectiveness. Although the views of leaders are essential to comprehend the institutional-level decision-making and leadership practices, it is possible that future research would include a variety of informants (e.g., educators, students, industry representatives) to have a more detailed and well-rounded perspective on the effectiveness of TVET program. This would assist in triangulating the data and minimise the chances of biases that may occur as a result of one source of information.

6.4. Future Research Directions

Given the limitations of the current study, several avenues for future research are suggested:

In future research, it is important to remember that a longitudinal design may be employed to trace the shifts in digitalization and leadership practices over a certain period of time, specifically when the results of TVET programs are taken into account. The longitudinal data would give better information about the development of digital tools and interventions of leadership and their lasting effects on educational quality. This would also enable the researchers to observe the changes in contextual barriers as time goes by, especially as the national policies are enacted in a country such as the Skills for All project in Pakistan.

To enhance the external validity of the results, it would be reasonable to increase the sample size and cover a larger variety of regions in Pakistan or in other developing countries that face a similar issue with TVET in the future. A wider scope of institutions would offer more detailed information on the role of regional variations and contextual variations in influencing the introduction of digital tools and leadership practices in vocational education.

To address the risk of common method bias, future research might gather information on various sources, such as educators, students, and industry representatives, to have the closest picture of TVET program effectiveness. Mixed-methods research based on the synthesis of qualitative and quantitative data might contribute to a better comprehension of the issues and opportunities of digital transformation and leadership in TVET institutions.

The article emphasizes the role of leadership in digital transformation, yet future studies can examine definite leadership approaches, including transformational and transactional leadership, and their influence on the adoption of digital and the effectiveness of the programs. Researching the effects of various leadership strategies on the adoption of digital technologies would provide more specific advice on how leadership development programs in TVET institutions can be improved.

The other area which could be examined in future is the direct impact of digital pedagogy on the learning outcomes of the student such as skills acquisition, engagement as well as employment rates. This can provide a closer understanding of the use of digital tools in the

learning process of students and their readiness to the labor market.

The comparison between developing and developed countries could assist to comprehend the traps and chances of digitalization in TVET in a range of situations. Such studies would inform regarding the effects of policy and infrastructure differences on the implementation and success of digital strategies in vocational education.

In conclusion, even though the current study provides valuable information on the role of digitalization and leadership in increasing the effectiveness of TVET programs in Pakistan, the research ought to be performed in the future to address the disadvantages identified and take into account the problems considered in more detail.

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