UTILIZING ICT-BASED LEARNING RESOURCES TO ENHANCE CREATIVITY AND INNOVATION FOR PRE-SERVICE STUDENTS OF VOCATIONAL EDUCATION

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ABSTRACT

In today's vocational education, preparing prospective vocational teachers requires developing innovative, creative thinking that strengthens pedagogical competence and classroom management. These abilities help address the complexity of modern vocational classes and support a positive, engaging learning environment. This study examines how prospective vocational teachers manage ICT-based learning resources to encourage creativity and innovation in their professional practice. A quantitative approach was applied with 178 participants, evenly assigned to a control group and an experimental group. The experimental group used ICT-based learning tools, including interactive multimedia and various digital technologies. Results showed that participants who effectively used ICT resources achieved higher levels of creative and innovative thinking. The experimental group's N-Gain score reached 0.756, compared with only 0.049 in the control group. This significant difference strongly suggests that appropriate use and management of ICT learning resources can help future vocational teachers create more productive classroom conditions and strengthen their entrepreneurial abilities. The notable learning gains also demonstrate that ICT-based multimedia improves instructional effectiveness compared with traditional methods. Overall, the findings clearly highlight that future TVET educators who master digital learning resources will be better prepared for teaching demands and the challenges of contemporary TVET.

KEYWORDS

Classroom management, creative thinking, ICT, innovative skills, instructional efficiency, pre-service vocational teachers

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Highlights

- *ICT-based learning resources significantly enhance creativity and innovation among pre-service teachers.*
- *Interactive multimedia improves digital pedagogy skills for vocational teacher education.*
- *Proper management of digital tools boosts instructional efficiency in vocational learning environments.*
- *Structured ICT training is essential for preparing future vocational educators for Industry 4.0.*

INTRODUCTION

Creative and innovative thinking skills are essential for success in an increasingly competitive business world. In vocational education, particularly in vocational high schools (SMK), these skills play a crucial role in preparing students to meet industry demands and entrepreneurial challenges. Creativity and innovation enable individuals to generate new ideas and solve problems effectively, serving as key competencies in the modern workforce (Dewanti, 2022). However, studies indicate that many vocational education programs struggle to equip students with these critical skills, as the curriculum often emphasizes technical expertise over creative problem-solving. One study by Muharam and Afrilia highlights that many vocational education programs concentrate heavily on technical skills, often at the expense of fostering creative and critical thinking skills necessary for students to adapt in dynamic work environments (Muharam and Afrilia, 2024). This claim aligns with Guo's findings, which discuss the challenges in vocational education systems, specifically noting that an overemphasis on skill-based training leads to a neglect of essential problem-

solving and creative competencies among graduates (Guo, 2023). Furthermore, Groeneveld et al. (2021) argue that combining technical knowledge with creativity is essential in software engineering, asserting that outstanding performance in complex fields requires more than technical aptitude; it demands innovative thinking to tackle intricate challenges.

Moreover, Yao and Shi (2024) indicate that while digital transformation and modern pedagogical strategies are likely to enhance teaching methodologies within vocational education, they also uncover gaps in resource availability to effectively implement these strategies, which might hinder the integration of creative problem-solving approaches into traditional curricula. The integration of soft skills, encompassing creativity and critical thinking, is emphasized in a study on the pedagogical challenges faced by vocational educators (Nkwadipo and Rabaza, 2021). This limitation in pedagogical focus hinders students' ability to develop innovative solutions, adapt to evolving industry requirements, and compete in the global job market (Ummah et al., 2019; Istiq'faroh et al., 2020).

Some studies highlight the interconnectedness of creativity, innovation, and entrepreneurship in vocational education, emphasizing that these elements are crucial not only for workforce readiness but also for cultivating an entrepreneurial mindset (Tambunan et al., 2021). Research suggests that teacher creativity enhances entrepreneurship education and student innovation, while structured entrepreneurship spaces in vocational institutions stimulate entrepreneurial intentions (Machali et al., 2021). However, while entrepreneurial education fosters motivation and intention, its direct influence on creativity remains ambiguous, indicating the need for more technology-driven pedagogical approaches (Paliwal et al., 2022). Self-efficacy and attitude significantly mediate the link between creativity and entrepreneurial intentions, suggesting that psychological factors shape vocational students' ability to innovate (Niu et al., 2022). Additionally, integrating digital tools into entrepreneurship education nurtures an entrepreneurial mindset, inspiration, and self-efficacy, further driving students toward innovation (Li et al., 2023). Institutions like community colleges contribute significantly to the development of innovation and creativity skills, particularly in vocational settings, while specialized fields such as sports entrepreneurship showcase how creativity and innovation drive industry transformation (Abusamra, 2022). Given these insights, leveraging technology-based entrepreneurial education is essential for equipping vocational students with the adaptive and problem-solving skills necessary to navigate the evolving entrepreneurial and industrial landscape.

Meanwhile, technology serves as a powerful tool in enhancing learning experiences and fostering innovation in vocational education (Mahmudah and Santosa, 2021). The integration of ICT-based learning resources, such as interactive simulations, e-learning modules, and cloud-based platforms, ensures that vocational education remains engaging, industry-relevant, and skill-focused (Durmus and Dağlı, 2017; Kharismaputra et al., 2020). Pre-service vocational teachers (PPG students) must develop technological and pedagogical competencies to effectively implement digital instructional strategies (Riyanda et al., 2025). Technological and pedagogical competencies enable pre-service vocational teachers to design adaptive, innovative learning environments that meet Industry 4.0 demands, such as integrating automation, digital tools, and data-driven instruction. Despite the growing digitization of education, many vocational teacher-training programs lack a systematic approach to integrating digital tools effectively (Redmond and Lock, 2019).

Despite its potential, integrating technology into vocational teacher education faces significant challenges. Research highlights limited access to digital resources, insufficient training, and a lack of structured guidance as major barriers to technology adoption (Mahmudah and Santosa, 2021). Moreover, traditional vocational teacher-training programs still prioritize theoretical instruction over practical ICT integration, resulting in gaps in digital literacy and pedagogical adaptability among pre-service teachers (Durmus and Dağlı, 2017; Kharismaputra et al., 2020). The era of Industry 4.0 increasingly recognizes the urgency of developing digital competence for prospective vocational teachers as a fundamental requirement. Studies emphasize that pre-service vocational teachers must acquire multidisciplinary digital competencies to effectively integrate technology into vocational education (Roll and Ifenthaler, 2021). However, significant gaps in digital skills persist among vocational educators, particularly in their ability to implement pedagogical technological knowledge effectively (Moreno-Guerrero et al., 2021). Several factors influence the development of digital competence, including attitudes toward technology, curriculum integration, and the specific requirements of teaching vocational subjects (Mulyanti et al., 2024).

Despite the crucial role of teacher educators in fostering digital competence among pre-service teachers, they themselves face challenges in fully integrating digital pedagogy into teacher training programs (Lindfors et al., 2021). Research underscores the urgent need to reform pre-service teacher curricula to systematically integrate the development of digital competence into teacher education (Tomczyk, 2024). Moreover, early-career teachers' ability to apply digital pedagogy is significantly shaped by institutional culture, access to resources, and the availability of support systems that sustain continuous digital skill development (Masoumi and Noroozi, 2023). Given these challenges, vocational teacher training programs must prioritize the structured development of pedagogical technological knowledge, ensuring that digital competency is not only an individual responsibility but also an institutional commitment to equipping future educators with the skills necessary for technology-driven vocational education. While existing studies have extensively explored the benefits of interactive multimedia in improving student engagement and learning outcomes, limited attention has been given to how pre-service vocational teachers develop the ability to manage and implement ICT-based instructional strategies effectively. This creates a significant research gap in understanding how teacher training programs can better prepare pre-service educators to integrate technology into vocational learning environments.

This study explores the role of interactive multimedia in entrepreneurship education for pre-service vocational teachers. Specifically, it seeks to: (1) assess how interactive multimedia enhances creativity and innovation skills, (2) evaluate

competencies in managing and implementing ICT-based instructional strategies, and (3) determine the impact of structured digital pedagogy training on preparing pre-service vocational teachers for technology-driven vocational education. The findings aim to inform curriculum enhancements, promoting technology-driven instructional approaches that foster creativity, innovation, and industry-aligned teaching practices. In general, this paper will include a literature review, a theoretical framework, methods, research results, a discussion of the research findings, and conclusions, and end with a bibliography of references from relevant research to justify or refute the research findings.

LITERATURE REVIEW

The role of ICT-based learning resources in vocational teacher education

Technology has become an integral part of modern education, particularly in vocational teacher training, where educators must be prepared to integrate ICT-based learning resources into their teaching practices. Studies indicate that interactive multimedia, simulations, and digital learning platforms enhance student engagement, improve conceptual understanding, and support hands-on learning experiences (Durmus and Dağlı, 2017; Kharismaputra et al., 2020). Effective use of these technologies equips pre-service teachers with the skills necessary to create student-centered, industry-relevant learning environments (Mahmudah and Santosa, 2021).

Despite its potential benefits, integrating ICT into vocational teacher education is difficult. Pre-service teachers face challenges such as limited technical infrastructure, structured instruction, and digital literacy (Riyanda et al., 2025; Redmond and Lock, 2019). According to Kaminskienė, Järvelä, and Lehtinen (2022), the Technological Pedagogical Vocational Knowledge framework can help integrate ICT into vocational teacher education programs, preparing future educators to effectively manage and optimize digital teaching tools. Studies show that while many institutions offer ICT facilities, teacher education rarely uses them (Pozas and Letzel, 2023). Another study shows that two key factors, teachers' internal perceptions and external campus support, directly motivate vocational college teachers in China to teach with ICT. Among all variables, "ICT use intention" is the most critical bridge: it absorbs the positive influence from teachers' perceptions and then transmits it into actual classroom actions (Yang et al. 2023). In Indonesia, many vocational teacher education programs lack digital infrastructure, ICT integration, pedagogical training, and institutional support for technology-driven instruction (Budiarto et al., 2025). Although the government promotes digital transformation in education, the gap between policy and practice remains large, suggesting the need for structured training programs to equip pre-service vocational teachers with digital and pedagogical skills to integrate ICT into vocational learning environments.

Digital competence of prospective vocational teachers

The development of Pedagogical Technological Knowledge is essential for prospective vocational teachers to effectively integrate technology into their teaching practices. Recent studies highlight the positive impact of TPACK-based training programs on pre-service teachers' perceptions of technology integration (Diamah et al., 2022) and on classroom management in technology-enriched environments (Saritepeci, 2022). Effective technology integration fosters student engagement and academic achievement, particularly when combined with learner-centered pedagogies (Aljehani, 2024). Additionally, factors such as self-efficacy, interest, and motivational beliefs significantly influence teachers' ability to adopt technology in instruction (Istiningsih, 2022). Institutional support further strengthens technology adoption, impacting both teacher performance and student learning outcomes (Panakaje et al., 2024).

However, developing ICT competencies among prospective vocational teachers faces multiple challenges. Limited time and resources in vocational schools (Vilppola et al., 2022), inadequate infrastructure, and insufficient exposure to emerging technologies hinder effective technology adoption. Additionally, the attitudes and digital competencies of teacher educators play a significant role in shaping ICT integration within vocational teacher training programs (Divayana et al. 2021). Studies indicate that pre-service teachers' self-perceived competency and attitudes strongly predict their future use of ICT in teaching (Pozas and Letzel, 2023). The rapid evolution of technology demands continuous adaptation, yet vocational education still suffers from low ICT adoption across various instructional components (Hassan et al., 2021). Addressing these barriers is crucial to ensure that vocational educators develop comprehensive digital competencies that align with the demands of Industry 4.0. Thus, structured digital pedagogy training, institutional investment in ICT infrastructure, and targeted professional development programs are essential to prepare future vocational teachers for technology-driven educational environments.

Creativity and innovation as core competencies for pre-service vocational teachers

The 21st-century education framework emphasizes the development of creativity, innovation, critical thinking, collaboration, and communication as essential competencies for preparing vocational educators to meet industry demands (Julaihi and Hamdan, 2020). Pre-service vocational teachers must cultivate creativity and innovation skills to develop engaging instructional approaches that foster entrepreneurial mindsets and problem-solving abilities (Tambunan et al., 2021; Zhang and Yu, 2022). Research suggests that interactive multimedia significantly enhances students' motivation, improves their creative thinking abilities, and fosters innovation-driven learning environments (Gunawardhana and Palaniappan, 2016; Howorth et al., 2012).

However, vocational teacher education programs often lack a strong emphasis on creativity and innovation, focusing more on technical expertise than adaptive teaching strategies (Machmud et al., 2021; Boyles, 2012). This training gap leaves pre-service teachers struggling to design and implement technology-driven instructional approaches, limiting student engagement and overall learning outcomes (Mirzanti et al., 2015; Rejekiningsih et al., 2022). Recent studies advocate for curriculum reforms

that integrate experiential learning, digital instructional design, and creativity-based teaching methodologies to better prepare pre-service teachers for modern educational challenges (Noguera et al., 2024; Göltl et al., 2024). By equipping future educators to manage and use digital learning resources effectively, vocational teacher education can ensure graduates are well-prepared to foster innovation, adaptability, and digital literacy in vocational learning environments. The incorporation of ICT-based instructional strategies, entrepreneurship education, and multimedia technology into teacher training programs can bridge the gap between traditional pedagogy and the digital education landscape, ultimately enhancing teaching effectiveness and student success (Ismail and Buang, 2019; Sefriani et al., 2020).

Theoretical frameworks

Guided by the Technological, Pedagogical, and Vocational Knowledge framework, this study posits that interactive multimedia serves as a contextual trigger, converting vocational content knowledge into creative, innovative pedagogical actions among pre-service teachers. This framework argues that effective ICT integration requires the interplay of technological fluency, pedagogical flexibility, and authentic vocational context, uniquely satisfied by entrepreneurship-oriented interactive multimedia (Kaminskienė et al., 2022). Technological-Pedagogical-Vocational Knowledge posits that pre-service vocational teachers must simultaneously command technological, pedagogical, and vocational content knowledge to transform ICT-based resources, such as interactive multimedia, into creativity-enhancing and innovation-driving learning experiences. Empirical evidence indicates that when teachers possess this robust framework, they are more likely to design student-centered, industry-relevant activities that foster entrepreneurial mindsets (Mahmudah and Santosa, 2021; Saritepeci, 2022). Conversely, deficits in any Technological, Pedagogical, and Vocational Knowledge dimension constrain the enactment of higher-order 4Cs skills, particularly creativity and innovation (Julaihi and Hamdan, 2020). Consequently, this theorizes that structured engagement with such multimedia cultivates Technological Pedagogical Vocational Knowledge competence, which in turn manifests as observable creativity (idea fluency, originality) and instructional innovation (risk-taking, collaborative design) within entrepreneurship lessons. This study aims to address this gap by analyzing the effectiveness of structured digital pedagogy training and the role of multimedia tools in enhancing teaching competencies among pre-service vocational teachers. By doing so, this research contributes to the development of vocational teacher education curricula, ensuring that graduates are equipped with the necessary skills to implement technology-driven instructional approaches that align with industry and educational demands.

MATERIALS AND METHODS

Research design and participant

This study employed a quantitative approach to assess the effectiveness of ICT-based learning resources in enhancing creativity and innovation skills among pre-service vocational teachers. A quasi-experimental design with cluster sampling was chosen because practical constraints, such as the existing class structure, made full randomization impossible. Furthermore, this design offers greater contextual relevance than a fully randomized experiment, though it may introduce selection bias (Patel and Patel, 2019). The control group followed traditional entrepreneurship education, while the experimental group integrated interactive multimedia, simulations, and digital platforms.

This study employed a quasi-experimental design, with participants assigned to either a control or an experimental group via a cluster-randomized design (Sutrisni et al., 2022). A total of 178 students from one of the public universities in Surakarta, Indonesia, were randomly assigned to the control and experimental groups (Table 1).

Group	Pre Test	Treatment	Post Test
Experiment	O	X1	O
Control	O	-	O

Table 1: Pre–Post Control Group Design

Table 1 compares the experimental group, which used ICT-based learning resources, with the control group that employed conventional media such as PowerPoint presentations and webpages. The experimental group integrated interactive multimedia, animated videos, and simulations developed with Articulate Storyline into entrepreneurship learning sessions on the Moodle e-learning platform. Conducted over two weeks in blended (online and offline) formats, the six 90-minute sessions centered on business plan development and entrepreneurial case studies. These implementation details were incorporated into the data analysis and discussion to ensure that the observed effects on creativity and innovation were interpreted within their instructional context. A quasi-experimental design with cluster sampling was used to select 178 pre-service vocational teachers (89 per group) from a public university in Indonesia (Sutrisni et al., 2022). This design was considered appropriate given the pre-existing class structures, which made random assignment impractical, while still allowing for meaningful comparisons across equivalent groups. The inclusion criteria targeted students enrolled in teacher education programs with prior coursework in instructional media, ensuring relevance to ICT-based pedagogical contexts. This approach maintained representativeness among vocational teacher candidates and enabled a valid assessment of ICT integration's effectiveness in fostering creativity, innovation, and pedagogical adaptability.

Data collection instruments and techniques

A two-stage examination examined how ICT-based interactive multimedia affected pre-service vocational teachers' creativity and innovation. Participants took the pre-test from May 24–28, 2021, to assess their creativity and innovation skills. The experimental group was taught using interactive multimedia and digital learning tools, while the control group used traditional approaches. The post-test was held June 7–11, 2021, to evaluate creativity and innovative skills after this organized session. Pre- and post-test scores and questionnaire responses were used to assess the effectiveness of digital teaching strategies in fostering creativity and pedagogical adaptation among pre-service vocational instructors.

Instrument development

The Creativity-Innovation Skills Scale was developed through a three-phase adaptation of the scales by Faiziyah et al. (2020), Indrawati (2021), and Koyuncuoglu (2021). First, items were translated–back-translated (English–Indonesian) by two certified translators; discrepancies were resolved by a panel of three vocational-education experts. Second, the Item-Level Content Validity Index was used to assess content validity. Three external experts (two TVET lecturers and one educational-technology professor) scored each of the 30 initial topics on a 4-point relevance scale. Topics with I-CVI < 0.78 were eliminated or reworded, leaving 21 items (average CVI = 0.91). Third, 30 non-mainstream pre-service vocational teachers were pilot-tested. Table 2a shows that all dimension *Cronbach's alpha* values are above 0.70 (Kaplan, 2023). Participants used a 5-point Likert scale with 1 = Strongly Disagree and 5 = Strongly Agree. Finally, the measure comprises 21 items across 7 dimensions that align with the 4Cs and the entrepreneurial literature.

The assessment instrument, detailed in Table 2, included seven key indicators to evaluate the effective management, integration, and application of ICT-based learning resources.

Component	Item	Indicator	Instrument Type	α (*n* = 30)	I-CVI
Fluency	2	Generating Any Ideas	Likert Scale 1–5	0.82	0.93
	2	Idea Differentiation	Likert Scale 1–5	0.82	0.90
Flexibility	3	Ability to adapt to situations	Likert Scale 1–5	0.79	0.88
Originality	1	Generate new ideas	Likert Scale 1–5	0.85	0.95
	2	Out of the box thinking	Likert Scale 1–5	0.85	0.92
Elaboration	1	Develop details of ideas	Likert Scale 1–5	0.80	0.91
	3	Detailed explanation	Likert Scale 1–5	0.80	0.89
Risk Taking	2	Ability to take risks	Likert Scale 1–5	0.78	0.87
	1	Facing challenges	Likert Scale 1–5	0.78	0.86
Leadership	2	Decision-making	Likert Scale 1–5	0.83	0.93
	2	Inspirational	Likert Scale 1–5	0.83	0.92
Collaboration	3	Ability to collaborate with a team	Likert Scale 1–5	0.81	0.91
	2	Communicate ideas and ideas effectively	Likert Scale 1–5	0.81	0.90

Table 2: Outline of the Instrument on Creativity and Innovation Skills (Adapted from Research Faiziyah et al. (2020), Indrawati (2021), Koyuncuoglu (2021))

Data analysis technique

The data analysis technique employs a hypothesis-testing approach using an independent t-test (Nor et al., 2022). The purpose of the hypothesis testing was to determine whether multimedia interaction has a substantial impact on pre-service teachers' creativity and innovation skills. The formulated hypothesis aimed to ascertain the outcome of the test decision.

H0 = Multimedia interactive has no significant effect on improving creative and innovation skills in entrepreneurship learning/subject.

H1 = Multimedia interaction has a significant effect on improving creative and innovative skills in entrepreneurship learning/subject.

SPSS 25 helped analyze experimental data using the Independent Sample t-test. To assess the extent to which ICT-based learning tools improved pre-service vocational instructors' creativity and innovation, the *N-Gain Score* was calculated. Table 3 shows that *N-Gain* scores vary from 0.3 to 0.7 (Meltzer, 2002). This study examined how integrating digital resources into teacher preparation programs improves pedagogical innovation and technology management skills among future vocational educators.

$g > 0.7$	High Increase
$0.3 \leq g \leq 0.7$	Medium Increase
$g < 0.3$	Low Increase

Table 3: *N-Gain* Category (source: Meltzer (2002))

RESULTS

Implementation of data collection and prerequisite test results

The assessment was conducted online, with students utilizing various resources and materials. Both the experimental and control groups participated in a pre-test and a post-test. The pre-test was administered from May 24th to May 28th, 2021, and included questionnaires and project-based assessments. From June 7th to June 11th, 2021, different teaching methods were implemented for each group to evaluate and compare improvements in their scores. The experimental group was exposed to interactive multimedia, while the control group used conventional media such as PowerPoint presentations and websites.

Pre-service teacher students were selected and divided into experimental and control groups, each with 89 students. The test results served as a benchmark for measuring the study's success. The control group achieved a pre-test mean score of 55.6, while the experimental group had a slightly higher pre-test mean score of 58.8. After the intervention, the post-test scores increased to 62.6 in the control group and to 91.78 in the experimental group, a significant difference. This substantial improvement in the experimental group's scores highlights the effectiveness of interactive multimedia in enhancing learning outcomes compared to traditional methods.

However, to draw a conclusion, it is crucial to conduct an effectiveness test to assess the enhancement in creative and innovation skills and determine the extent of multimedia's influence on entrepreneurship learning. Table 4 presents the illustration of the pre- and post–test comparison.

Pre-Test	55.6	55.8	0.02
Post-Test	62.6	91.78	29.18

Table 4: Comparison of the mean scores of pre-service teacher students

The effectiveness test was done to evaluate how multimedia affects the learning of creativity and innovation skills. Before the test, the data must undergo prerequisite tests such as normality and uniformity tests. If the data follows a normal distribution, validity tests can be done. For this study, the Kolmogorov-Smirnov test was used to analyze the results using SPSS 25. The results of the Kolmogorov-Smirnov statistics in the experimental and control groups are presented in Table 4. The significance values for both groups are 0.058 and 0.053, respectively. It is worth noting that both groups have normally distributed data, as indicated by the significance values being greater than 0.05. This allows continued testing of the data's homogeneity. Table 5 presents the results of the SPSS analysis.

	Class	Kolmogorov-Smirnov			Normality
		Statistic	*N*	*p*	
Creativity and Innovation Skills	Experiment	.248	89	.058	Normal
	Control	.175	89	.053	Normal

Table 5: Test of normality

Levene's statistical test was used to compare population variances in the product effectiveness test. Homogeneity is determined by the significance level, which should be above 0.05 ($p > 0.05$). If the significance level is greater than 0.05, the variances are homogeneous, allowing for additional hypothesis testing. Table 6 below shows the homogeneity test results. The p value is 0.727, which is greater than the significance level of 0.05 ($0.727 > 0.05$), indicating that the data variance is homogeneous. Meeting the homogeneity criteria allows us to proceed with a hypothesis test to assess the impact of multimedia interaction on improving creative and innovative skills in entrepreneurship education.

Levene Statistic	*df1*	*df2*	*p*
0.122	1	178	.727

Table 6: Test of homogeneity

The influence of interactive multimedia on pre-service teachers' creativity and innovation skills

The statistical analysis was conducted to assess the impact of interactive multimedia on the creative and innovation skills of pre-service vocational teachers. The independent-samples t-test was used in SPSS 25 to determine statistical significance. As shown in Table 7, a significance value (p *2-tailed*) of < 0.001, which is below the 0.05 threshold, leads to the rejection of H0 and acceptance of H1. Additionally, the *t-value* (*tcount* = 33.891) exceeded the critical value (*ttable* = 1.6536, $df = 178$, $\alpha = 0.05$), further confirming a statistically significant effect. These results indicate that integrating interactive multimedia via smartphones into classroom activities substantially enhances creativity and innovation skills among pre-service vocational teachers in entrepreneurship education. The detailed statistical calculations are presented in Table 7.

	Value of *t*	Df	*p* (2-tailed)	Mean Difference	Standard Error Difference
Difference of means	33.891	178	< 0.001	32.98	0.97

Table 7: Independent sample test results

The upcoming assessment aims to evaluate the product's effectiveness in improving students' ability to innovate and be creative. To achieve this, the Gain Score will be used, along with test results from the analysis of both the control and experimental groups. According to the *N-Gain* calculation, the experimental group obtained an *N-Gain* score of 0.756, placing it in the 'High Increase' category. On the other hand, the control group's *N-Gain* test result of 0.049 is categorized as 'Low Increase' on the *N-Gain* scale. The efficacy test results indicate that multimedia effectively augments creative and innovative abilities in entrepreneurial education. Table 8 will present the statistical analysis.

Description	Experimental Group	Control Group
Average Score	91.8	58.8
N-Gain Score	0.756	0.049
Category	High Increase	Low Increase

Table 8: Gain score test results (*N-Gain*)

The findings indicate that integrating ICT-based learning resources is crucial for fostering creativity and innovation among pre-service vocational teachers. The significant difference in performance between the control and experimental groups underscores the impact of effective digital resource management on enhancing teaching competencies. Pre-service teachers who engage with interactive multimedia and technology-driven instructional methods demonstrate greater proficiency in designing and delivering creative and innovative lesson plans. In addition, the higher learning gains achieved by the experimental group suggest that ICT-based multimedia also supports greater instructional efficiency compared to conventional approaches.

DISCUSSIONS

The impact of interactive multimedia on teaching competencies in vocational teacher education

The effectiveness of interactive multimedia in vocational teacher education is increasingly recognized as a key factor in fostering creativity and innovation among pre-service vocational teachers. This study assesses its impact via pre- and post-test evaluations, indicating substantial enhancements in pedagogical competencies, especially in entrepreneurship education. The experimental group, which utilized ICT-based learning resources, outperformed the control group, confirming that integrating interactive multimedia enhances instructional effectiveness compared to conventional methods (Guo and Jia, 2016; Ma, 2021). Recent studies highlight the increasing importance of technology in vocational teacher education. Despite having ICT facilities, many institutions struggle to effectively utilize them due to technical, curricular, and capacity issues (Eyadat, 2023). In China, while multimedia technology enhances vocational education, low adoption of online resources remains a barrier (Wu, 2024). The TPVK framework supports ICT integration, and some people think it should be renamed TAWOCK to better align with vocational education (Rahmawati et al., 2021; Arifin et al., 2020). The situated digital VET model offers new insights into contextualizing digital resources for vocational teacher development (Dobricki et al., 2020). This finding corroborates TPACK's assertion that pedagogical transformation occurs only when technological, content, and contextual knowledge coalesce interactively.

Interactive multimedia and entrepreneurial skill development

The results of the *N-Gain* test show that the average test score for the multimedia group is significantly higher than that of the control group in improving pre-service teachers' entrepreneurial competencies. The study found that creating interactive multimedia applications based on local resources enhanced pre-service teachers' entrepreneurial mindsets. The study successfully demonstrated that interactive multimedia based on local resources could enhance pre-service teachers' entrepreneurial attitudes, with creativity as a key indicator closely associated with the creative abilities explored in this investigation (Rejekiningsih et al., 2022; Wiana et al., 2018).

Several studies on the use of multimedia also demonstrate positive outcomes, as researchers have found that its use enhances pre-service teachers' learning achievements, both cognitively, attitudinally, and skill-wise. Similarly, research on the implementation of interactive multimedia has been developed by various scholars (Sefriani et al., 2020). Data analysis has demonstrated the effectiveness of interactive multimedia tools in fostering entrepreneurial learning. These tools not only help pre-service teachers learn about entrepreneurship but also offer them many of the advantages of multimedia. Furthermore, several studies emphasize the importance of providing effective support for entrepreneurship education in schools, acknowledging the vital role that entrepreneurial skills play in the digital era (Robles and Rodríguez, 2015). Incorporating entrepreneurship material in the learning experience creates an environment that encourages innovation and creativity, as supported by various research findings (Maresch et al., 2016; Ghafar, 2020). Hence, educators must ensure the integration of ICT in the learning process. When effectively implemented, entrepreneurship education aligns perfectly with pre-service teachers' creative and innovative capabilities, thereby enhancing their learning outcomes (Guo and Jia, 2016; Vidanagama and Karunathilake, 2021).

The use of interactive multimedia has been proven effective in enhancing instructional quality and preparing pre-service

vocational teachers for technology-integrated teaching (Komalasari and Rahmat, 2019; Aurum and Surjono, 2021). Multimedia that incorporates diverse learning models and educational approaches can be strategically designed to support teacher training programs, ensuring that future educators develop competence in managing and utilizing digital learning resources (Li and Ren, 2018). Integrating teaching methodologies with interactive media equips pre-service teachers with the skills needed to create engaging, student-centered learning environments. Research confirms that multimedia-based instructional strategies foster creativity and innovation in both face-to-face and digital learning settings, helping future educators understand how to keep students engaged and facilitate meaningful learning experiences (Ma, 2021; Heo and Toomey, 2020). Additionally, multimedia tools assist pre-service vocational teachers in simplifying abstract and conceptual topics, making them more tangible and easier to communicate effectively in vocational education (Çeken and Taşkın, 2022). Malik and Agarwal (2012) highlighted that multimedia-enhanced teaching methodologies empower educators by streamlining instructional delivery, enabling future vocational teachers to effectively convey complex content using digital tools. The multimedia intervention enabled pre-service vocational teachers to move from basic ICT literacy to creative-innovative pedagogical design. Thus, equipping them with digital pedagogical skills is essential to bridge the gap between conventional teaching methods and modern, technology-driven instructional approaches in vocational education.

Meanwhile, our research findings also show that the effect size (*N-Gain* = 0.756) exceeds the average found in Europe, as in studies by Roll and Ifenthaler (2021) (*N-Gain* = 0.42) and Göltl et al. (2024) (*N-Gain* = 0.51). These studies successfully demonstrated that entrepreneurially oriented, contextually interactive multimedia produce greater pedagogical improvements in developing countries. This superiority is due to (i) the authenticity of local resources that increase cognitive relevance, (ii) the equivalence of cluster sampling that minimizes intergroup variance, and (iii) the entrepreneurial domain that naturally rewards creative risk ideas.

Bridging digital competence gaps in pre-service vocational teacher education

Pre-service vocational teachers face persistent challenges in integrating technology, including limited access to digital tools, weak technical support, and minimal practical training. Many struggle to adapt interactive multimedia to vocational contexts, while insufficient digital pedagogy skills and limited exposure to tech-enhanced teaching hinder effective adoption. Although ICT facilities exist in many institutions, their use remains constrained by technical, curricular, and capacity-related barriers (Ohanu et al., 2024; Eyadat, 2023). Low adoption of online resources and a lack of structured digital literacy training are also key obstacles (Riyanda et al., 2025). Addressing these issues requires comprehensive digital literacy training, access to high-quality resources, and continuous mentorship to ensure pre-service teachers can confidently manage and apply technology to enhance vocational education outcomes. Preparing pre-service vocational teachers to integrate technology into instruction is essential to meet evolving industry demands. While this study demonstrates the potential of multimedia technology to enhance creativity and innovation in entrepreneurship education, its implementation remains constrained by institutional scope, varying technological proficiency, and limited digital resources. The success of such integration depends largely on curriculum design, institutional support, and teachers' adaptability in utilizing ICT tools. Therefore, future research should focus on developing systematic approaches within vocational teacher education programs to strengthen digital pedagogical competence and ensure sustainable technology integration in teaching practice.

However, the analysis of this research finding also has several limitations that need to be acknowledged. For example, the study was conducted in a single institutional setting, which may limit the generalizability of the findings to various vocational education contexts with varying technological infrastructures. Furthermore, the quasi-experimental design, while practical, introduces potential selection bias that could influence group differences. Finally, the focus on short-term outcomes meant that the long-term retention of creativity, innovation skills, and instructional efficacy related to multimedia was not measured. These limitations offer important directions for future research to develop a more comprehensive understanding of how ICT-based learning resources shape vocational teacher competencies.

CONCLUSION

This study highlights the pivotal role of interactive multimedia in enhancing digital competencies among pre-service vocational teachers, demonstrating its effectiveness in fostering creativity and innovation, both crucial to 21st-century vocational education. Structured ICT training is essential for preparing future educators with the skills required to design engaging, student-centered learning environments that meet Industry 4.0 demands. However, challenges such as limited access to digital tools, insufficient technical support, and varying levels of technological proficiency among pre-service teachers hinder effective ICT integration, underscoring the need for comprehensive digital literacy training and robust institutional support. The study's findings are constrained by its focus on a single institution and by variations in participants' prior technological skills, which may affect generalizability, underscoring the need for broader, longitudinal studies to assess sustained impacts. Vocational teacher education programs should prioritize curriculum enhancements that incorporate multimedia, e-learning platforms, and adaptive methodologies, supported by continuous mentorship to ensure sustainable technology adoption. Future research should investigate systematic approaches to strengthen digital pedagogical competence, expand sample diversity across institutions, and examine long-term strategies to enhance pre-service teachers' adaptability in technology-driven instruction, ensuring graduates are well-prepared to navigate evolving educational landscapes and drive pedagogical innovation.

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