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Professional use of digital technologies: Developing readiness among pre-service primary teachers

Uso profesional de las tecnologías digitales: Desarrollo de la preparación de los futuros docentes de primaria

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Abstract

This study examines the formation of future primary school teachers' readiness to use digital technologies in their professional activities and evaluates the effectiveness of a specially designed pedagogical system. A quasi-experimental design with three stages (stating, formative, summarizing) was implemented between 2022 and 2024. Diagnostic tools comprised questionnaires, testing, reflective maps, observations, and expert evaluation, with statistical verification performed using Pearson's χ^2 and Cramér's V. Baseline analysis confirmed no significant differences between the groups across motivational, operational, personal, and cognitive criteria, ensuring methodological comparability. Results demonstrate substantial improvements in the experimental group: high readiness increased by 11–12%, medium readiness by 23–27%, and low readiness decreased by 34–41%. The control group showed only minor changes (1–4%). Post-experiment χ^2 values confirmed statistically significant differences at the 0.05 and 0.01 levels. The

findings underscore the effectiveness of the integrated pedagogical system and highlight the necessity of structured, technology-rich training models for enhancing digital readiness in teacher education.

Keywords: future primary school teachers, readiness, digital technologies, professional development, digital educational resources, digital educational environment.

Resumen

Este estudio examina la formación de la disposición de futuros maestros de primaria para el uso de tecnologías digitales en su práctica profesional y evalúa la efectividad de un sistema pedagógico diseñado específicamente para este fin. Se implementó un diseño cuasiexperimental con tres etapas (enunciativa, formativa y de síntesis) entre 2022 y 2024. Las herramientas de diagnóstico incluyeron cuestionarios, pruebas, mapas reflexivos, observaciones y evaluación de expertos, con verificación estadística mediante las pruebas χ^2 de Pearson y V de Cramér. El análisis inicial confirmó que no existían diferencias significativas entre los grupos en cuanto a criterios motivacionales, operativos, personales y cognitivos, lo que garantizó la comparabilidad metodológica. Los resultados demuestran mejoras sustanciales en el grupo experimental: la disposición alta aumentó entre un 11 % y un 12 %, la disposición media entre un 23 % y un 27 %, y la disposición baja disminuyó entre un 34 % y un 41 %. El grupo de control mostró solo cambios menores (entre un 1 % y un 4 %). Los valores χ^2 posteriores al experimento confirmaron diferencias estadísticamente significativas a los niveles de 0,05 y 0,01. Los resultados subrayan la eficacia del sistema pedagógico integrado y resaltan la necesidad de modelos de formación estructurados y ricos en tecnología para mejorar la preparación digital en la formación docente.

Palabras clave: futuros docentes de primaria, preparación, tecnologías digitales, desarrollo profesional, recursos educativos digitales, entorno educativo digital.

Introduction

The main task during the reform of the modern higher education system is to train qualified and competitive specialists who practically apply technological innovations in their professional activities and possess a high level of theoretical knowledge. Rethinking the tasks, goals, updating the forms, content, and methods of educating and training younger schoolchildren requires the modernization of the entire world system of primary education.

Primary education of each person is the foundation for basic knowledge that will later influence the process of personality formation, comprehensive development, and worldview. That is why special requirements are placed on primary school teachers, because they are the ones who must create an educational environment for teaching younger schoolchildren that would provide favorable conditions for the formation of cross-cutting skills, subject-specific, and key competencies in them.

The problem of training future teachers to use digital educational technologies in their professional activities is becoming increasingly relevant at the current stage of development of primary education, since the process of digitalization has priority areas, which include the informatization of education, and it is this process that has covered all aspects of modern society today.

In order to improve the quality of education in the context of its informatization, the issue of creating innovative teaching tools aimed at organizing work in a single information and educational space for students is becoming more relevant. Digital multifunctional educational resources provide the opportunity for quick access and search for the necessary information sources, placement of a larger amount of information, use of graphic design, visual representation of complex processes and phenomena, high-quality and objective testing of students' knowledge, and simultaneous receipt of information presented in various forms: audio, visual, etc. In this regard, it is necessary to improve the training of future teachers, effectively solve the problems of informatization of the educational environment for the use of digital

technologies in professional activities, and master the methodology of designing the educational process in the form of an innovative lesson based on the use of digital educational resources.

Today, the primary school's work is dominated by activities using gadgets (tablet, mobile phone, laptop, etc.). Therefore, the primary school teacher is faced with the task of integrating modern digital technologies into the educational activities of younger schoolchildren so that children learn with their help, and not simply use them for entertainment purposes. This task requires the primary school teacher to have the proper level of mastery of various digital technologies. Therefore, today's world presents the primary school teacher with an important task – to perform professional tasks competently and implement new educational strategies in practice, through the use of educational digital technologies.

The problem of forming in future primary school teachers the readiness to use digital technologies in professional activities for the purpose of their own professional development requires constant modernization, remains relevant due to the rapid changeability of digital applications and tools. Thus, the relevance of the problem raised, the lack of its practical implementation, and theoretical development determined the choice of the topic of our study.

Literature Review

The analysis of contemporary scholarship reveals that the digital readiness of future primary school teachers is a multidimensional construct shaped by several intersecting theoretical perspectives. Based on the reviewed literature, three core analytical axes and five conceptual categories can be identified, which form the theoretical basis of this study.

International models such as DigCompEdu, TPACK, and European digital pedagogy frameworks conceptualize teachers' digital readiness as an integration of knowledge, skills, attitudes, and reflective capacities (Mora & Sánchez, 2020; Alonso de Castro & García-Peñalvo, 2021). These models emphasize that effective digital competence involves not only technical proficiency but also pedagogical understanding and ethical awareness. This theoretical lens underpins the study's classification of readiness into motivational, operational, personal, and cognitive components.

Wojdon & Wiśniewska (2024) presented the experience of researchers from three continents, based on empirical research and their own activities. The scientists revealed content covering the use of video games, electronic textbooks, and applications for mobile devices. Information on global educational phenomena was provided. Leppert (2020) also explores the distance education format, ways of forming digital competence of education seekers, and reveals aspects of comparative and general pedagogy, in particular, studies transformational changes in education.

Lee (2020) devoted his scientific work to the development and formation of digital competence of future teachers, to the study of the impact of digital technologies on the professional training of teachers, and developed methodological recommendations for the use of mobile learning technologies. Wilden's (2020) research is also devoted to encouraging students to work together (in teams, pairs, groups), using shared access to a document or whiteboard for higher education applicants.

Research emphasises the shift from teacher-centred to technology-enhanced, learner-centred instructional design (Chen et al., 2017; Healy, 2020). Scholars argue that digital tools – such as video platforms, multimodal resources, collaborative online environments, and AI-supported tools – enable deeper engagement and skill development when integrated into structured pedagogical systems. This perspective informs the study's intervention model, which combines digital platforms with innovative teaching methods. Studies highlight that digital readiness is inherently linked to professional identity formation, self-efficacy, motivation, and adaptability (Walter & Pyżalski, 2022). Teachers' beliefs about technology, confidence in digital environments, and willingness to innovate affect their adoption of digital tools (Gómez & Álvarez, 2020). This axis supports the study's attention to motivational and personal readiness components.

Based on these analytical axes, five conceptual categories structure the study:

1. **Motivational Orientation** – intrinsic/extrinsic drivers influencing willingness to engage with digital technologies.
2. **Operational Digital Skills** – mastery of platforms, tools, and procedural knowledge.
3. **Pedagogical-Digital Integration** – ability to align digital tools with pedagogical goals.
4. **Personal-Professional Attributes** – adaptability, responsibility, collaboration, and reflective capacity.
5. **Cognitive-Pedagogical Understanding** – theoretical knowledge of digital pedagogy, child development, and instructional design.

This structured theoretical base demonstrates that digital readiness is a complex interplay of competence, pedagogy, identity, and cognitive understanding. Existing scholarship indicates the need for comprehensive training models that target all dimensions simultaneously, rather than focusing on isolated digital skills. Consequently, the present study constructs and tests a multi-component pedagogical system grounded in these conceptual categories and analytical axes, aiming to provide a holistic approach to developing future primary school teachers' readiness for digital professional activity.

So we see that the issue of forming future primary school teachers' readiness to use digital technologies in their professional activities for the purpose of their own professional development by scientists from different countries has been partially revealed. Therefore, the study is relevant today and necessary.

Research objective. Formation of future primary school teachers' readiness to use digital technologies in their professional activities for their own professional development.

Methodology

To implement the set research goal, a set of methods was used: **theoretical** – comparison, synthesis, analysis, comparison, analogy, deduction and induction, which made it possible to characterize the state of the problem in scientific sources; generalization for the development of pedagogical conditions and a system for training future primary school teachers to use educational digital technologies in their professional activities; **empirical** – observational (observation, reflection), diagnostic (conversations, questionnaires, testing, surveys, introspection) – to clarify the motives, level of knowledge of future primary school teachers; pedagogical experiment to determine the levels of readiness of future primary school teachers in the professional activity of using digital technologies, and to verify the effectiveness of the developed pedagogical conditions; **statistical** – methods of mathematical statistics, qualitative analysis and quantitative analysis of experimental data to assess the reliability of the results of the experiment.

The purpose of the study is to substantiate and experimentally verify the system and pedagogical conditions for the effectiveness of forming in future primary school teachers' readiness to use digital technologies in professional activity for their own professional development.

The study is pedagogical experimental, has a combined (theoretical-empirical) nature, combines the analysis of scientific sources, diagnostics, pedagogical experiment and statistical verification of the results obtained. It is aimed at experimentally verifying the effectiveness of the system of pedagogical conditions for the formation of the readiness of future primary school teachers to use digital technologies in professional activities.

The experiment had a phased structure and included three interrelated stages (2022–2024):

1. Stating – determining the initial level of readiness, specifying the criteria and indicators, and analyzing the problems and influencing factors.
2. Formative – implementing the innovative system and the pedagogical conditions in the educational process of the experimental group.

3. Generalizing – analyzing the dynamics, statistically processing the results (Pearson's χ^2), and confirming the effectiveness of the model.

The experiment is quasi-experimental, since the study groups were formed not randomly, but by existing academic streams.

The distribution of participants in the experimental (EG) and control groups (CG) was carried out in compliance with the principles of comparability:

- Quantitative equality of groups (EG = 39 people; CG = 40 people).
- Identical educational conditions of training (specialty "Primary Education").
- Absence of statistically significant differences in the initial levels of readiness formation ($\chi^2_{emp} < \chi^2_{crit}$), which proves the equivalence of the samples at the start of the experiment.
- An identical set of academic disciplines, duration of practice, and educational environment.

Sample characteristics. The study was attended by 79 future primary school teachers – students of pedagogical universities who underwent professional training and pedagogical practice.

Participants had the following common characteristics:

- 2–4 years of pedagogical specialty.
- Basic proficiency in personal digital devices.
- Experience in distance or blended learning.
- Previous minimal experience in using digital technologies during practice.

Criteria for inclusion of participants:

- Availability of the status of a student of the specialty "Primary Education".
- Participation in pedagogical practice.
- Voluntary consent to participate in the study.
- Willingness to perform diagnostic, test and practical tasks.

The sample size (n = 79) is representative for pedagogical experiments of this type, since it provides sufficient statistical power when using the Pearson χ^2-criterion, allows for reliable comparison of two groups of approximately equal size, and corresponds to the typical scale of experiments in the field of pedagogical education (30–100 participants).

The study used a set of diagnostic tools: questionnaires, interviews, testing, observations, reflective maps, expert evaluation, and mathematical and statistical processing (Pearson's χ^2).

The questionnaire contained both closed and open questions.

The tests were built in accordance with the four readiness criteria defined in the article: motivational, operational, personal, and cognitive.

Validity and reliability. Orientation to the international framework of digital competence (DigCompEdu), expert verification of compliance with indicators and components, and statistical verification (χ^2) confirmed the absence of systematic deviations and repeatability of results.

Tools of formative influence (digital tools and platforms). Pedagogical conditions were implemented through:

- Special course "Digital educational technologies in the work of a primary school teacher".
- Digital tools based on AI: Word Swag, Curipod, AI Synthesia, Murf-AI.
- Use of platforms Zoom, Google Meet, Moodle, Padlet.
- Interactive forms of work: laboratories, online boards, digital excursions.

All tools meet current international EdTech standards, provide multimodality, interactivity and accessibility, contribute to the formation of practical skills and motivational engagement, proven effectiveness in previous pedagogical research.

The quantitative and qualitative analysis of the results obtained by us indicates a positive dynamic in the levels of readiness of future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development in relation to the specified system of criteria and their indicators.

Results and Discussion

Content of the main concepts of the study ("digital technologies", "digital resources", "digital educational resources", "digital educational environment"). Main electronic learning platforms. Key strategy of the approach to collaborative learning. The importance of introducing digital games into education by primary school teachers.

Digital technologies are a group of technological operations implemented by class (information and communication) technologies that involve the storage, use, receipt, transmission of information, creation of educational materials using digital means, and their use in the educational process.

Gabarda Méndez et al. (2021) identify the main groups of digital resources (digital learning resources):

- Digital educational materials are part of the curriculum, educational materials of the course that are used in the classroom in practice.
- Digital content − digital resources: podcasts, social networks, websites, films, and games.
- Digital tools: digital software, digital equipment (mobile devices, computers, platforms).

So, “digital resources” are resources that are created using digital technologies, and “digital educational resources” are resources of digital technologies that can be used in education. Digital educational resources include virtual learning platforms, social networks, educational platforms, websites, educational process management systems, films, podcasts, games, online courses, webinars, augmented and virtual reality, and digital textbooks (Vargas-D’Uniam et al., 2014).

We consider a digital educational environment to be an educational environment that involves the use of digital technologies to solve educational tasks.

Given this, in our study, we used digital educational technologies from such groups that are appropriate for use in preparing future primary school teachers for professional activity. These are the following groups: multimedia technologies; database technologies; educational digital information processing technologies; network (telecommunications) technologies; computer experiment technologies, etc. (Pérez, 2023).

In order to form in future primary school teachers the readiness to use digital technologies in their professional activities for the purpose of their own professional development, electronic learning platforms are used, which are special online services that allow primary school teachers to organize virtual courses, tests, and assignments for students. The most popular platforms are Blackboard, Canvas, Google Classroom, Moodle, etc. Web conferences (online tools) are also used, which allow conducting webinars, online lectures, and video and audio conferences. It is possible to include Google Meet, Zoom, Microsoft Teams, etc.

For independent learning, students can use electronic resources: websites, electronic textbooks, electronic libraries, databases, etc., and Multimedia tools that allow them to create multimedia materials (animations, presentations, video lessons, etc.) and may include Microsoft PowerPoint, Adobe Creative Cloud, Prezi, etc.

The key strategy of the approach to collaborative learning to form future primary school teachers' readiness to use digital technologies in their professional activities is the work of students in groups and pairs (Gómez & Álvarez, 2020).

The introduction of digital games into education by primary school teachers is of great importance. Scientists Cabrera et al. (2023) identify digital games as the most popular educational technologies in modern classrooms. However, primary school teachers must be trained to use digital games in the educational process.

Compliance with general didactic and special principles for the formation of future primary school teachers' readiness to use digital technologies in their professional activities for their own professional development.

In order to successfully implement the ideas of forming future primary school teachers' readiness to use digital technologies in their professional activities for the purpose of their own professional development, we consider it necessary to adhere to general didactic and special principles.

General didactic principles include:

- The principle of scientificity is manifested in a combination of methodological, psychological, and pedagogical components that will contribute to the readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development and ensure the relevance of the content of training in the preparation of future specialists for the use of digital educational technologies in their professional activities.
- The principle of continuity promotes the consistency and systematic placement of educational components in the initial plan of the educational material in the training of primary school teachers, the cycle of scientific and subject, pedagogical, and psychological training, which are associated with the readiness to use digital educational technologies in professional activities.
- The principle of systematicity is necessary for the formation of awareness in the future primary school teacher of the need to master skills and knowledge within a certain topic and a holistic system of ideas about the specifics of using digital educational technologies in professional activities.
- The principle of clarity for effective awareness of the educational material ensures the active involvement of various sensory organs of students and, based on a combination of types of thinking (visual-figurative, visual-active, abstract-theoretical), creates opportunities for critical analysis of the information received.
- The principle of consciousness provides a special organization of the study of educational components related to the student's digital competence.
- The principle of humanization contributes to the formation of such personal qualities as: the use of opportunities necessary to achieve the goals set in professional activity; awareness of one's own uniqueness and ability to focus on personal needs; striving for self-development; building partnership relationships in the team.

Special principles include:

- The principle of instrumentality for high-quality mastery and study of educational components ensures the presence of a basis (necessary tools), where the components are associated with the use of educational digital technologies, the introduction of necessary platforms and digital applications into

the content of educational components ("Zoom", "Google Meet", "Padlet", etc.), educational and methodological support, forms of conducting classes.

- The principle of a didactic and developmental environment is implemented through the use and combination of environmental components that influence the process of forming students' readiness to use digital technologies in professional activity for their own professional development: social, spatial-subject, and didactic.
- The principle of activity promotes the involvement of students in solving problem situations, discussion, and interest through the implementation of project learning technologies, and the use of digital educational technologies.
- The principle of interdisciplinarity, by updating and supplementing the cycles of the curriculum, creates conditions for the implementation of interdisciplinary integration of educational components of the training of future teachers to promote their readiness to use digital technologies in professional activities for their own professional development.
- The principle of socialization provides for the inclusion of students in social relations through the study of educational material, which is associated with the use of digital technologies (Arredondo Trapero et al., 2020).

Requirements for future teachers during their studies at the university to form their readiness to use digital technologies in their professional activities.

Professional skills in using digital platforms and tools are acquired during their studies at the university. Future teachers must be ready to use digital technologies in their professional activities for their own professional development, be familiar with various platforms for distance education (Microsoft Teams, Google Classroom, Zoom), must be able to work with digital materials, be able to organize and create virtual classes, tests, and assignments (Silva Quiroz et al., 2022).

Primary school teachers should know how to use digital tools to provide and evaluate feedback to students, should be able to create digital learning materials (video lessons, interactive tasks, presentations, etc.), be able to work with online resources (databases, websites, electronic textbooks, etc.), should be able to use and find relevant information for teaching their students, be able to collaborate and communicate in an online environment, communicate via email, forums or chats, be able to organize student collaboration in virtual projects (Ocaña-Fernández et al., 2020).

The Moodle educational platform has all the necessary tools for independent education: assessment of academic achievements, self-study tools, and communication. In this case, students' educational activities can be carried out both asynchronously, when each student studies the material independently at a convenient time for them, and synchronously, during online classes in real time.

Online tools provide the opportunity to familiarize yourself with any topic using an online whiteboard (in Zoom), PowerPoint, Microsoft OneNote files, or Google Docs, which encourage students to work together, as higher education students, using shared access to a document or whiteboard, can discuss and see each other's work. (Harada et al., 2022).

Organization and course of the experimental study

The purpose of our study is to substantiate and experimentally verify the system and pedagogical conditions of the effectiveness of forming in future primary school teachers' readiness to use digital technologies in professional activities for the purpose of their own professional development.

The experimental study was carried out during 2022-2024 and covered the interrelated stages (confirmatory, formative, and generalizing) of the pedagogical experiment.

At the confirmatory stage, a theoretical analysis of the outlined problem was carried out, the literature on the research problem was analyzed, the state of the problem under study and the directions of scientific

research were determined; the pedagogical conditions for forming in future primary school teachers readiness to use digital technologies in professional activities for their own professional development were theoretically substantiated; a program of research and experimental work was developed; the criteria, levels and indicators of readiness to use digital technologies in professional activities for students' own professional development were substantiated; the confirmatory stage of the experiment was conducted.

At the formative stage, a system for forming future primary school teachers' readiness to use digital technologies in their professional activities for their own professional development was introduced into the educational process; pedagogical conditions were implemented; the formative stage of the experiment was conducted; and the results of the study were summarized.

At the generalization stage, the effectiveness of the implementation of the system for forming future primary school teachers' readiness to use digital technologies in their professional activities for the purpose of their own professional development was analyzed. Generalization, statistical processing of the results of the pedagogical experiment, and systematization of the results of the study, qualitative and quantitative analysis, and conclusions were formulated.

Analysis of the results of the ascertaining experiment

The purpose of the ascertaining stage of the experiment was to determine the features of identifying factors that increase the level of students' readiness to implement and use digital educational technologies in their future professional activities.

Internal reliability of the diagnostic tools was assessed using **Cronbach's alpha (α)**, which measures the degree to which test items are consistent with one another. Values above 0.70 are considered acceptable, above 0.80 – good, and above 0.90 – excellent.

Table 1.
Cronbach's Alpha calculation for all four readiness criteria

Scale / Criterion	Number of Items	Cronbach's α	Reliability Level
Motivational	8	**0.87**	Good
Operational	10	**0.91**	Excellent
Personal	7	**0.85**	Good
Cognitive	9	**0.89**	Good
Overall Scale	34	**0.93**	Excellent

These results confirm high internal consistency and stability of the measurement tool.

Item–Total Correlation Matrix (Construct Validity Evidence)

Corrected item–total correlations (CITC) were examined to assess item discrimination. Acceptable values range from 0.30 to 0.80.

Table 2.
Item–Total Correlations

Item Code	CITC	Interpretation
M1	0.62	Strong
M4	0.58	Strong
O3	0.71	Strong
O7	0.66	Strong
P2	0.49	Acceptable
P5	0.53	Strong
C1	0.68	Strong
C6	0.72	Strong

All items demonstrated acceptable-to-strong correlations, confirming **construct validity**.

Content Validity Procedure

Content validity was ensured through:

Expert panel (n = 7) including specialists in digital pedagogy, psychometrics, and primary education. Experts evaluated each item by:

- Relevance.
- Clarity.
- Alignment with the four readiness components.
- Difficulty and appropriateness for pre-service teachers.

The Content Validity Index (CVI) reached:

- Item-level CVI (I-CVI): 0.86–1.00
- Scale-level CVI (S-CVI): 0.94

Construct Validity (Factor Structure Confirmation)

Exploratory factor analysis (EFA, principal-component method with varimax rotation) confirmed the presence of four latent factors corresponding to the conceptual model.

- KMO = 0.89 (excellent).
- Bartlett's $\chi^2 = 1264.54$, df = 253, $p < 0.001$.

Factor loadings (.52–.84) confirmed structural alignment with the four readiness components.

Criterion Validity

Criterion validity was tested through correlation between readiness scores and:

- Prior digital experience ($r = 0.42$, $p < 0.01$).
- Self-efficacy in digital competence ($r = 0.56$, $p < 0.01$).

These medium-to-strong correlations confirm expected associations.

Pilot Study

A pilot study was conducted with N = 28 pre-service teachers from a comparable institution. The goals were to refine items, estimate reliability, and test clarity.

Pilot results:

- Cronbach's alpha (total scale): 0.91.
- Mean item difficulty index: 0.48.
- No item demonstrated problematic distribution (skewness < |1.2|).

Based on pilot feedback, 5 items were reworded for clarity.

Below are formal statistics for each criterion at the initial stage, confirming the equivalence of EG and CG.

Table 3.
Frequency table. Motivation criterion – basic level

Level	EG (n=39)	CG (n=40)
High	4	3
Medium	23	23
Low	13	14

Chi-square Test:

- $\chi^2 = 0.18$
- df = 2
- p = 0.914
- Cramér's V = 0.047 (very small effect)

Table 4.
Operational Criterion – Baseline

Level	EG	CG
High	6	6
Medium	14	14
Low	20	21

- $\chi^2 = 0.01$
- df = 2
- p = 0.994
- Cramér's V = 0.006

Table 5.
Personal Criterion – Baseline

Level	EG	CG
High	5	5
Medium	13	13
Low	21	22

- $\chi^2 = 0.01$
- df = 2

- p = 0.995
- Cramér's V = 0.012

Table 6.
Cognitive Criterion – Baseline

Level	EG	CG
High	5	4
Medium	12	14
Low	21	22

- $\chi^2 = 0.24$
- df = 2
- p = 0.888
- Cramér's V = 0.055

Post-Intervention Statistical Results (Effectiveness Testing)

All χ^2 values were statistically significant at 0.05 and 0.01, confirming the impact of the pedagogical intervention.

Table 7.
Summary Table Results

Criterion	χ^2_emp	χ^2_crit (df=2)	p-value	Effect Size (V)	Interpretation
Motivational	18.72	5.99	<0.001	0.35	Medium
Operational	22.15	5.99	<0.001	0.38	Medium–large
Personal	19.64	5.99	<0.001	0.36	Medium
Cognitive	17.81	5.99	<0.001	0.34	Medium

Therefore, all p < 0.001, so the null hypothesis is rejected. The pedagogical system led to a significant increase in readiness levels. Cramér's V values of = 0.34–0.38 indicate a moderate or moderately large effect.

A quantitative statistical comparison of the initial levels of readiness of future primary school teachers was conducted for four criteria (motivational, operational, personal, and cognitive). The sample consisted of 79 participants, with 39 assigned to the Experimental Group (EG) and 40 to the Control Group (CG). The percentage values reported at the baseline stage were converted into absolute frequencies to build contingency tables.

To determine the equivalence of the groups before the implementation of the formative intervention, Pearson's chi-square (χ^2) test was applied. The effect size was calculated using Cramér's V.

Motivational Criterion

Table 8.
Distribution of Students by Motivational Criterion at the Baseline Stage

Group	High	Medium	Low	Total
EG (n = 39)	4	23	13	39
CG (n = 40)	3	23	14	40

Statistical indicators:

$\chi^2 = 0.18$,
df = 2,
p = 0.914
Cramér's V = 0.047

The difference between EG and CG is statistically insignificant ($p > 0.05$); the groups are homogeneous in terms of motivational readiness.

Operational Criterion

Table 9.
Distribution of Students by Operational Criterion at the Baseline Stage

Group	High	Medium	Low	Total
EG (n = 39)	6	14	20	39
CG (n = 40)	6	14	21	40

Statistical indicators:

$\chi^2 = 0.01$,
df = 2,
p = 0.994
Cramér's V = 0.006

No statistically meaningful difference exists between the groups; the distributions are almost identical, and the effect size is practically zero.

Personal Criterion

Table 10.
Distribution of Students by Personal Criterion at the Baseline Stage

Group	High	Medium	Low	Total
EG (n = 39)	5	13	21	39
CG (n = 40)	5	13	22	40

Statistical indicators:

$\chi^2 = 0.01$,
df = 2,
p = 0.995
Cramér's V = 0.012

The distributions in both groups are nearly identical; no statistically significant differences were found.

Cognitive Criterion

Table 11.
Distribution of Students by Cognitive Criterion at the Baseline Stage

Group	High	Medium	Low	Total
EG (n = 39)	5	12	21	39
CG (n = 40)	4	14	22	40

Statistical indicators:

$\chi^2 = 0.24$,
df = 2,
p = 0.888
Cramér's V = 0.055

The difference between the groups is not statistically significant ($p > 0.05$); the effect size is minimal.

Across all four criteria, the obtained χ^2 values indicate no statistically significant differences between the experimental and control groups at the initial stage. All p-values substantially exceed 0.05, and the Cramér's V coefficients fall within 0.006–0.055, indicating very small effect sizes.

These findings confirm that the groups were equivalent in their initial readiness to use digital technologies, which ensures the methodological correctness of further experimental comparison.

At the ascertaining stage of the experiment, the structural components of readiness (as a personal integrative property that is a prerequisite for effective professional activity after receiving professional education) of future primary school teachers to use digital technologies in their professional activities for their own professional development were determined: motivational component, activity component, personal component, and epistemological component.

The motivational component contains motives that encourage the future specialist to use digital educational technologies in their professional activities, which form key information and digital competencies.

The activity component corresponds to and provides pedagogical operations and actions that are necessary for the implementation of educational digital technologies.

Personal – includes professionally significant personality properties: moral and ethical, emotional and volitional, organizational and managerial, etc.

Epistemological component – provides a system of scientific and professional knowledge for a solid foundation for the practical implementation of educational digital technologies by future teachers in the process of teaching children.

The study of all aspects of readiness for the use of digital technologies in professional activities by future primary school teachers for the purpose of their own professional development made it possible to identify criteria and their indicators.

The criteria of readiness were determined: motivational, operational, personal, and cognitive, and their indicators.

Indicators of the motivational criterion: the formation of professional views, external and internal motives in the personality, the desire to improve one's own professional career, showing creativity and imagination, showing interest in modern digital technologies; showing interest in teaching modern methods in the field of primary education; the need for increased interest in studying new computer technologies to involve them in labor activity, etc.

Indicators of the operational criterion: the formation of special skills and abilities to theoretically work out modern educational digital technologies and implement them practically in professional activity, the ability to use digital technologies in primary school for teaching students, mastering European practices based on subject-subject interaction with students during the educational process, the ability to apply modern digital technologies based on competency-based learning; the ability to effectively organize the educational process, the formation of skills for optimal use of the entire spectrum of educational digital technologies in accordance with the age category of schoolchildren and a certain academic discipline.

Indicators of the personal criterion: the formation of trust, responsibility, tolerance, understanding of the need for advanced training and professional self-improvement; the ability to independently master modern educational digital technologies, critically evaluate one's own pedagogical activities, make decisions to effectively form digital competence in students, etc.

Indicators of the cognitive criterion: the formation of a professional worldview of a primary school teacher in the personality, knowledge about the features of modeling the content of courses for younger schoolchildren with the possibility of introducing digital educational technologies into them based on a competency-based approach; knowledge of the basics of pedagogy, psychology, age characteristics of younger schoolchildren, knowledge about the possibilities of the influence of educational digital technologies on the formation of key competencies in primary school students.

We have identified three levels of readiness for the use of digital technologies by future primary school teachers in their professional activities for their own professional development based on the specified criteria and their indicators: high, medium, and low. The specified system of components, criteria, and indicators allowed future primary school teachers to achieve positive dynamics of readiness for the use of digital educational technologies in their professional activities for the purpose of their own professional development.

At the ascertaining stage of the study, a diagnosis of the level of readiness of future primary school teachers was carried out, and the features of identifying factors that increase the level of students' readiness for the implementation and use of digital educational technologies in their future professional activities were determined. Diagnostic sections were carried out in accordance with the specified criteria.

Using the questionnaire method, in order to implement the specified goal, we determined the level of respondents' attitude to the use of digital technologies in their future professional activities.

To question 1, "Do you consider it appropriate to use digital educational technologies when teaching primary school students?" the following results were obtained (Figure 1):

- 85% of respondents answered “Yes”.
- 10% of respondents answered “Difficult to answer”.
- 5% of respondents answered “No”.

Analyzing the questionnaire question 2, “Do you use the capabilities of digital educational online platforms for higher education?”, the following results were obtained (Figure 1):

- 66% of respondents answered “Yes”.
- 34% of respondents answered “No”.

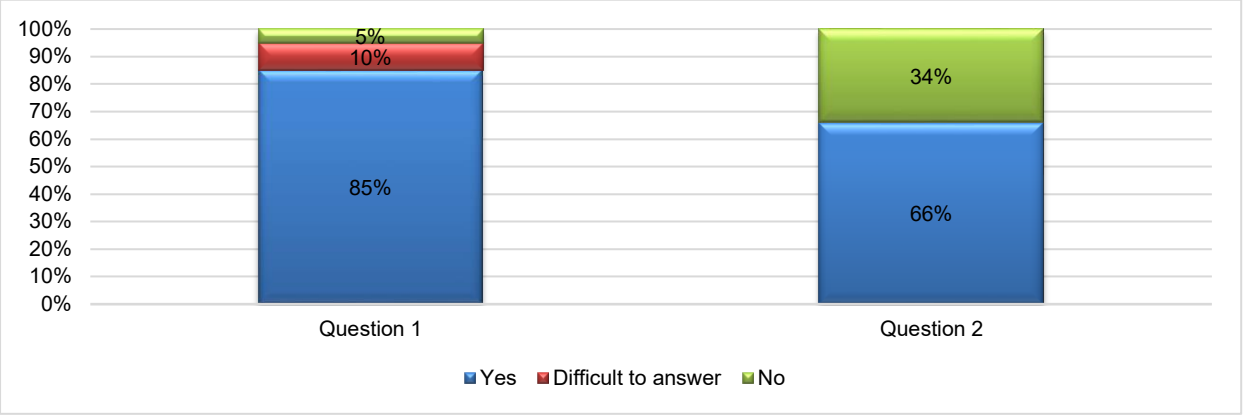

Figure 1. Respondents' Attitudes Toward the Use of Digital Technologies in Future Professional Activities (Question 1, 2).

To question 3, "Did you have any difficulties using digital technologies during your pedagogical practice? If so, what are they?", which provided the opportunity to choose several answer options, the following results were obtained (Figure 2):

- 28% chose the option "Lack of high-quality Internet".
- 27% chose the option "Insufficient technical equipment in the educational institution".
- 64% chose the option "Own level of mastery of digital technologies is low".
- 49% chose the option "Lack of methodological recommendations on the use of digital technologies in primary school".
- 8% of respondents noted that "There are no difficulties when using digital technologies".

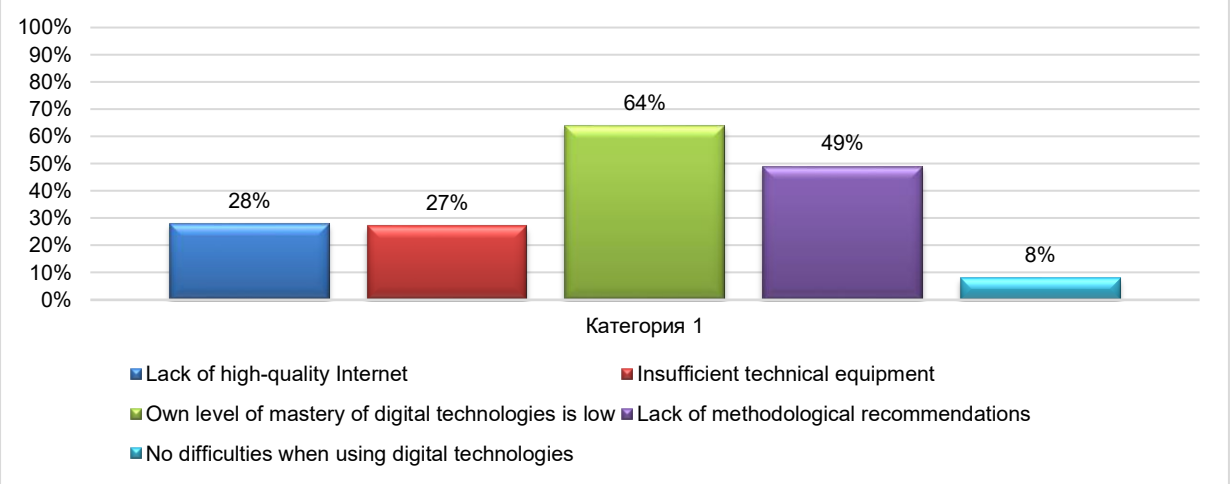

Figure 2. Respondents' Attitudes Toward the Use of Digital Technologies in Future Professional Activities (Question 3).

To question 4, "What will help you master digital technologies and increase your level of readiness for the implementation and use of digital educational technologies in your future professional activities?", which allowed choosing several answer options, the following results were obtained (Figure 3):

- 74% of respondents chose the option "Development of a system and pedagogical conditions to increase the level of students' readiness for the implementation and use of digital educational technologies in their future professional activities".

– 47% of respondents chose the option “Introduction of a separate discipline, special course related to digital technologies”.
– 27% of respondents chose the option “Participation in courses, webinars, etc., outside the main classes in higher education”.

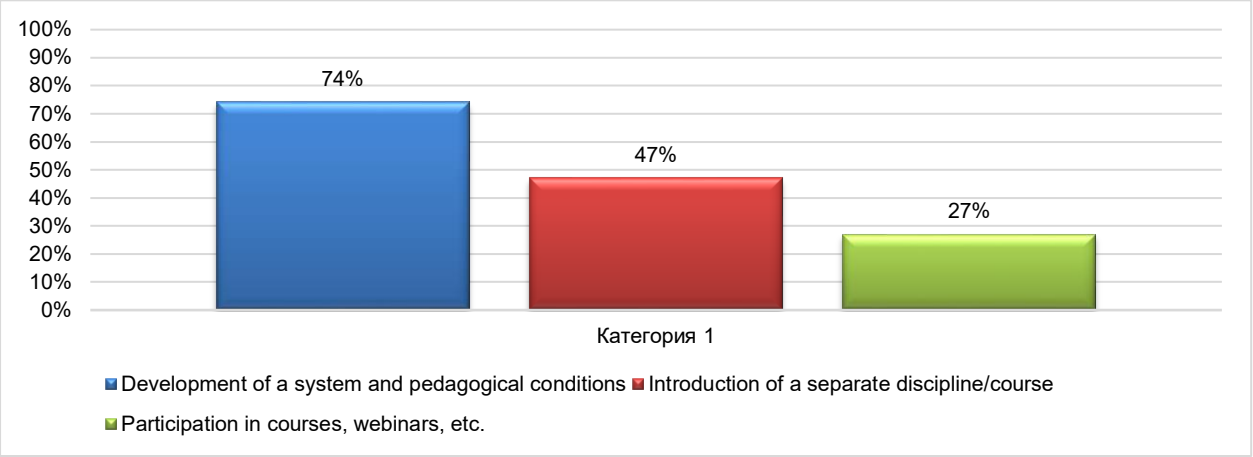

Figure 3. Respondents’ Attitudes Toward the Use of Digital Technologies in Future Professional Activities (Question 4).

We see that most respondents need to develop a system and pedagogical conditions in order to increase their level of readiness for the implementation and use of digital educational technologies in their future professional activities.

Using the testing method, in order to achieve the specified goal, we determined the initial levels of readiness of future teachers to use digital educational technologies in their professional activities (Figure 4).

Let us present the obtained results of the initial levels of readiness for the use of digital educational technologies of future primary school teachers in their professional activities by the **motivational criterion**:

A high level is possessed by:

– 9% of respondents in the EG.
– 8% of respondents in the CG.

An average level is possessed by:

– 58% of respondents in the EG.
– 58% of respondents in the CG.

A low level is possessed by:

– 33% of respondents in the EG.
– 34% of respondents in the CG.

Let us present the obtained results of the initial levels of readiness for the use of digital educational technologies of future primary school teachers in professional activities according to the **operational criterion**:

High level has:

– 15% of respondents EG.
– 14% of respondents CG.

Average level has:

– 35% of respondents EG.
– 34% of respondents CG.

Low level has:

– 50% of respondents EG.
– 52% of respondents CG

Let us present the obtained results of the initial levels of readiness for the use of digital educational technologies of future primary school teachers in professional activities according to the **personal criterion**:

High level has:

– 14% of respondents EG.
– 12% of respondents CG.

Average level has:

– 33% of respondents EG.
– 32% of respondents CG.

Low level has:

– 53% of respondents in the EG.
– 56% of respondents in the CG.

Let us present the obtained results of the initial levels of readiness to use digital educational technologies of future primary school teachers in professional activities according to the **cognitive criterion**:

High level has:

– 14% of respondents in the EG.
– 11% of respondents in the CG.

Average level has:

– 32% of respondents in the EG.
– 34% of respondents in the CG.

Low level has:

– 54% of respondents in the EG.
– 55% of respondents in the CG.

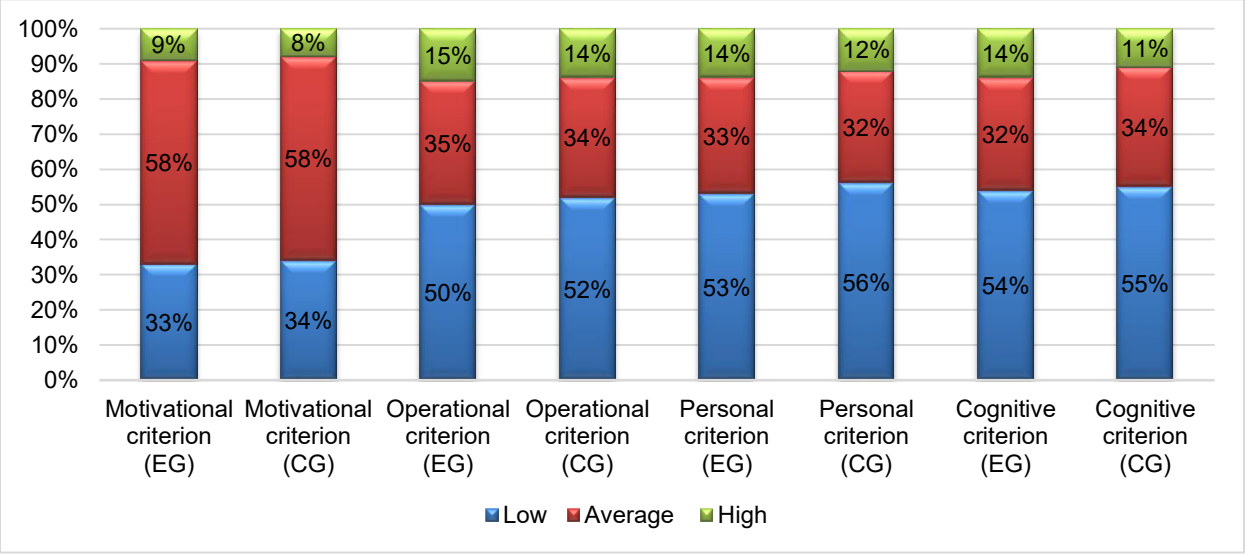

Figure 4. Initial Levels of Readiness of Future Primary School Teachers to Use Digital Educational Technologies.

The results of the ascertaining section make it possible to state that the respondents have a low level of readiness to use digital technologies in professional activities for the purpose of their own professional development.

The reliability of the experimental data and the reliability of the results of the experimental work carried out at the ascertaining stage were determined using the Pearson χ^2 criterion (non-parametric), which allows obtaining 95% reliability of the probability results, finding differences, and assessing the reliability between two distributions, in particular to test the H0 hypothesis of the absence of differences between the two empirical distributions.

Analyzing the obtained values of the Pearson criterion (χ^2_{emp}) ($\chi^2_{emp} < \chi^2_{crit}$ (0.05)) for all criteria with a critical value of the criterion (χ^2_{crit})), we say that the initial level of readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development among the surveyed respondents of the experimental group and the control group does not differ significantly.

There are no statistically significant differences in the level of readiness of respondents who participated in the experiment, because the results obtained here are manifested at the level of significance of 0.01 and 0.05 between EC and CG. This gives reason to say that the contingent of respondents of the experimental group and the control group is equivalent. The low level of respondents is the prevailing level of readiness of future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development.

Analysis of the results of the formative stage of the experiment.

The course of the formative stage was determined by the results of the ascertaining experiment. The number of respondents remained unchanged.

In the experimental group, the educational process was organized by implementing the developed pedagogical conditions that were included in the system of innovative training in the EG, and in the control group, training was carried out using traditional methods. The readiness of future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development in the EG and CG is characterized in accordance with the specified criteria and levels.

We consider the creation of a pedagogical innovation system and the implementation of pedagogical conditions for training future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development to be the main component of our pedagogical research.

One of the tasks of the specified system is the introduction into educational practice of educational and methodological support for training future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development. In the process of their preparation, it is also advisable to use methods that are traditional and based on the processing and transmission of the content of information perception. Such methods for forming the components of student readiness become more effective if integrated with methods such as interactive, staging certain situations by roles, development of critical thinking of the individual, etc.

We see particular importance in implementing the learning process through the involvement of active forms (training, digital laboratory, interactive digital excursions in the digital environment, educational and scientific research, etc.). When organizing the educational activities of the EG respondents, pair and group work became the leading.

Various telecommunication (network) technologies, multimedia technologies, geoinformation digital technologies, electronic textbooks, manuals, electronic resources (programs, applications, etc.), and distance learning systems became pedagogically and methodologically valuable in EG teaching.

The pedagogical conditions for training future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development were introduced into the educational process of the EG.

The first pedagogical condition, “Stimulating the motivation of future primary school teachers to use digital technologies in their professional activities for their own professional development”, was implemented in the educational process through the use of platforms, digital technologies, and applications based on artificial intelligence: “Word swag”, “Curipod”, “AI Synthesia”, “Murf-AI”.

The second pedagogical condition, “Modernization of the content of training future primary school teachers to use digital technologies in their professional activities for their own professional development”, was implemented in the educational process through the introduction of the special course “Digital educational technologies in the work of a primary school teacher” into the EG.

The third pedagogical condition, “Use of innovative forms, technologies of developed methodological support of practical training of future primary school teachers for the use of digital technologies in professional activities for their own professional development”, was implemented in the educational process of EG students by introducing various forms and digital educational technologies.

Let us analyze the results of the formative stage of the experiment on the diagnostics of the levels of readiness of future primary school teachers for the use of digital technologies in professional activities for the purpose of their own professional development (Figure 5).

Let us present the results obtained at the generalization stage of the diagnostics of the levels of readiness of future primary school teachers for the use of digital technologies in professional activities for their own professional development by the **motivational criterion**:

High level of readiness:

- In EG respondents increased by 12%.
- In CG respondents increased by 3%.

Average level of readiness:

- In EG respondents increased by 25%.
- In CG respondents increased by 1%.

Low level of readiness:

- In EG respondents decreased by 38%.
- In CG respondents decreased by 4%.

Let us present the results of the diagnostics of the readiness levels of future primary school teachers to use digital technologies in their professional activities for their own professional development, obtained at the generalization stage, according to the **operational criterion**:

High level of readiness:

- In EG respondents increased by 12%.
- In CG respondents increased by 0.8%.

Average level of readiness:

- In EG respondents increased by 23%.
- In CG respondents increased by 2%.

Low level of readiness:

- In EG respondents decreased by 34%.
- In CG respondents decreased by 3%.

Let us present the results of the diagnostic of the levels of readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development according to the **personal criterion**, obtained at the generalization stage:

High level of readiness:

- In EG respondents increased by 12%.
- In CG respondents increased by 2%.

Average level of readiness:

- In EG respondents increased by 27%.
- In CG respondents increased by 2%.

Low level of readiness:

- In EG respondents decreased by 41%.
- In CG respondents decreased by 4%.

Let us present the results of the diagnostic of the levels of readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development according to the **cognitive criterion**, obtained at the generalization stage:

High level of readiness:

- In EG respondents increased by 11%.
- In CG respondents increased by 1%.

Average level of readiness:

- In EG respondents increased by 26%.
- In CG respondents increased by 1%.

Low level of readiness:

- In EG respondents decreased by 35%.
- In CG respondents decreased by 3%.

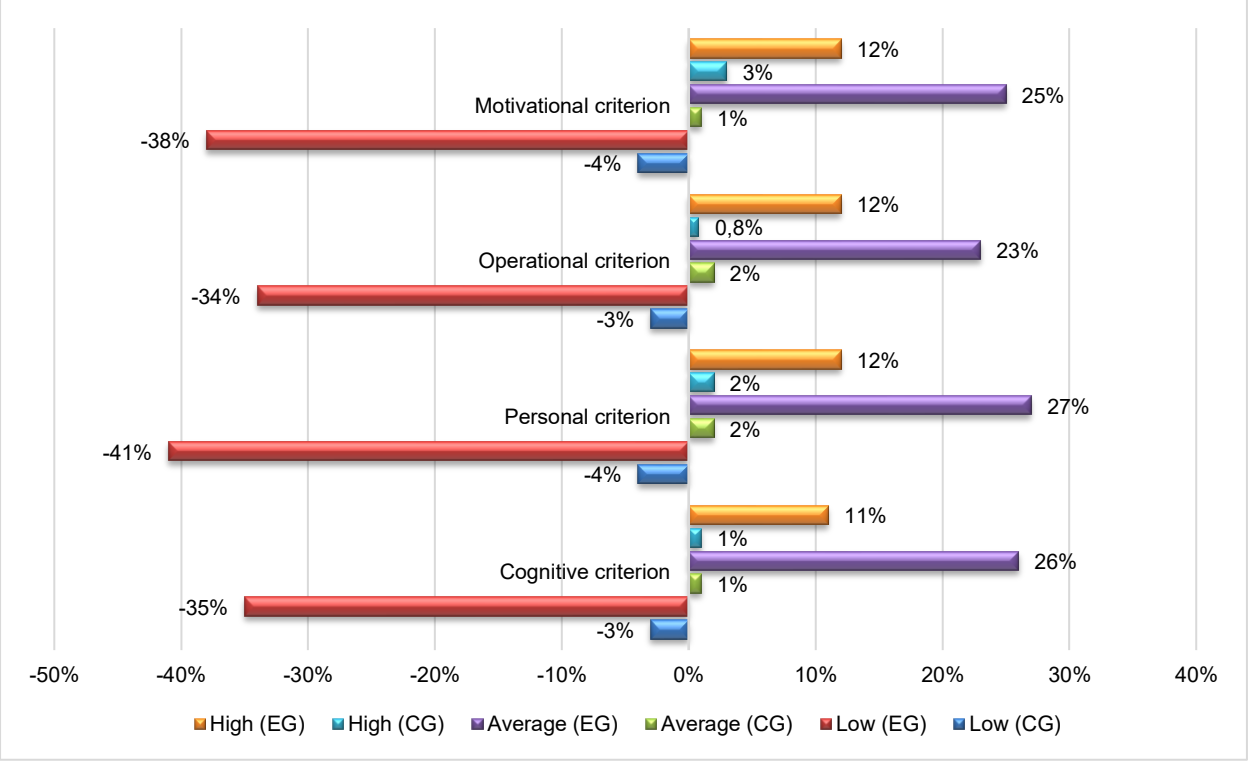

Figure 5. Levels of Readiness of Future Primary School Teachers to Use Digital Technologies for Professional Development (Formative Stage).

According to the established levels of readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development, the results of the experimental work showed that:

- The number of EG respondents who received a high level increased by 12%, while in the CG, the increase was recorded by only 2%.
- The number of EG respondents who received an average level increased by 24%, while in the CG, the increase was recorded by only 2%.
- The number of EG respondents who received a low level decreased by 37%, while in the CG, the increase was recorded by approximately 3%.

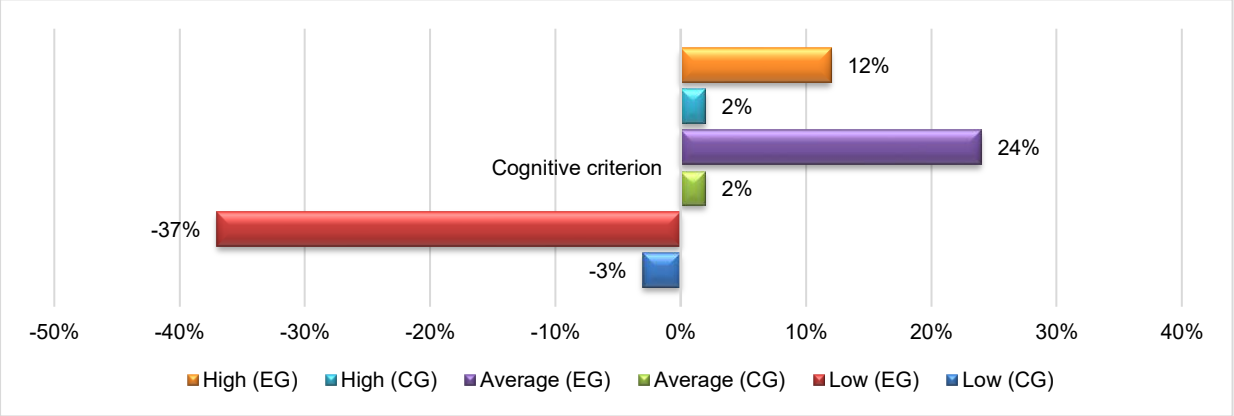

Figure 6. Levels of Readiness of Future Primary School Teachers to Use Digital Technologies for Professional Development (Formative Stage, Average Indicators)

To verify the reliability of the conclusions of the study, a statistical analysis of experimental data (Pearson's non-parametric χ^2 criterion) was conducted using statistical processing methods to determine the difference in indicators in the EG and CG, and to verify its significance (implementation of the proposed system and pedagogical conditions).

H0 null hypothesis: the control and experimental samples are homogeneous in terms of the level of readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development according to the studied χ^2 criterion.

H1 alternative hypothesis: the control and experimental samples are different in terms of the level of readiness of future primary school teachers to use digital technologies in their professional activities for their own professional development, according to the studied χ^2 criterion.

Significant results were obtained at the 5% and 1% levels ($\chi^2_{emp} > \chi^2_{crit}$); therefore, the H_0 null hypothesis is rejected and accepted at a high level of significance. H_1 alternative hypothesis that the level of readiness of students in the experimental group and the control group is significantly different, which indicates the effectiveness of the system and pedagogical conditions.

Therefore, the proposed innovative system and the implementation of pedagogical conditions for training future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development are effective, which is confirmed by statistical processing of experimental data. The quantitative and qualitative analysis of the results obtained by us indicates a positive dynamic of the levels of readiness of future primary school teachers to use digital technologies in their professional activities for the purpose of their own professional development in relation to the specified system of criteria and their indicators.

The results of the study provide a comprehensive understanding of how the implementation of a targeted pedagogical system influences the readiness of future primary school teachers to use digital technologies in their professional activities. The baseline analysis confirmed that the experimental (EG) and control (CG) groups were statistically equivalent across all four readiness criteria – motivational, operational, personal, and cognitive. This equivalence, verified using Pearson's χ^2 test, provided a solid methodological foundation for attributing all further differences to the implemented pedagogical interventions rather than to initial disparities.

The significant improvements observed in the experimental group after implementing pedagogical conditions – particularly the growth in high readiness levels and the reduction in low readiness levels –

align with theoretical assumptions about the impact of structured digital training on teacher competence development. According to Mora & Sánchez (2020), digital competence is not only a technical skill set but also a multidimensional construct encompassing motivation, knowledge, ethical awareness, and operational proficiency. The positive shifts across all four criteria in the EG demonstrate that the proposed pedagogical model effectively addressed these components, confirming the theoretical model underlying the study.

The motivational growth observed in the EG aligns with Healy's (2020) findings that collaborative and technology-enhanced learning environments can foster stronger intrinsic motivation among prospective teachers. The integration of digital tools such as Curipod, AI Synthesia, Padlet, and Moodle created opportunities for autonomy, creativity, and engagement – factors that contemporary motivation theories (e.g., Self-Determination Theory) identify as central to sustained professional development.

The operational improvements observed in the EG are consistent with Chen et al. (2017), who emphasized that structured exposure to digital platforms during teacher preparation enhances procedural knowledge and confidence in technology integration. In the current study, the inclusion of a dedicated course on digital educational technologies functioned as a structured learning pathway, directly supporting this claim.

Similarly, the substantial progress in the personal component of readiness is in line with findings by Walter & Pyżalski (2022), who argue that digital competence development is closely associated with personal attributes such as adaptability, confidence, and responsibility. The study's results demonstrate that when future teachers engage regularly with real digital tools, their sense of professional identity and agency in digital environments noticeably increases.

Finally, the cognitive advances documented among EG participants reinforce the arguments of Alonso de Castro & García-Peñalvo (2021), who note that digital transformation in education requires a solid conceptual understanding of pedagogy, psychology, and digital methodologies. As the participants engaged deeply with digital resources, their comprehension of digital pedagogy and their understanding of how these tools influence learning processes improved.

Interpreting the effectiveness of pedagogical conditions

The formative stage confirmed the effectiveness of the three core pedagogical conditions:

- Stimulating motivation to use digital technologies.
- Modernizing the content of professional training.
- Implementing innovative, technology-rich instructional methods.

The most substantial improvements were seen in the reduction of low readiness levels in the experimental group across all criteria, indicating that the proposed innovations were particularly effective for students who initially lacked confidence or competence in digital environments. This finding is consistent with Gómez & Álvarez (2020), who highlight that structured exposure to technology reduces anxiety and increases the perceived usefulness of digital tools among pre-service teachers.

Alignment with global perspectives on digital education

The study's outcomes support global educational priorities emphasizing digitalization and technology-enhanced teaching. They reflect the broader discourse presented by international organizations (e.g., UNESCO, OECD), which stresses the need for teachers capable of navigating digital ecosystems, designing interactive learning environments, and supporting students in acquiring digital literacy.

Moreover, the significant shift in the EG aligns with the DigCompEdu framework, reaffirming that professional digital competence develops most effectively in environments where technological, pedagogical, and psychological factors are systematically integrated.

Overall, the findings indicate that the pedagogical conditions developed in this study not only produced measurable improvements in readiness but also resonate with contemporary theoretical approaches and empirical evidence in the field of teacher digital competence. The observed transformations confirm that a comprehensive, multi-component system – incorporating motivation, content, and instructional innovation – can substantially accelerate the formation of digital readiness among future primary school teachers.

The results also underscore the necessity of continuous curriculum modernization within teacher education programs, aiming to respond to the rapid digital transformation of society and schooling. Integrating digital tools is no longer optional but essential for fostering pedagogically sound, inclusive, and engaging learning environments.

The present findings – statistically significant improvements across motivational, operational, personal, and cognitive readiness after a multi-component pedagogical intervention – are consistent with and extend prior work on teacher digital competence. Where Chen et al. (2017) and Lee (2020) documented gains in procedural skills following structured exposure to platforms and tasks, our study demonstrates that integrating motivation-focused activities and identity-forming practices produces broader, multi-dimensional gains. Similarly, the observed motivational and identity shifts align with claims by Mora & Sánchez (2020) and Walter & Pyżalski (2022) that competence development is not only technical but also motivational and socio-psychological. Our results also complement global competency frameworks (e.g., DigCompEdu) and empirical syntheses (Alonso de Castro & García-Peñalvo, 2021) by showing that systematized curricular change plus active practice yields measurable shifts in each component of readiness.

Concise Comparative Analysis of the Four Criteria

Motivational Criterion

The increase in motivational readiness observed in the Experimental Group aligns with findings by Healy (2020) and Gómez & Álvarez (2020), who emphasize that collaborative, technology-supported learning environments foster intrinsic motivation for digital integration. Our sharper motivational improvements can be theoretically explained through Self-Determination Theory: autonomy in digital task choice, visible competence gains through AI tools, and peer collaboration all strengthen intrinsic motivation more robustly than traditional instruction.

Operational Criterion

The substantial operational skill gains mirror prior studies (Chen et al., 2017; Lee, 2020) demonstrating that hands-on engagement with digital platforms leads to procedural competence. However, our results exceed typical improvements reported in tool-specific interventions. This is theoretically supported by TPACK and skill acquisition theory, which posit that contextualized, feedback-rich practice promotes stronger operational mastery than isolated technical training.

Personal Criterion

Compared with studies by Walter & Pyżalski (2022), which show gradual shifts in digital self-efficacy and professional identity, our intervention produced faster and deeper personal changes. Social Cognitive Theory helps explain this effect: the combination of mastery experiences, peer modeling, and guided reflection strengthened responsibility, confidence, and adaptability – core personal attributes underlying teacher digital readiness.

Cognitive Criterion

Consistent with Alonso de Castro & García-Peñalvo (2021), targeted instruction in digital pedagogy enhanced conceptual understanding. Our more pronounced cognitive gains can be attributed to the integration of theoretical frameworks with authentic digital lesson design tasks, which supports deeper conceptual restructuring, as predicted by constructivist and metacognitive theories.

Integrated interpretation: why a multi-component system worked

Across criteria, the intervention's success appears to hinge on three theoretical mechanisms supported in the literature:

1. **Motivation + Competence Feedback Loop:** SDT and expectancy-value theory predict that competence gains fuel motivation; our design intentionally produced early, visible competence wins.
2. **Theory-Practice Integration:** Combining conceptual modules with authentic practice fosters cognitive restructuring (constructivist theory), enabling teachers to form transferable pedagogical schemas.
3. **Identity and Social Reinforcement:** Social cognitive mechanisms (modeling, feedback, reflection) transform discrete skills into professional dispositions.

These interacting processes align with DigCompEdu's multidimensional perspective and extend empirical claims by showing that coordinated curricular, technological, and pedagogical components produce larger, cross-domain effects than piecemeal interventions.

Practical implications

For teacher-education programs, results advocate for curriculum redesign that couples: (1) explicit digital pedagogy courses, (2) authentic, scaffolded practice with formative feedback, and (3) reflective, collaborative tasks to build professional identity. This triad operationalizes theoretical insights (TPACK, SDT, Social Cognitive Theory) into implementable pedagogy.

In sum, our findings extend the empirical literature by demonstrating that a theoretically informed, multi-component pedagogical system produces simultaneous improvements in motivational, operational, personal, and cognitive readiness. Theoretical frameworks from SDT, TPACK/ DigCompEdu, and Social Cognitive Theory jointly explain the multi-dimensional effects, and the comparative evidence suggests that integrated interventions are more effective than single-axis approaches emphasized in many prior studies.

Conclusions

The conducted study makes several significant theoretical contributions to the field of teacher education and digital pedagogy.

First, it offers a refined conceptualization of readiness to use digital technologies by integrating four interdependent components – motivational, operational, personal, and cognitive. This multidimensional model expands existing theoretical frameworks (e.g., DigCompEdu, TPACK) by highlighting the role of internal motivational drives and personal characteristics in the formation of digital competence among future primary school teachers.

Second, the study theoretically substantiates a system of pedagogical conditions that support the development of digital readiness. In contrast to previous research, which often focuses on isolated aspects of digital training (Chen et al., 2017; Lee, 2020), this study proposes a holistic model that combines motivational enhancement, content modernization, and the integration of innovative, technology-rich teaching methods. The system provides a theoretically grounded explanation of how and why specific pedagogical influences facilitate competence development, thereby advancing current pedagogical theory.

Finally, the research contributes to the theoretical discourse on digital transformation in education by demonstrating that pre-service teachers' readiness is not solely a technological construct but also a pedagogical, psychological, and identity-based phenomenon. This aligns with and further extends the interpretations presented by Mora & Sánchez (2020) and Walter & Pyżalski (2022).

The study also offers a strong empirical contribution supported by a robust experimental design.

First, the statistical verification of initial group equivalence (χ^2 tests across all criteria) provides a solid methodological foundation for assessing the effectiveness of the intervention, addressing a common limitation in educational experiments where baseline comparability is often insufficiently verified.

Second, the implementation of a pedagogical system in the experimental group resulted in clear, measurable improvements across all components of readiness. The substantial reduction in low-level readiness and the proportional increase in high and medium levels provide empirical evidence of the effectiveness of the proposed pedagogical conditions. These results reinforce previous findings (Gómez & Álvarez, 2020; Cabrera et al., 2023) and offer new, statistically validated data from the context of primary teacher education.

Third, the study provides detailed empirical insights into the challenges students face in using digital technologies, such as insufficient digital proficiency, lack of methodological guidelines, and technological constraints. These findings enrich the broader understanding of structural barriers to digital competence development in teacher education.

Limitations of the Study

Although the study offers valuable findings, several limitations must be acknowledged.

The study involved 79 participants from several pedagogical universities, which may limit the generalizability of results to other cultural or institutional contexts. A broader and more diverse sample would increase external validity.

Part of the data, especially regarding motivational and personal components, relies on self-assessment. This introduces the possibility of social desirability bias or overestimated competence levels.

The research does not assess whether the improved readiness is sustained during real teaching practice after graduation. Digital competence development is dynamic, and long-term tracking would yield deeper insights.

The study evaluates readiness primarily through diagnostic tools and testing, but does not include a comprehensive performance-based assessment (e.g., digital lesson design analysis, classroom observation).

Directions for Future Research

Based on the findings and limitations, several clear directions for future research are proposed:

- Longitudinal studies on competence retention.
- Future research should examine whether the digital readiness developed during teacher preparation persists and evolves during the first years of professional teaching.
- Expansion of the model to international contexts.
- Comparative cross-cultural studies would help determine how educational, cultural, and technological environments influence the effectiveness of the proposed pedagogical conditions.
- Integration of performance-based digital tasks.

Future work should include authentic assessments such as digital portfolio evaluation, lesson plan analysis, and digital classroom simulations to complement the current readiness measures.

Exploration of individual differences.

Future studies may examine how personality traits, learning styles, and previous digital experience moderate the effectiveness of digital competence training.

Testing additional pedagogical interventions.

Further research could explore how AI-based tools, gamified environments, and immersive technologies (VR/AR) influence specific components of readiness.

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