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Scientific And Methodological Foundations For Organizing Experimental Research On The Development Of Digital Competence In Prospective Primary School Teachers

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ABSTRACT

This article examines the theoretical, methodological, and organizational foundations for conducting pedagogical experiments aimed at developing the digital competence of prospective primary school teachers through an integrative approach. It systematizes the aims, objectives, stages, diagnostic criteria, assessment indicators, and methods for establishing the statistical reliability of experimental findings. A comparative analysis is undertaken of the scholarship of international researchers, including C. Redecker, P. Mishra, M. Koehler, İ. Reisoğlu, A. Çebi, A. Lachner, W. Shadish, and J. Cohen, alongside the contributions of Uzbek scholars H. Raxmatova, M. Tillaboyeva, Sh. Xujakulov, T. Kadirov, M. Sheraliyeva, and B. Umirov. Drawing on the DigCompEdu, UNESCO ICT-CFT, and TPACK frameworks, the article proposes an organizational model of an experimental programme designed to develop prospective teachers' digital competence. It substantiates the interrelationships among the formation of experimental and control groups, baseline assessment, formative pedagogical intervention, final monitoring, and statistical analysis. A multidimensional assessment of digital competence is proposed, encompassing cognitive, methodological-technological, practical, communicative, axiological and safety-related, and reflective components. The article presents a scientific and methodological design for a pedagogical experiment; the collection and evaluation of actual empirical findings are identified as tasks for subsequent research.

KEYWORDS: Digital competence, pedagogical experiment, prospective primary school teacher, integrative approach, diagnostic assessment, formative intervention, control group, DigCompEdu, TPACK, Student's t-test, Pearson's chi-square test, pedagogical monitoring.

INTRODUCTION

The accelerating digital transformation of contemporary education has generated a need to improve both the content and the technological foundations of teachers' professional preparation. The use of digital tools, electronic resources, interactive platforms, distance-learning systems, and artificial intelligence in educational practice is placing new demands on teachers' professional work.

In this context, teachers' digital competence is increasingly understood as an integrative professional attribute that enables them to design and implement instruction using contemporary technologies, assess learning outcomes, and support pupils' individual development.

The development of digital competence is particularly significant in primary education. In addition to establishing pupils' foundational knowledge and skills, primary school teachers are responsible for fostering logical reasoning, creativity, communication, independent learning, and information literacy.

The age-related and individual characteristics of primary school pupils, their predominantly visual and imaginative thinking, inclination towards play-based activities, and levels of cognitive development require teachers to make pedagogically informed choices when selecting digital tools.

Meeting these demands calls for the development of prospective teachers' digital competence not solely through theoretical instruction, but also through purposeful pedagogical activity, practical training, the simulation of professional situations, project-based learning, and reflective assessment.

In C. Redecker's DigCompEdu framework, educators' digital competence is conceptualized across six areas: professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence [1].

The TPACK framework developed by P. Mishra and M. Koehler identifies the integration of pedagogical knowledge, subject content knowledge, and technological knowledge as a fundamental condition for the meaningful use of technology in education [3].

An important implication of this approach for pedagogical experimentation is that assessments of digital competence should consider not only how frequently technologies are used but also their alignment with educational objectives, methodological effectiveness, and practical outcomes in professional teaching.

UNESCO's ICT Competency Framework for Teachers describes teachers' technological preparation through the stages of knowledge acquisition, knowledge deepening, and knowledge creation [2]. This framework provides a methodological basis for designing curricula aimed at the progressive development of prospective teachers' digital competence.

P. Mishra and M. Koehler developed the TPACK model around the integration of technological, pedagogical, and content knowledge, demonstrating that effective use of digital tools depends on subject-specific and pedagogical preparation as well as technological knowledge [3].

This conceptual position is especially relevant to primary education, where prospective teachers must adapt a variety of digital tools to the didactic aims of teaching mathematics, the mother tongue, reading literacy, and natural sciences.

In a study on the development of prospective teachers' digital competences, İ. Reisoğlu and A. Çebi drew on the DigComp and DigCompEdu frameworks and emphasized the importance of collaborative learning, pedagogical modelling, and applying theoretical knowledge in practice [4].

Their findings suggest that theoretical instruction alone is insufficient in pedagogical experimentation and that practical assignments and activities situated in authentic professional contexts are also needed.

A quasi-experimental study conducted by A. Lachner and co-authors in 2021

Perspectives of Uzbek Researchers

Uzbek scholars have likewise investigated the pedagogical conditions and methodological instruments involved in developing digital competence, the organization of digital learning environments, and the improvement of prospective teachers' professional preparation.

In her research on enhancing the digital competence of prospective primary school teachers, H. Raxmatova highlighted the importance of specialized training, interactive platforms, and innovative pedagogical approaches [9].

These perspectives provide a rationale for integrating digital educational tools with practical activities during the formative stage of a pedagogical experiment.

M. Tillaboyeva investigated the substantive and methodological dimensions of developing prospective teachers' digital pedagogical competence, focusing on improvements to professional preparation within digital learning environments [10].

Sh. Xujakulov and T. Kadirov examined discrepancies between theory and practice in the development of prospective teachers' digital competence, insufficient interdisciplinary integration, and challenges concerning methodological support [11].

Taken together, these studies suggest that the effectiveness of digital competence development depends on the coherent integration of interdisciplinary connections, practical assignments, digital educational resources, and pedagogical reflection.

M. Sheraliyeva explored approaches to designing individualized trajectories for the professional development of prospective primary school teachers in digital learning environments and proposed a model incorporating blended learning, artificial intelligence, and electronic portfolios. The published study reports experimental findings involving 120 students [12]. This work indicates that an individualized professional development trajectory may be examined as a distinct pedagogical factor in experimental research.

Relationship to the Author's Previous Research

Earlier studies by B. Umirov have addressed the integration of pedagogical and information and communication technologies, competence development in primary education, and the theoretical foundations of digital competence.

In the article "Development of Personal Competence of Students in the Integration of Pedagogical and Information-Communication Technologies," the author analyzed the integration of pedagogical and information and communication technologies as a factor in

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competence development and highlighted the importance of theoretical, technological, and practical modules [13].

This approach may provide a scientific and methodological foundation for structuring instructional content into distinct modules and fostering progressive development within experimental research.

In addition, the author's article "The Concept of Digital Competence: A Scientific and Theoretical Interpretation and an Analysis of International and Domestic Research" examined digital competence through international conceptual frameworks and scholarly perspectives [16].

As a logical continuation of these investigations, it is necessary to establish an integrated methodological system encompassing the stages of pedagogical experimentation, diagnostic indicators, and statistical procedures for assessing the development of digital competence.

Accordingly, unlike the author's earlier theoretical studies, the present article focuses on the organizational and diagnostic foundations for empirically testing a methodology designed to develop digital competence.

Research Methodology

The methodological foundations of the study comprise systemic, competence-based, activity-oriented, learner-centred, integrative, and reflective approaches.

The competence-based approach entails evaluating prospective primary school teachers' digital knowledge and skills in terms of their ability to perform professional tasks.

The systemic approach makes it possible to identify the interrelationships among the structural components of digital competence, pedagogical conditions, developmental methods, and assessment instruments.

The activity-oriented approach conceptualizes digital competence as a professional attribute manifested in practical pedagogical situations.

The integrative approach brings together digital technologies, primary education methodology, pedagogy, psychology, digital assessment, and reflective practice within a coherent educational process.

The following research methods are proposed: review of scholarly literature, pedagogical observation, questionnaires, knowledge tests, practical assignments, expert assessment, electronic portfolios, pedagogical experimentation, comparative analysis, and mathematical-statistical data analysis.

The integrative instructional programme is designated as the principal independent variable, while students' level of digital competence is identified as the dependent variable.

Relevant covariates to be recorded include students' baseline preparation, year of study, access to digital devices, internet connectivity, and prior pedagogical experience.

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Organization Of The Pedagogical Experiment

Aim and Objectives of the Experiment

The primary aim of the pedagogical experiment is to determine the educational effectiveness of a methodology for developing digital competence that has been designed on the basis of an integrative approach.

The following objectives are proposed to achieve this aim:

1. To assess the baseline level of digital competence among prospective primary school teachers.
2. To establish experimental and control groups and compare their baseline indicators.
3. To implement an integrative methodological programme designed to develop digital competence.
4. To monitor changes in students' cognitive, methodological, technological, practical, and reflective skills on an ongoing basis.
5. To compare the final results of the experimental and control groups statistically.
6. To identify the effectiveness, limitations, and potential improvements of the methodology on the basis of the results obtained.

Stages of the Experiment

Formation Of Experimental And Control Groups

Students enrolled in programmes preparing prospective primary school teachers may be selected as participants in the experimental study.

To strengthen the internal validity of the study, random assignment to experimental and control groups is recommended wherever feasible.

If existing academic groups must remain intact, a quasi-experimental design may be adopted. In this case, the groups should be examined for differences in baseline digital preparation, year of study, and other relevant characteristics.

The experimental group would receive instruction based on the integrative methodological programme, while the control group would continue under the prevailing instructional approach.

Sample size should be justified in advance through statistical power analysis. A large number of participants does not, in itself, guarantee reliable findings; group allocation, diagnostic quality, and consistent implementation of the pedagogical intervention are also essential.

Assessment tasks, diagnostic conditions, and requirements for evaluators should be identical across the experimental and control groups.

Methodological content of the formative intervention

Statistical analysis of experimental results

Mathematical and statistical methods must be used appropriately to establish the scientific reliability of findings from pedagogical experiments.

Initially, means, standard deviations, medians, and confidence intervals should be calculated for baseline and final diagnostic outcomes in the experimental and control groups.

The change in each student's competence score may be calculated using the following equation:

$\Delta K = K(\text{post-test}) - K(\text{pre-test})$

Here, ΔK denotes the change in the digital competence score.

The observed changes in the experimental and control groups are then compared.

Student's t-test

Student's t-test may be used to compare mean scores between two groups. However, the appropriate form of the test depends on the research design.

A paired-samples t-test may be used to compare the baseline and final scores of the same students.

To compare change scores between independent groups, an independent-samples t-test may be applied when its assumptions are satisfied; Welch's t-test is appropriate when group variances are unequal.

To account for differences in baseline competence, analysis of covariance (ANCOVA) is often appropriate, treating the final score as the dependent variable, group membership as the main factor, and the baseline score as a covariate.

The statistical hypotheses may be formulated as follows:

H_0: There is no statistically significant difference between the experimental and control groups in the effect of the integrative programme.

H_1: There is a statistically significant difference between the experimental and control groups in the effect of the integrative programme.

The significance level may be specified in advance as $\alpha = 0.05$.

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If the p-value for the relevant statistical model is below 0.05, the findings provide statistical evidence against the null hypothesis. This result does not, however, establish on its own that the pedagogical effect is large or practically meaningful.

Pearson's chi-square test

If students are classified into categories according to their level of digital competence, Pearson's chi-square test may be used to examine the association between group membership and the distribution of competence levels.

The general formula for the test is:

$$\chi^2 = \Sigma (O - E)^2 / E$$

where:

O denotes the observed frequency;

E denotes the expected frequency under the null hypothesis.

Application of this test requires verification of the independence of observations and the adequacy of expected cell frequencies.

Where expected frequencies in some categories are very small, suitable alternative procedures should be considered. Moreover, repeated measurements of the same students over time must not be analyzed as an ordinary contingency table of independent observations.

Results And Discussion

The present theoretical and methodological investigation proposes a conceptual and organizational model for conducting pedagogical experiments aimed at developing the digital competence of prospective primary school teachers.

First, the functional relationships among the preparatory-organizational, baseline diagnostic, formative, and final evaluation stages of the experiment were systematized.

Second, a six-component diagnostic framework for assessing digital competence was proposed. Beyond digital knowledge, it encompasses instructional design, practical implementation, pedagogical collaboration, digital safety, and reflective evaluation.

Third, the formative intervention was structured around modules addressing digital pedagogy, development of electronic resources, interdisciplinary integration, innovative teaching methods, digital assessment, and reflective practice.

Fourth, a procedure was recommended for comparing baseline and final diagnostic outcomes, selecting appropriate statistical tests, and estimating the magnitude of the educational effect.

Fifth, the need for a control group, standardized assessment criteria, valid diagnostic instruments, protection of participants' rights, and verification of statistical assumptions was substantiated as a prerequisite for the scientific credibility of the experiment.

The conceptual strength of the proposed model lies in its treatment of digital competence not merely as the ability to operate technological devices, but as an integrative combination of primary curriculum content, methodological preparation, developmental psychology, digital safety, and reflective practice.

Nevertheless, establishing the model's actual pedagogical effectiveness requires controlled empirical testing, statistical analysis of the resulting data, and verification using independent assessment instruments.

This article does not claim that the effectiveness of the proposed model has been empirically demonstrated. Rather, the model is presented as a scientific and methodological foundation for subsequent applied research.

Conclusion

Pedagogical experimentation aimed at developing prospective primary school teachers' digital competence through an integrative approach must be conducted in accordance with clearly defined scientific-methodological, organizational-pedagogical, and diagnostic requirements.

A comparative analysis of international and Uzbek scholarship highlights the importance of integrating technological, pedagogical, and methodological knowledge, practice-oriented learning, collaboration in digital environments, and reflective assessment in the development of digital competence.

A rigorous pedagogical experiment requires the assessment of baseline competence, implementation of an integrative methodological programme, monitoring of changes in learning activities, and comparison of final outcomes.

A comprehensive approach to digital competence assessment should incorporate cognitive-digital, methodological-technological, practice-oriented, communicative-collaborative, axiological and safety-related, and reflective-assessment components.

Key conditions for ensuring the scientific credibility of the experiment include the validity of diagnostic instruments, the comparability of experimental and control groups, the appropriate use of statistical procedures, and the estimation of effect size.

The proposed scientific and methodological model may serve as a theoretical and methodological foundation for the development of experimental programmes, the refinement of diagnostic instruments, and the design of future empirical studies on the digital competence of prospective primary school teachers.

In summary, the methodological robustness of experimental research aimed at developing prospective primary school teachers' digital competence depends on organizing instructional

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content, digital technologies, practical pedagogical activity, diagnostic assessment, and reflective evaluation as a unified integrative system.

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