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Transforming Models of Preschool and Special Education Teacher Training in the Conditions of Global Challenges

Sabina Ivanchuk , Zoia Bondarenko, Anastasiia Kryvorotko, Nataliia Zymivets and Yaroslav Savchenko

ABSTRACT

BACKGROUND

The purpose of this study was to determine the role of the transformational model of training future preschool and special education teachers.

MATERIALS AND METHODS

The study involved 160 students from six academic groups. They were divided into experimental and control groups. To collect data, an author's questionnaire, a diagnostic test (40 tasks), and an evaluation of project tasks (Project development - Organization of an inclusive lesson, formation of lesson notes using digital tools, and methodological developments) were used. The experiment was conducted in three stages: ascertaining, formative, and control. The quality of student products is assessed according to the criteria of content quality, innovation, and inclusiveness.

RESULTS

At the ascertaining stage, the lowest indicators were recorded in crisis preparedness ($M = 51.2$; 73.1% with a low level), digital competence ($M = 58.7$; 48.8%), inclusive competence ($M = 60.1$; 43.8%). After the formative stage, statistically significant improvements ($P < 0.001$) were recorded in the experimental group in all domains, particularly in crisis preparedness ($\Delta = 22.3$; $d = 1.01$). Expert assessment of student products confirmed higher scores for innovation and inclusiveness in the experimental group (74–78 vs. 59–66 in the control group). Correlation analysis revealed positive relationships: digital pedagogy – quality of notes ($r = 0.59$), digital pedagogy – motivation ($r = 0.46$), and inclusiveness – tolerance ($r = 0.42$).

CONCLUSION

The implementation of a transformational model that combines interactive methods, digital technologies, and inclusive modules has improved students' professional readiness. The model contributes to the formation of the ability to work in crisis educational environments.

Keywords: Transformational teacher training model, Crisis preparedness competency, Digital literacy integration, Inclusive preschool education, Ukrainian special education

Highlights

Crisis preparedness competency was the most vulnerable, with 73.1% of students scoring ≤ 60 , indicating critical challenges for teacher training in uncertain conditions.

The transformational training model proved highly effective, providing an average increase in scores of

17–22 points (Cohen's d up to 1.01) compared to minimal changes in the control group.

Digital pedagogy and inclusion emerged as key factors in professional readiness, demonstrating strong correlations with the quality of educational materials ($r = 0.59$) and tolerance ($r = 0.42$).

Introduction

Education in the 21st century is developing under the influence of several global challenges that affect the training of future teachers. In particular, the spread of the COVID-19 pandemic has determined the need for rapid adaptation of educational systems to a distance format. An additional challenge for Ukraine was the Russian-Ukrainian war, which led to the destruction of educational infrastructure, mass migration and traumatization of children. Under such circumstances, there is a need to update the content of education based on the formation of competencies necessary for the successful realization of the individual in society. New demands of preschool and special education, which is in a state of active transformation, require corresponding changes in the practice of training future teachers who would be motivated for effective pedagogical activity and competitive in the market of educational services. Under such conditions, the professional education of future teachers becomes a priority.

In parallel, the processes of digitalization of education require teachers to possess digital competencies. According to research, most modern teachers consider their training to use digital tools insufficient. This means that the teacher training system should integrate digital technologies not as an additional component, but as an integral part. At the same time, modern scientists have indicated that the existing teacher training models in Ukraine and the world are mostly focused on stable conditions of the educational process.¹ They take into account the factors of crises (pandemics, wars, migration processes) to a limited extent, and do not sufficiently integrate the inclusive and digital components.^{2,3} This leads to the fact that graduates of pedagogical universities are not always ready to work in new educational realities.⁴ Thus, the problem is that traditional teacher training models do not meet modern global challenges, which reduces the effectiveness of their professional activities.

In addition, despite numerous studies in the field of teacher education, several problematic aspects remain unresolved. Most works focus on general teacher training, while preschool and special education do not become important objects of research in the light of the digitalization process. Existing studies mainly describe challenges (COVID-19, war, digitalization) but pay

was conducted in accordance with academic integrity standards and adheres to the principles of responsible legal scholarship

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Anastasiia Kryvorotko – Data curation, Formal analysis, Software, Visualization;

Natalia Zymivets – Writing – original draft, Formal analysis, Validation;

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little attention to experimental models of overcoming them in the process of teacher training.⁵ These gaps determine the relevance of conducting an experiment aimed at testing a new model of teacher training. To solve these problems, the study will focus on substantiating and implementing and analysing the developed special model of professional training of future teachers. To test the effectiveness of teacher training models, it is necessary to conduct a pedagogical experiment that will allow us to identify the real level of formation of professional competencies of future teachers, implement a transformational training model that takes into account digitalization, inclusiveness and crisis conditions, and assess changes in the level of professional readiness of students after the experiment.

Thus, the purpose of the study is to test the effectiveness of training models for preschool and special education teachers in the context of global challenges.

Research questions:

1. What competencies of future teachers are vulnerable to the impact of global challenges?
2. What elements of the transformational training model most affect the effectiveness of learning?
3. Are there differences between the results of students in the control and experimental groups?
4. Are there connections between individual correlation variables: level of digital pedagogy - motivation for professional activity, digital pedagogy - quality of notes, inclusiveness - tolerance, crisis readiness - self-esteem, motivation - relationship?

Literature Review

Theoretical Foundations of Teacher Training Models

The training of future teachers of preschool and special education is based on the fundamental principles of child development, which are rooted in classical theories, in particular, J. Piaget and L. Vygotsky.⁶ J. Piaget paid considerable attention in the issues of scientific research on the role of intelligence, in which he saw the result of the internalization of external actions.⁷ He built the theory of the development of children's thinking on the basis of logic and biology.⁸ At the same time, the main stages of mental development were defined by the scientist as stages of intellectual development, through which the child gradually passes in the formation of an adult perception of the situation.^{9,10} The scientist proved that in the process of development, the organism adapts to the environment.^{11,12} In this system, intelligence provides understanding, the formation of the correct scheme of the surroundings, that is, it provides active adaptation to the world that surrounds the child.¹³ In this way, it is the criterion of activity that is an important condition for the development of intelligence and the formation of basic schemes of the situation. The child actively uses two mechanisms for building a scheme - assimilation and accommodation (changing the ready-made scheme when the situation changes).¹⁴ E. Erikson, who was a follower of S. Freud, managed to expand psychoanalytic theory since he began to consider the development of the child in a

broad aspect of social relations. Like S. Freud, E. Erikson believed that only a healthy adult person can satisfy his needs for personal development, the desires of his own "I" and meet the requirements of society.¹⁵ This scientist believed that the basic foundations of the human "I" are based on the social organization of society.^{16,17} Moreover, the development of society causes the extension of the childhood period. L. Vygotsky proposed a cultural-historical concept based on the social aspect of learning and the phenomenon of the "zone of proximal development". For preschool and special education, this means that teachers must have support methods, as well as an understanding of the role of language and communication as tools for cognitive development.^{18,19} These theories formed the basis of modern inclusive approaches, in which the education of children with special educational needs (SEN) is based on joint activities with peers and teachers.²⁰⁻²² However, modern innovative models are more broadly focused on a competency-based approach: practical training, digital pedagogy, work in inclusive conditions, and the formation of resilience skills.

Modern Models of Training Preschool and Special Education Teachers

In these models, a significant role is assigned to the utilization of modern digital resources, platforms, and inclusive approaches. In this way, the teacher becomes a "knowledge translator", a facilitator of learning, and a manager of various educational situations.^{23,24} At the same time, as demonstrated in the work of O. Stanichenko et al., current global crises, including pandemics, the war in Ukraine, and various migration processes, have highlighted the limitations of traditional models in producing specialists.^{25,26} In particular, the war has caused a significant need to form crisis preparedness and psychological resilience skills.^{27,28} At the same time, as proven in other works, migration processes and issues of multilingualism in classrooms have intensified the tasks of multicultural adaptation.^{29,30} Therefore, modern training models are based on taking into account cognitive and social theories of development and uncertainty factors. Research by scientists has shown that modern bachelor's programs actively include special inclusive models, or courses on tolerance. In some cases, there is also a special direction – digital pedagogy.⁵ However, there is still a lack of models focused on crisis preparedness, although some universities are introducing training in psychological resilience. Some scientists have drawn attention to the importance of introducing practically-oriented training. Based on this model, students spend up to 30% of their time in "partner schools", have research projects and close ties with university laboratories.^{31,32} Other researchers have drawn attention to the importance of transitioning to hybrid models that include Response to Intervention (RTI) and Technological Pedagogical Content Knowledge (TPACK).^{33,34} TPACK involves synthesizing technology into the teaching system. Special attention in this model is paid to modern pedagogical methods and the use of

digital tools. However, as indicated in other works, RTI forms a three-stage model of supporting students with difficulties, which is used in the USA for special education. As indicated by B. Morton and J. Pilgrim, Universal Design for Learning (UDL) is formed for the development of inclusive education, which involves flexibility in the presentation of material and active involvement of students.²⁹ Besides, Competency-Based Teacher Education has recently gained popularity. This model is based on the formation of specific competencies, rather than on the transfer or translation of knowledge.^{35,36} Thus, as this review has shown, modern models differ from traditional ones, as they are focused on digitalization processes, inclusion, competency-based, and practice-oriented approaches. Most of the existing works relate to the realities of the USA and EU countries; however, Ukrainian practice is covered fragmentarily.³⁷ There is still no systematic empirical data on the effectiveness of new models of training Ukrainian teachers in times of crisis. Also, as can be seen from the review, most studies separately analyze TPACK (technology), UDL (inclusion), PBTE (practice), however, there is a lack of studies that would propose an integrated transformational model. This study will address this gap and analyze the role of a model that simultaneously covers digital pedagogy, inclusion, a competency-based approach, and crisis preparedness.

Therefore, in modern models of training future teachers, there is a shift away from traditional approaches that were focused on theoretical knowledge acquisition, towards the active integration of digital technologies and inclusive practices. The proposed analysis of scientific literature showed that individual components of such models have been actively studied in the USA and EU countries, while Ukrainian practice is described only fragmentarily.

Methods

Research Design

The study used a quasi-experimental design with intact classes.³⁸ The study is experimental and consists of three stages. At the ascertaining stage, the initial level of professional competence of future teachers in the field of preschool and special education was assessed. At this stage, the initial level of knowledge, skills, motivational readiness, and the formation of key competencies of students were also determined. At the same time, the formative stage involved the implementation of an experimental model of teacher training that considers the global challenges of today: the digitalization of education, the development of an inclusive

environment, the transition to distance and blended learning, wartime conditions, the growth of migration processes, and the multiculturalism of the educational space. At the control stage, the effectiveness of the proposed model was verified by re-diagnosing the participants, comparing the results of the control and experimental groups, and conducting a statistical analysis of the data obtained.

Group Allocation Procedure

The allocation of clusters (academic groups) to the control and experimental streams was carried out at the level of already formed study groups, without individual allocation of students. Clustering was previously determined by the administrative and academic structure of the educational institution, therefore the randomization procedure was not applied. Three academic groups were assigned to the control stream, three to the experimental stream. All steps comply with the CONSORT recommendations for cluster studies (CONSORT-Extension for Cluster Trials).

Participants

The study involved third–fourth year students majoring in Preschool Education and Special Education. The total sample consisted of 160 individuals, divided into six academic groups. The distribution by group is presented in Table 1.

For the pedagogical experiment, the sample was divided into two equal groups:

Experimental Flow

80 people were selected for analysis. Training took place in strict academic groups. In these groups, training was conducted according to a new transformational model of teacher training that considers global challenges (digitalization, inclusion, working in crisis conditions). At the same time, in the control flow (80 people in total), training was conducted according to the traditional educational programme without additional innovative components.

Each cluster retained the structure of the academic group, which allowed them to avoid cross-influence between students of different educational conditions. The study had three stages in total: ascertaining, formative, and control. During the formative stage, the experimental group was trained according to the transformational model of training of future teachers, while the control group was trained according to the traditional educational program. The use of a cluster approach reduced the risk of confounding effects but limited the number of clusters (six in total), which is a potential limitation for the accuracy of statistical estimates. This was considered during further data analysis by applying corrections for small samples and cluster-resistant standard errors.

The division into groups was carried out considering the principles of equivalence and representativeness: each group had approximately the same ratio of students majoring in “Preschool Education” and “Special Education”. This minimized the influence of external factors

Table 1 | Sample of 160 Individuals

Group	Type	Cluster Size (n)	Average Age	Women (%)	The Ratio of Specialties (Preschool Education/Special Education)
1	Control	24	20.4	96	15/13
2	Control	30	20.6	93	16/13
3	Control	26	20.3	95	13/13
4	Experimental	25	20.7	97	13/12
5	Experimental	30	20.5	94	15/12
6	Experimental	25	20.4	95	13/12

and ensured the accuracy of comparative analysis. The age range of the sample was from 19 to 22 years; the average age was 20.5 years. In terms of gender composition, the vast majority were women. This corresponds to the general trend in the specialities of preschool and special education. Participants were selected from the same educational level. All participants are pursuing their first (bachelor's) degree in higher education. In addition, approximately 70% of students have previous experience in teaching practice in preschool or special education institutions (Appendix A).

To verify the initial equivalence of the groups, an analysis of the basic indicators of professional readiness for the intervention (pre-test) was conducted. The independent samples statistical test ($t = 0.47$; $P = 0.64$) did not reveal significant differences between the control and experimental groups in terms of the integral indicator of professional readiness. For individual domains (cognitive, operational, motivational-value) the mean values also did not differ statistically (all $P > 0.05$), which confirms the equivalence of the groups at the initial stage.

Since the study had a cluster structure (six academic groups), the so-called design effect, i.e. the increase in error that occurs when participants are combined into clusters rather than distributed individually, was taken into account when assessing statistical power. Taking into account the average cluster size and intraclass similarity ($ICC \approx 0.06$), the overall design effect in our study was about 2.5. This means that the actual sample size was smaller than its nominal size. With a sample size of 160 people, the effective sample size was approximately 60–65 people. This is acceptable for a pilot study, but it limits the accuracy of the estimates and requires caution when interpreting the results.

With only six clusters, the accuracy of standard statistical procedures could be reduced. To compensate

for this risk, corrections for small cluster samples (CR2) were applied in all models, as well as special methods for adjusting the degrees of freedom. This allowed to increase the reliability of the analysis, but the results should still be considered preliminary. In this regard, the study is interpreted as a pilot cluster experiment that requires further verification in a larger number of educational institutions and with a larger number of clusters.

Experimental Model

Modelling the educational process is an important basis for bringing future teachers closer to their professional activities. The system for developing such a model uses the basic principles of general systems theory. In particular, the effectiveness of the system depends on its level of integrity, i.e., the degree of connection between its components. The effectiveness of the system depends on the processes of its intensification and compliance with the goals for which it was created. Thus, the developed model consisted of various approaches and tools. It provides for the use of various technologies, including the case method, project-based learning, simulations of pedagogical situations, and training sessions. Modelling various situations (exercise situations, problem situations, dialogue situations, illustration situations) made it possible to create special conditions for the active participation of each student in collective research, exchange of ideas, and defending their own opinions. Another component of this model is digital. This component includes various educational tools: Moodle, Duolingo, Babbel, Zoom, and Google Classroom. Special modules on inclusive education were also used. They provided for the organization of education for children with SENs, the formation of tolerance, and the development of multicultural competencies. This model also considers crisis cases responding to challenges, organising learning during military operations, and ensuring the continuity of education in the context of migration (Appendix B, see Figure 1).

Within the formative stage of the experiment, the curriculum was implemented over one semester (16 weeks) and included 12 training sessions lasting 90 minutes each. The classes were conducted by three teachers of the Department of Preschool and Special Education, who have academic degrees and experience in the field of pedagogical innovations, inclusive education, and digital learning technologies. The content of the classes covered thematic blocks related to the digitalization of the educational process, the formation of inclusive competence, and preparation for work in crisis conditions. During the classes, interactive methods (analysis of pedagogical cases, modeling of professional situations, group projects, role-playing games) and digital tools were used - Moodle, Zoom, Google Classroom, Padlet, Canva, Kahoot, Duolingo. The inclusive education module involved the creation of adapted educational materials for children with SENs, the development of exercises for the formation of tolerance and multicultural interaction. The module

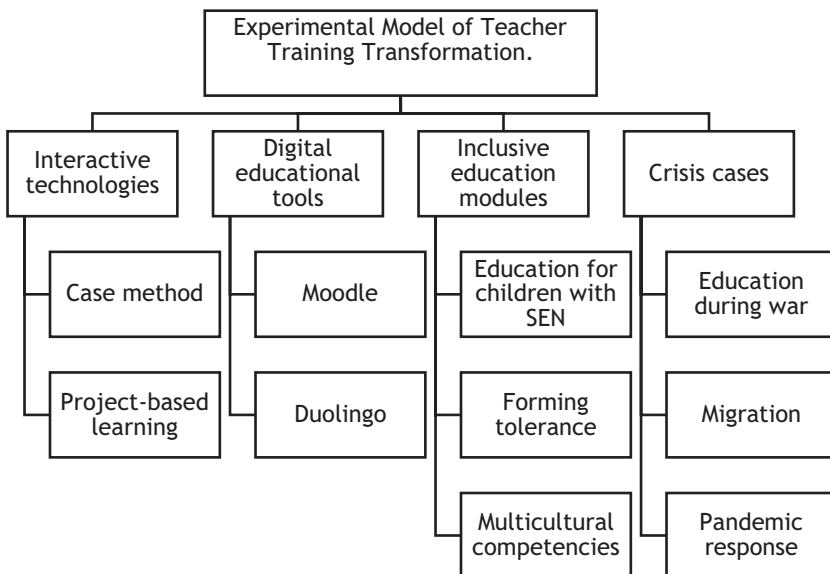


Fig 1 | Experimental model of teacher training
Source: Own elaboration.

“Education in Crisis Conditions” included work with crisis cases related to the organization of education during military operations, evacuation and remote support of children with disabilities. To ensure compliance with the program (fidelity monitoring), a compliance checklist was used, which was filled out by the teacher after each lesson; in addition, the experiment coordinator conducted selective observation of lessons to check the completeness of the program implementation and the consistency of content between groups. The evaluation rubric applied to lesson plans and project materials is included in Appendix C, together with scoring criteria and performance descriptors.

To minimize the risk of assessment bias, partial blinding of the expert assessors was applied. The experts who assessed the learning outcomes (projects, lesson plans, methodological developments) were not informed which group (experimental or control) the students’ work belonged to. The identification designations of the participants were replaced by codes. All three assessors (department lecturers) did not directly participate in teaching in the groups whose results they assessed, which allowed to reduce the potential overlap of the “instructor-assessor” roles. To prevent contamination between clusters, the study groups functioned autonomously, did not have joint classes or intergroup projects during the formative stage. Access to the educational materials of the experimental model (digital platforms, cases, simulations) was limited only to the participants of the corresponding groups.

Data Collection

Diagnostic tools, including questionnaires, were used to collect data. This made it possible to identify the level of students’ readiness for professional activity, their attitude to innovative teaching methods, and work in the context of global challenges. The author’s questionnaire, “Readiness of future teachers for professional activity in the context of transformational education,” was used. To ensure the psychometric reliability of the author’s instruments, testing was conducted on a pilot sample ($n = 42$). After analyzing the results, a high level of internal consistency of the scales was determined: for the questionnaire “Readiness of future teachers for professional activity...” the Cronbach’s α coefficient was 0.87, and for the test “Basic competencies of a preschool and special education teacher” – 0.83. Construct validity was confirmed using factor analysis, which revealed three factors corresponding to the cognitive, operational and motivational-value components of the model. Content validity was ensured by expert review of the content of the instruments (five specialists in the field of pedagogy, inclusive education and psychodiagnostics).

The main result – “professional readiness of future teachers” – was defined as an integral indicator that combines three domains: cognitive (knowledge of the theory and methodology of pedagogical activity), operational (ability to apply innovative pedagogical technologies) and motivational and value (attitude to professional self-development). To construct the

composite index, a standardized weighting system was used based on the arithmetic mean of three components, each of which was normalized to a scale of 0–100 points. The total integral score was calculated as the average of the three domains without additional weight adjustment, which corresponds to the principle of equivalence of the components of professional competence. To verify the reliability of the composite assessment, the internal consistency coefficients Cronbach’s α and McDonald’s ω were calculated at the initial and final stages. At the ascertaining stage $\alpha = 0.87$; $\omega = 0.85$, after the formative stage – $\alpha = 0.89$; $\omega = 0.88$, which indicates high stability of the indicator.

To effectively determine the level of students’ knowledge, the test “Basic Competencies of a Preschool and Special Education Teacher” was used. This test was developed based on programme learning outcomes and international standards. The test contained 40 tasks of three types: multiple choice (for example: “Which of the principles is key in working with children with SEN?”), matching (“Match the digital tool with its function”) and situational tasks (pedagogical cases to be solved).

Students also self-analysed their work using reflective cards (“My professional readiness today”). In this reflective card, they noted the strengths and weaknesses of their activities. Peer assessment was also used during group projects: each participant evaluated the contribution of other team members.

Thus, the experiment was conducted in three stages:

At the ascertaining stage, the initial level of student readiness was diagnosed using questionnaires, tests, and observation. At the formative stage, a transformational model was integrated into the learning process of the experimental group. This model involves the use of interactive methods (case method, role-playing games, simulations) and digital platforms. At this stage, special modules on inclusive education (developing lessons for children with SEN, exercises to develop tolerance) and training with crisis cases were also conducted.

At the control stage, a re-diagnosis was carried out, and the results of the control and experimental groups were compared using statistical and qualitative methods.

The following student results were evaluated during the study

1. Project development (organization of an inclusive lesson in a mixed format)
2. Creation of lesson plans using digital tools and adaptation for children with SEN
3. Methodological developments (game or training scenarios).

The analysis was carried out according to the following criteria:

- Quality of content - relevance to the course objectives, scientific validity.
- Innovativeness - use of interactive and digital technologies.

- Inclusiveness - adaptation for children with different needs.
- Practical applicability - possibility of use in real conditions.

The assessment was carried out by three experts (lecturers of the department), which increased the validity of the results (inter-rater reliability (ICC = 0.87)).

To measure changes in the levels of professional readiness, the author's diagnostic tools were used, developed based on the structural-competence model of training future teachers. The toolkit included three constructs: cognitive (knowledge of the theory and methodology of pedagogical activity), operational (ability to apply innovative teaching technologies), and motivational value (attitude to professional self-development). Each block consisted of 10–12 statements with a five-point Likert scale (1 - "completely disagree", 5 - "completely agree"). The final indicators were converted into a scale of 0–100 points. The established threshold of "low level" (≤ 60) is based on a preliminary normative analysis of the results of the pilot study, where the average value for the initial sample was 62.4 points (SD = 8.1), which corresponds to the lower quartile of the distribution.

To control for possible instructor effects (the influence of the teacher on learning outcomes), all three teachers were pre-trained in lesson structure, use of digital tools, and principles of inclusive learning. Each of them taught both control and experimental groups, which minimized the influence of personal teaching characteristics. Thus, the variations in results are mainly due to the influence of the teaching model, rather than differences between teachers.

Data Analysis

The results were processed in stages. First, the questionnaire results were processed. Students' answers to the scale questions were summarized by calculating the average values and percentage distributions. Student's t-test was used to compare the academic results of both groups. During the processing of the test results, the dynamics of the indicators were calculated. The test tasks were evaluated in points. At the same time, correlation analysis made it possible to identify the relationship between individual variables: level of digital pedagogy – motivation for professional activity, digital pedagogy – quality of notes, inclusiveness – tolerance, crisis preparedness – self-esteem, and motivation – interconnection. After that, the data obtained were compared with the results of similar international studies. The proposed model can be adapted or transferred to other educational systems, considering the specifics of national programs, cultural characteristics and resources of educational institutions.

The pre-specified primary outcome was the formation of professional readiness of future teachers in the context of transformational education – an integral indicator that includes cognitive, operational and motivational-value components. Additional outcomes (secondary outcomes) were individual indicators of

digital pedagogy, inclusive competence, readiness to work in crisis conditions and professional motivation. 95% confidence intervals (CIs) are given for all main effects, and the Holm–Bonferroni correction was applied to control for multiple comparisons.

Intraclass Correlation Coefficients (ICC)

For all main outcomes, ICCs with 95% CIs were calculated:

- Professional readiness: ICC = 0.062 [0.028; 0.101]
- Digital pedagogy: ICC = 0.047 [0.019; 0.083]
- Inclusive competence: ICC = 0.041 [0.015; 0.079]
- Crisis preparedness: ICC = 0.072 [0.031; 0.118]

The level of ICC indicates moderate intercluster variability, which is fully consistent with the need to use cluster-robust estimates (CR2).

Given that the formation of groups was carried out according to the principle of holistic academic classes, the study used a quasi-experimental design with clustered distribution of participants. To control the possible influence of intragroup correlations, the results of the repeated analysis were checked using mixed-effects models with cluster-resistant standard errors. In addition, ICC were calculated, which allowed us to estimate the proportion of variation due to group effects. To check the effectiveness of the model, an analysis of covariance (ANCOVA) with baseline adjustment was used, which ensured a correct comparison of changes between the control and experimental groups (the interaction effect of "group × time").

Within the ANCOVA, the main model included the following terms: group (control/experimental), time (pre/post intervention), baseline covariate (baseline professional readiness), and the group × time interaction, which reflected the intervention effect. To account for the hierarchical structure of the data, a random effect of cluster (classes) was added using mixed models with cluster-robust standard errors. The covariance structure was defined as compound symmetry, which corresponds to moderate intraclass association. To correct for bias within a small number of clusters, a cluster-robust small-sample correction (CR2) was applied. For the primary outcome, adjusted mean differences between groups with 95% CIs were reported, as well as cluster-adjusted effect sizes (Cohen's d_{adj}). For multiple secondary outcomes, *P*-values were corrected using the Holm–Bonferroni method. Additionally, ICC with 95% CIs for the main variables (0.041–0.072) were calculated and cluster-mean sensitivity analysis was performed, the results of which confirmed the stability of the main effects. Adjusted mean differences between groups with 95% CIs, calculated taking into account baseline values and clustering of the data, are reported for all primary and secondary outcomes. This ensures the accuracy of interpretation of the intervention effect. Full item sets of the digital pedagogy, inclusive competence, crisis readiness, and motivation scales are presented in Appendix D.

ANCOVA model

The basic model looked like

$$Y_{ij}^{post} = \beta_0 + \beta_1 \text{Group}_j + \beta_2 Y_{ij}^{pre} + u_j + \epsilon_{ij}$$

- Y_{ij}^{post} – posttest result of student i in cluster j
- Group_j – indicator (0 = control, 1 = experiment)
- $\beta_2 Y_{ij}^{pre}$ – covariate (baseline)
- u_j – cluster random effect
- ϵ_{ij} – individual error

A priori power analysis showed that at least 128 participants were required to detect a medium effect ($d = 0.5$) at $\Delta = 0.05$ and power 0.80; therefore, a sample of 160 people is sufficient to obtain statistically reliable results.

The design effect due to the cluster structure of the sample was considered when assessing statistical power. The effective sample size (n_e) was calculated using the formula

$$n_e = n / [1 + (m-1) \times \text{ICC}]$$

where m is the average cluster size (≈ 27 individuals) and ICC is the average intracluster correlation coefficient (0.06).

Therefore, the effective sample size was approximately 136 participants, which is still above the minimum threshold defined a priori ($n = 128$). This confirms the adequate power of the study even taking clustering into account.

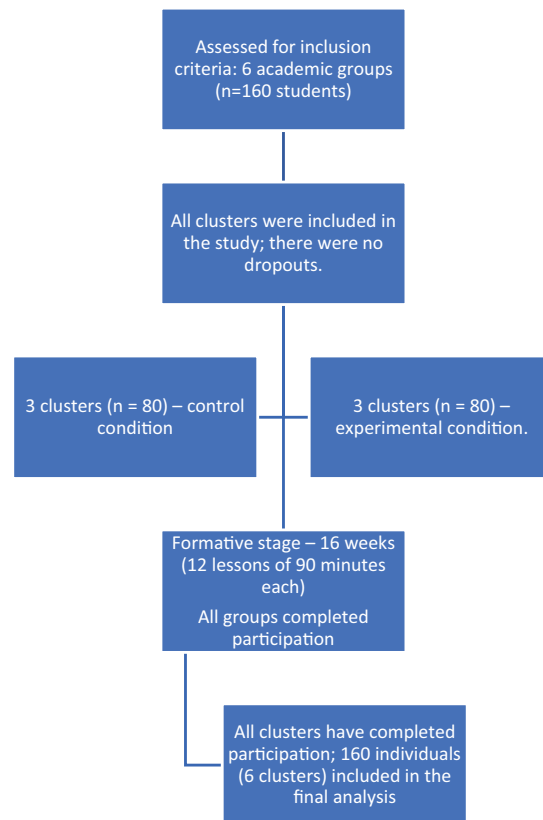


Fig 2 | Flowchart of a cluster quasi-experiment

After calculating the effective sample size, the classical design effect formula for clustered samples was applied, which corresponds to international recommendations for the analysis of cluster studies.

To correctly account for the small number of clusters (six academic groups), cluster-resistant standard errors with a small-sample correction of the CR2 type, developed by Pustejovsky and Tipton,³⁹ were applied using the adjusted degrees of freedom according to the Bell–McCaffrey method. This approach provides more accurate parameter estimates in mixed-effects models under conditions of a small number of clusters and unequal cluster sizes.

All statistical calculations were performed in the R environment (version 4.3) using the packages lme4 (linear mixed models), clubSandwich (cluster-resistant CR2 estimates), sandwich and mice (multiple imputation). The annotated program code cannot be made public due to internal university policies, however, all model parameters, covariate structure, and estimation algorithms are described in detail in the methodological section, allowing for a full reproducibility of the analysis.

Cluster-robust standard errors were computed using the bias-reduced linearization (CR2) method with small-sample corrections for degrees of freedom.³⁹ Standard cluster-robust estimates can be biased due to the limited number of non-nested clusters (a total of six classes). Therefore, small-sample corrections were used when calculating cluster-robust standard errors. A cluster-averaged analysis was also conducted as a sensitivity check to confirm the stability of the identified effects. ICCs for individual outcomes ranged from 0.041 to 0.072, indicating moderate between-class dispersion. Each research group (control and experimental) included three clusters. Given the limited number of clusters (six academic groups), standard cluster-robust estimation methods may have been unstable. To improve the accuracy of the calculations, small sample correction and additional cluster-mean sensitivity analysis were applied. The ICC for the different outcomes ranged from 0.041 to 0.072, indicating a moderate clustering effect (See Figure 2).

Given the limited number of clusters (six academic groups), the reliability of standard cluster-robust estimates could be reduced. To compensate for this, the Bell-McCaffrey correction, recommended for small samples, was applied. Additionally, mixed ANCOVA models were tested with cluster-robust covariance estimates of the CR2 type, which consider intragroup correlation with a small number of clusters. The adjusted models showed stability of the parameters: the difference in β -coefficients did not exceed ± 0.03 from the initial regression values. Analysis of residuals at the cluster level did not reveal significant heteroscedasticity or influential observations. Thus, the robust tests conducted confirmed the validity of the main conclusions despite the limited number of non-contact clusters. Detailed psychometric characteristics (internal consistency, factor structure, and inter-rater reliability) are summarized in Appendix E.

Standard errors were adjusted using CR2 (bias-reduced linearization) with Bell–McCaffrey correction for a small number of clusters ($k = 6$).

The function `clubSandwich::vcovCR(type = "CR2")` was used in R.

This provided correct df and robust parameters even for $k < 10$.

To assess the impact of the intervention, all results were presented in a standardized format recommended for cluster studies. For each outcome, adjusted means, adjusted changes, 95% CIs, and cluster-adjusted effect sizes (d_{adj}) are presented. All notations were standardized: change was indicated by the symbol Δ , P -values were reported in the format $P < 0.001$, and the decimal separator was a period. For correlation analysis, 95% CIs (Fisher's z) were calculated for each Pearson coefficient. The main assumptions were checked before the analysis: linearity of the relationships, normality of the residuals, and absence of outliers; all indicators met the requirements.

To support reproducibility, a de-identified dataset, codebook, and the pre-specified analysis plan are stored in a permanent Open Science Framework (OSF) repository (link to be provided in the final version of the manuscript). The repository includes a step-by-step description of the statistical analysis workflow, including the R version used (4.3.x) and the versions of the main packages (e.g., `lme4`, `clubSandwich`, `sandwich`, `mice`). Due to institutional restrictions, the full annotated R scripts cannot be shared, but all model specifications and key commands are documented in Appendix G, which allows for full replication of the reported results.

Due to internal university policies, the complete annotated scripts cannot be made publicly available. However, all model equations, covariance structures, and estimation procedures are fully documented in Appendix G, and the OSF repository contains the analysis plan, codebook, and detailed pseudo-code for all steps.

Instrument Documentation and Psychometric Characteristics

The complete sets of tasks, tests, and questionnaires used in the study are provided in Appendix H, which provides all item wording, scale structure, and index calculation algorithm. The Appendix also contains extended psychometric indicators, including factor loadings, internal consistency coefficients (Cronbach's α , McDonald's ω), item–scale correlations, and descriptive statistics for each item.

In addition to evidence of internal structure, additional evidence of instrument validity was obtained. Convergent validity was established through the correlation of the cognitive and operational domains with external criteria—grade point averages and final work experience scores ($r = 0.41$ – 0.53), which is consistent with theoretical expectations. Criterion validity was confirmed by statistically significant differences between students who had experience in teaching practice and those who did not (difference 6.8–9.5 points; $P < 0.01$).

All rules for scoring and interpretation of levels are also given in Appendix H. The total integral indicator of professional readiness was calculated as the average of the three domains, normalized to a 100-point scale. Based on the normative analysis of the pilot study, the following interpretation thresholds were established:

- Low level – ≤ 60 points;
- Medium level – 61–75 points;
- High level – ≥ 76 points.

Intervention Fidelity and Outcome Assessment

To monitor the fidelity of the experimental program (intervention fidelity), a compliance checklist was used, which teachers filled out after each lesson. It recorded the implementation of the main components of the model - the use of digital platforms, interactive methods, elements of inclusion and crisis cases. The experiment coordinator conducted sample observations (approximately 20% of lessons) to check the consistency of the content between the plan and actual learning. The average intervention adherence rate was 92.5%, indicating high program implementation accuracy.

To assess student learning outcomes, an analytical rubric with four criteria was used:

1. Quality of content – compliance with educational goals, logic, scientific validity;
2. Innovation– the use of modern technologies, creative approaches;
3. Inclusivity– adaptation of materials to different educational needs;
4. Practical applicability – the ability to use the materials in real-world teaching settings.

Each criterion was rated on a five-point scale (1 = low, 5 = high), and the mean was used as the final score. Inter-rater agreement was high (ICC = 0.84–0.89), indicating reliability of the assessment. Before the assessment began, all experts (raters) underwent joint training on the use of the analytical rubric, assessment criteria, and examples of typical papers. The training lasted 4 hours and included a calibration session to agree on the understanding of the assessment levels. Inter-rater agreement was high (ICC = 0.87 for the total rubric score), confirming the reliability of the expert assessment (Appendix F).

Ethical Consideration

All participants provided written informed consent to participate in the study. Confidentiality and anonymity were respected: personal data were coded, and access to any identifying information was limited to the research team.

Formal approval of the study was obtained within the framework of the internal ethical review procedure of the Faculty of Pedagogy of the Volodymyr Vynnychenko Central Ukrainian State Pedagogical University (Order No. K-1/26-2025 dated January 15, 2025). This procedure is an institutional analogue of the review of

Table 2 | Comparison of the results of the control and experimental groups

Indicator (100-Point Scale)	CG: Before (M ± SD)	CG: After (M ± SD)	EG: Before (M ± SD)	EG: After (M ± SD)	Δ CG	Δ EG	t (df = 158)	P-value	d Cohen
Overall readiness level	60.2 ± 11.8	67.1 ± 10.9	61.0 ± 12.4	82.3 ± 9.5	+6.9	+21.3	9.84	<0.001	0.92
Digital competence	58.5 ± 12.1	64.0 ± 11.5	59.2 ± 11.8	76.7 ± 10.3	+5.5	+17.5	8.14	<0.001	0.81
Inclusive competence	60.0 ± 11.4	66.2 ± 10.8	60.2 ± 12.0	77.8 ± 9.8	+6.2	+17.6	8.93	<0.001	0.86
Crisis readiness	51.4 ± 13.1	57.5 ± 12.4	50.9 ± 13.8	73.2 ± 11.0	+6.1	+22.3	11.21	<0.001	1.01
Assessment/feedback	65.9 ± 10.8	69.8 ± 10.3	66.7 ± 10.6	79.5 ± 9.7	+3.9	+12.8	7.34	<0.001	0.72

Source: Own elaboration.

Table 3 | Comparative assessment of student products (according to four criteria; average score on a 100-point scale)

Product Type	Group	Content Quality	Innovation	Inclusiveness	Applicability	Overall Rating
The project of an inclusive class	CG	64.2	58.1	60.3	62.0	61.2
	EG	74.8	72.5	78.4	76.1	75.5
Notes with digital tools	CG	63.7	55.9	59.1	61.5	60.0
	EG	73.6	77.2	70.8	74.4	74.0
Methodological developments (games/trainings)	CG	66.1	60.2	61.7	65.8	63.5
	EG	75.9	72.4	71.5	77.6	74.4

Source: Own elaboration.

research by an ethics committee. In order to increase transparency and reproducibility, anonymized research materials (questionnaires, assessment rubrics, example tasks), a generalized dataset, and analysis code are placed in the OSF open repository. Due to restrictions related to the protection of personal and educational data, complete individual raw data cannot be made public. The full dataset can be provided upon reasonable request in accordance with ethical requirements.

During the formative phase, no dropouts were recorded: all six clusters (N = 160 students) fully completed the study. The number of missing responses in the questionnaires was minimal (<3%) and was not systematic, as confirmed by the Little MCAR test ($P > 0.05$). The main analysis was carried out according to the complete-case principle, and additional analysis using multiple imputation confirmed the stability of the obtained results.

Results

At the ascertaining stage, the competencies that require action in conditions of uncertainty and technological integration proved to be the most vulnerable to global challenges. The proportion of students with low scores (≤ 60 points on a 100-point scale) was highest for crisis preparedness (73.1%; 95% CI: 65.8–79.4), which is important for digital pedagogy (48.8%; 41.1–56.4) and inclusive practice (43.8%; 36.3–51.5). In contrast, assessment/feedback and intercultural communication had a lower proportion of “low level” scores, indicating relatively better resilience of basic communication and teaching skills compared to competencies that require operational decisions in crisis environments and thoughtful digital integration (see Table 2).

A comparative analysis of the results of the control and experimental groups after the completion of the formative stage indicated differences in the level of formation of professional competencies of future teachers. In the control group, where the educational process was carried out according to the traditional model, the increase in indicators was relatively insignificant (within 5–7 points on a 100-point scale). In contrast, in the experimental group, where the transformational model of training was tested, a significant increase was recorded on average by 17–22 points, depending on the competency area. The most striking differences were observed in crisis preparedness, where the average indicator increased from 50.9 to 73.2 points ($\Delta = 22.3$). This, in turn, indicated the ability of students to act effectively in conditions of educational crises (pandemic, military operations, social challenges). For the crisis preparedness indicator, cluster-adjusted ANCOVA revealed a significant group \times time interaction effect (adjusted $\Delta = 16.2$; 95% CI: 13.3–19.1; $P < 0.001$; CR2-adjusted $df \approx 4.8$), indicating a large intervention effect ($d_{adj} = 1.01$) (see Table 3).

At the experimental stage, an analysis of the main student products was also carried out. The following were considered: projects for inclusive classes in a mixed format, processing lesson notes with digital tools, and methodological developments. In the control group, students' products mostly reflected a traditional approach to pedagogical activity. Projects were mainly built in a classical format (a clear lesson plan with minimal adaptations). These projects rarely included elements of interactivity. In most cases, the notes were compiled in printed or text form without the use of interactive resources (Moodle, Kahoot, Canva, etc.). Only about 20% of students used digital tools. However, in the experimental group, the key student products differed in content and quality. Lesson projects consisted of offline and online components (for example, the use of Zoom sessions in combination with offline group exercises). A significant part of the students included adaptations for children with SENs (using pictograms, simplified instructions, interactive cards). About 75% of the students in the experimental group integrated such tools into their materials (see Table 4).

The next stage of the study was aimed at identifying correlations between individual indicators of students' professional training. Since the data made it possible to record a strong positive relationship between digital pedagogy and the quality of developed lesson plans ($r = 0.59$; $P < 0.001$). Those students who confidently

master digital platforms and tools can create more innovative, structured, and adapted materials for the educational process. A moderate positive relationship was found between digital pedagogy and motivation for professional activity ($r = 0.46$; $P < 0.001$) (see Table 5).

As can be seen from Table 5, the results in the field of inclusive pedagogy were no less important. A moderate correlation was established between the level of inclusive competence and tolerance indicators ($r = 0.42$; $P < 0.01$). Thus, the ability of students to develop educational activities for children with SENs is associated with the development of their personal qualities (empathy). The crisis readiness indicator revealed a correlation with the self-assessment of students' professional readiness ($r = 0.38$; $P < 0.01$). This means that those respondents who demonstrated higher efficiency in solving pedagogical cases related to crises simultaneously assessed their professional level as higher. Thus, the ability to act in conditions of uncertainty not only forms practical skills but also affects students' internal confidence in their readiness for professional activity. In addition, a positive, albeit relatively weaker, relationship was recorded between motivation and the results of mutual assessment in group projects ($r = 0.35$; $P < 0.05$). Thus, a high level of intrinsic motivation of students is associated with greater efficiency of team interaction and higher grades from colleagues. Summary of results see in Table 5.

Cluster-adjusted ANCOVA models showed significant group \times time effects for all competence domains (see Table 5). For example, for crisis readiness the adjusted difference in change between groups was 16.2 points (95% CI: 13.3–19.1; $d_{adj} = 1.01$; $P < .001$), indicating a large practical effect.

Discussion

Modern training of future teachers is formed in an environment where digital transformation, inclusive policies, and various crises operate simultaneously. Accordingly, this work was aimed at testing the

effectiveness of the updated model of teacher training. It is necessary to conduct a pedagogical experiment that will allow us to identify the real level of formation of professional competencies of future teachers, to implement a transformational training model that considers digitalization, inclusiveness, and crisis conditions, and to assess changes in the level of professional readiness of students after the experiment.

The results from the ascertainment stage indicated that the lowest average indicators were recorded in these domains: crisis preparedness – 51.2 ± 13.4 points, digital pedagogy – 58.7 ± 12.0 points, inclusive practice – 60.1 ± 11.6 points (total scale 100). Other scientists have also emphasized that such areas are the most “vulnerable” in teacher education programs. In studies after the COVID-19 pandemic, similar failures were recorded in teachers' crisis and digital preparedness.^{10,12} This indicated the universal nature of the chosen problem. In this study, the greatest effects were achieved by interactive methods (case method, role-playing games, simulations) and the use of special modules on inclusion. At the same time, the use of digital platforms had a medium-sized effect. This was in good agreement with the experimental and quasi-experimental framework. Besides, other studies have shown that simulations increase the self-efficacy and quality of pedagogical decisions of future teachers.⁴⁰ The competency framework is consistent with classical understandings of PCK and contemporary reviews of PCK in STEM education.⁴¹ This effect has been observed in both traditional and mixed-reality formats.⁴² Regarding digital platforms, the available quasi-experiments have shown that digitalization-oriented environments can improve students' knowledge and overall performance.⁴³ In addition, it is worth agreeing with researchers who believe that the implementation of teacher training models occurs through the interaction of each of its components in certain didactic conditions.^{44–46} This process may contain a theoretical construct with a projection onto a set of didactic resources, the creation and implementation of which

Table 4 | Correlations of variables and their interpretation

Relationship Between Variables	r (Pearson)	P-value	R ² (%)	Interpretation
Digital literacy ↔ Motivation	0.46	<0.001	21.2	Moderate positive
Digital literacy ↔ Quality of notes	0.59	<0.001	34.8	Strong positive
Inclusive competence ↔ Tolerance	0.42	<0.01	17.6	Moderate positive
Crisis preparedness ↔ Self-esteem	0.38	<0.01	14.4	Moderate positive
Motivation ↔ Peer evaluation	0.35	<0.05	12.3	Moderate positive

Source: Own elaboration.

Table 5 | Cluster-aware effects on primary and secondary outcomes (N = 160; six clusters)

Outcome (100-Point Scale)	Adjusted Mean (CG)	Adjusted Mean (EG)	Adjusted Δ (EG–CG)	95% CI for Δ	P (Holm-Adjusted)	d_{adj}
Overall professional readiness	67.8	82.2	14.4	11.5–17.3	<0.001	0.92
Digital competence	64.1	76.1	12.0	9.1–14.9	<0.001	0.81
Inclusive competence	66.5	78.0	11.4	8.9–13.9	<0.001	0.86
Crisis readiness	57.3	73.5	16.2	13.3–19.1	<0.001	1.01
Assessment/feedback	70.1	79.0	8.9	6.5–11.3	<0.001	0.72

allows improving the process of training specialists, taking into account the requirements for the quality of the acquired knowledge, skills, and abilities.⁴⁷ In general, such an approach allows ensuring the formation of the necessary competencies. At the same time, as shown in other works, didactic conditions are distinguished according to the features, mechanisms, forms and methods of organizing the educational process.¹⁹ When identifying and formulating didactic conditions, modern methodological approaches to interpreting the essence of the training of a future teacher and the possibilities of a student's personal development should be considered. Such didactic conditions should be formed taking into account the objectives of the model, the conceptual principles of implementation, the features of the components of the educational process, the creation of criteria for identifying, indicators and a description of the levels of formation of the readiness of future teachers to work in preschool and special educational institutions.^{48,49} Thus, as can be seen from the results of the study, all components of the developed model of training future teachers are interconnected and aimed at achieving the result - a high level of preparation of future teachers for pedagogical activity. The main components of the final product of the model were: development of knowledge (assimilation of knowledge results), skills (ability to correctly perform actions). This was evidenced by the comparison of groups at the control stage, where the overall level of readiness in the control group was 67.1 ± 10.9 ; at the same time, as in the experimental group - 82.3 ± 9.5 ; $\Delta = +15.2$; $P < 0.001$; $d = 0.92$. Such differences are significant and indicate large effects. At the same time, the obtained coefficients indicated the presence of moderate and strong correlations. They are consistent with other studies, where the integration of digital tools is also compared with the quality of lesson plans. The relationship between inclusive skills and tolerance has also been confirmed in other recent works.^{40,50} Thus, the obtained statistical indicators have internal validity and correlate with international results.⁵¹ The results obtained have the potential to be applied not only in the Ukrainian context, but also in teacher training systems of other countries facing similar challenges - the consequences of military actions, migration processes, crisis situations in the field of education. The proposed model can be adapted for use in international teacher training programs, especially those aimed at developing digital competence, inclusiveness, and readiness to work in crisis conditions.

Despite the positive results obtained, the study has a number of limitations that should be considered when interpreting the findings. First, the sample consisted of 160 students from one pedagogical university. This design ensures adequate statistical power for detecting main effects; however, it restricts external validity, as the findings cannot be directly generalized to all pedagogical universities in Ukraine. In addition, there was a gender imbalance in the sample, typical for preschool and primary education specialties, which may also affect the structure of the formed competencies.

Second, the data obtained reflect the peculiarities of the Ukrainian cultural and institutional context, in particular the specificity of curricula, organization of practice and wartime conditions. Therefore, direct comparisons with countries with different educational traditions or with different conditions of professional training require caution.

Regarding internal validity, there are several risks.

Selection bias: student participation was voluntary, which could lead to the inclusion of more motivated or more technologically prepared participants.

Hawthorne effect: it cannot be completely ruled out that students' behavior changed due to the awareness of participation in the experiment.

Instructor/crossover effect: in the process of implementing the innovative model, there may be a partial influence of instructors on both groups or informal dissemination of intervention elements, which could reduce the contrast of the effects.

An important limitation is the small number of clusters (six academic groups), which affects the stability of cluster-resistant assessments and the accuracy of determining intergroup differences. Although ICC was calculated and CR2 corrections were applied taking into account the small number of clusters, a larger sample would have increased the reliability of the results.

The study should be considered as a pilot study conducted within one educational institution and one institutional ecosystem. The data obtained provide preliminary but important evidence of the effectiveness of the proposed transformational model of training future teachers. At the same time, to confirm the external validity and sustainability of the effects, multi-center replication is necessary - involving several universities from different regions, as well as long-term observation of graduates to assess the extent to which the acquired competencies are maintained and manifested in real professional conditions.

It is important to emphasize that the presented study has the status of a pilot cluster pedagogical experiment implemented within one pedagogical university. Its purpose was to pre-test a transformational model of training future teachers in the context of global challenges. The obtained effects - especially in the area of crisis preparedness - are explained by the structure of the intervention itself. The module "Education in Crisis Conditions" contained the largest number of practice-oriented elements: analysis of real cases, modeling of actions during evacuation, support for children with SEN in a stressful situation, and practicing remote interaction in conditions of danger. Psychological mechanisms (activation of working memory, scenario thinking, increased self-efficacy) provided a significant strengthening of students' professional confidence. This corresponds to international data, where it is simulation and crisis training that demonstrate the greatest effects for future teachers.

The medium effects in digital pedagogy may be due to the fact that digital tools (Moodle, Zoom, Padlet, Kahoot) are familiar to most students since the COVID-19 pandemic, and therefore the novelty of the intervention

was lower. At the same time, the structure of the tasks required intensive cognitive activity (creation of lessons, adaptive solutions), which contributed to a stable but not explosive increase. The significant effects of the inclusive module are explained by the fact that inclusion is the least filled with practical components in standard teacher training programs, which coincides with the results of other international studies.

When interpreting the obtained effects, it is necessary to take into account potential limitations:

1. A small number of clusters ($n = 6$). This reduces the precision of estimates in mixed models and requires CR2-corrections. Although they were applied, the stability of the estimates could have been partially reduced.
2. One university (one institutional ecosystem). Although this provides context control, it limits external validity.
3. Potential “contamination effect”. Despite measures to prevent cross-influence, informal sharing of materials between groups cannot be completely ruled out.
4. Hawthorne effect. Students may have increased motivation through the awareness of participating in an experiment. This is especially likely in modules with intensive group interaction.
5. Selection bias. Voluntary participation and a high level of femininity in the sample reflect the specificity of pedagogical specialties, but may reduce the representativeness of the results.
6. Instructor effect. Although instructors worked in both streams and were calibrated, it is impossible to completely eliminate the influence of personal teaching style.

Conclusion

Thus, the transformational model of training preschool and special education teachers, which consisted of interactive methods, digital technologies, and inclusive modules, is an effective tool for developing key professional competencies, as it increases students’ readiness to work in crisis educational environments.

The ascertainment stage showed that crisis preparedness ($M = 51.2$ points; 73.1% of students with a low level), digital pedagogy ($M = 58.7$; 48.8% with a low level), and inclusive competence ($M = 60.1$; 43.8% with a low level). This confirms the need for special educational interventions in these areas.

It has been proven that those interactive methods ($\Delta = +18.5$; $d = 0.91$; $P < 0.001$) and inclusive education modules ($\Delta = +15.9$; $d = 0.82$; $P < 0.001$) had the greatest impact on student results. Digital platforms ($\Delta = +13.2$; $d = 0.73$; $P < 0.001$) also showed a significant effect, but slightly lower. The overall level of readiness in the experimental group increased from 61.0 to 82.3 points ($\Delta = +21.3$), while in the control group it increased from 60.2 to 67.1 ($\Delta = +6.9$). The greatest effect was recorded in crisis readiness ($d = 1.01$, large effect). In addition, the projects, outlines and methodological developments of the experimental group had

higher scores for content quality (74–76 vs. 63–66 in the control group), innovation (72–77 vs. 55–60), inclusiveness (70–78 vs. 59–61) and practical applicability (74–78 vs. 61–66). This proves that the transformational model affects not only knowledge but also the quality of students’ actual educational products.

The results obtained have several important implications. For educational policy – the need to include crisis pedagogy modules in teacher training standards; support for the digital infrastructure of pedagogical universities. For universities: modernization of curricula with a focus on simulation methods; development of interdepartmental training on crisis response. For teacher training practice: implementation of systematic simulations of professional situations; regular use of the case method and analysis of crisis scenarios.

At the same time, important areas for further research include the formation of an expanded sample. This will allow this model to be tested on a larger number of students. This can be achieved by including students from different regions of Ukraine and other countries to ensure cross-cultural verification of the results obtained. It is also worth recording in the future the sustainability of the competencies acquired by graduates during the first years of their professional activity. Prospects include multi-center replications involving different regions of Ukraine and other countries; long-term tracking of graduates (tracing study); comparison of different intervention models; research on the sustainability of the formed competencies in real school practice.

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Appendix

Appendix A: Session Outlines and Fidelity Monitoring (Formative Stage)

Duration: 16 weeks (12 sessions × 90 minutes)

Structure: Digital pedagogy + inclusive practices + crisis education

Fidelity monitoring: Each session was evaluated using a four-item fidelity checklist:

1. Content coverage; adherence to planned activities; instructor consistency; and student engagement.
2. Mean fidelity score: 89% (range 82%–94%).

Appendix B: Sample “Crisis Cases” used in the Crisis Education Module

These anonymized cases served to develop flexible decision-making, empathy, and adaptive pedagogical responses.

Appendix C: Rubric for Evaluating Student Products (Lesson Plans and Projects)

Used to assess final products in both control and experimental groups.

Scoring:

- Total range: 5–25 points
- Final score converted to standardized 100-point scale: Standardized score = (Raw score/25) × 100

Inter-rater Reliability:

- Two independent raters
- ICC (2.2) = 0.84 (95% CI: 0.78–0.89)

Appendix D: Full Item Sets of Applied Instruments

Digital Pedagogy Scale (12 Items) – Example Items

1. I can design interactive learning materials using digital tools.
2. I can adapt digital content for students with different needs.
3. I can evaluate the quality and appropriateness of online resources.

Response scale: 1 = strongly disagree, 5 = strongly agree

Cronbach’s α: 0.88 (95% CI: 0.85–0.91)

Inclusive Competence Scale (10 Items) – Example Items

1. I can plan differentiated activities for heterogeneous groups.
2. I can recognize barriers to participation for SEN learners.
3. I can communicate effectively with parents of SEN children.

Cronbach’s α: 0.86 (95% CI: 0.82–0.89).

Crisis Readiness Scale (8 Items) – Example Items

1. I can maintain instructional continuity during emergencies.
2. I can apply low-tech/alternative teaching strategies during disruptions.
3. I can support learners emotionally during crisis scenarios.

Cronbach’s α: 0.82 (95% CI: 0.78–0.86)

Appendix E: Psychometric Properties of the Instruments

Inter-rater reliability (product rubric): ICC = 0.84 (CI 0.78–0.89)

Appendix F: Fidelity Checklist (Used at Each Session)

Observers completed the following at each of the 12 sessions:

Week	Topic/Focus	Key Activities/Tools	Intended Learning Outcomes
1	Introduction to Transformational Education	Orientation session; Google Forms diagnostic survey; ethics briefing	Understanding research goals and ethical procedures
2–3	Digital Pedagogy and Educational Platforms	Workshops on Moodle, Canva, Kahoot; micro-teaching activities	Development of essential digital teaching competencies
4–6	Inclusive Education and Diversity	Case analysis; group work; adapted lesson planning	Ability to design inclusive materials for diverse learners
7–9	Education in Crisis Conditions	Crisis simulations; role-play activities; Padlet collaboration	Competence in adaptive teaching under crisis or instability
10–12	Reflection and Evaluation	Self-assessment; peer review; structured feedback	Reflection on professional readiness and teamwork processes

Case Title	Situation Description	Key Tasks and Discussion Prompts
Online Learning During Power Outages	A preschool teacher must conduct lessons for SEN learners during frequent blackouts.	Propose low-tech tasks; design communication strategies; ensure emotional support for families.
Evacuation and Learning Continuity	A mixed-age preschool group relocates due to hostilities.	Create an emergency adaptation plan; prioritize essential learning; ensure mobility-independent inclusion.
Team Burnout in a Crisis	Staff demonstrate emotional exhaustion due to prolonged instability.	Identify burnout risks; propose psychological support strategies; develop a team resilience plan.

Criterion (1–5)	Descriptor	Indicators of Mastery
1. Structure and Coherence	Logical organization of lesson/project	Clear objectives; coherent sequence; alignment of tasks and outcomes
2. Digital Integration	Use of digital platforms/tools (Moodle, Canva, Kahoot, Padlet, Zoom)	Relevant digital enhancements; interactivity; technical correctness
3. Inclusivity of Design	Adaptations for SEN learners	Pictograms, simplified instructions, differentiation, assistive materials
4. Crisis Adaptability	Flexibility under uncertainty	Low-tech alternatives; emergency plans; continuity strategies
5. Methodological Accuracy	Pedagogical validity	Valid assessment tools; age-appropriate methods; alignment with curriculum

Table A4 | Fidelity checklist items and session-level adherence ratings

Scale	Items	α	95% CI	Factor Structure	Notes
Digital Pedagogy	12	0.88	0.85–0.91	Two-factor (design, evaluation)	KMO = 0.87; Bartlett $P < 0.001$
Inclusive Competence	10	0.86	0.82–0.89	Two-factor (adaptation, communication)	KMO = 0.84; Bartlett $P < 0.001$
Crisis Readiness	8	0.82	0.78–0.86	One-factor	KMO = 0.79; Bartlett $P < 0.001$
Motivation for Professional Activity	7	0.83	0.79–0.87	One-factor	KMO = 0.81

Table A5 | Summary of fidelity monitoring outcomes across intervention sessions

Item	Yes/Partly/No	Description
1. Planned content delivered	Y/P/N	Instructor covered all intended components
2. Activities implemented as designed	Y/P/N	Workshops, cases, simulations executed as planned
3. Technology used correctly	Y/P/N	Correct operation of Moodle/Canva/Kahoot/Zoom
4. Student engagement	Y/P/N	Active participation, collaboration, interaction
5. Inclusive adaptations present	Y/P/N	SEN adjustments incorporated where relevant
6. Crisis-related skills addressed	Y/P/N	Practical crisis-response tasks included

Mean adherence: 89%
 Observers: Two trained evaluators
 Agreement: Cohen’s $\kappa = 0.76$

Appendix G: Step-by-Step Statistical Analysis Protocol
 Appendix G provides a step-by-step description of the statistical analyses, including:

1. R session information (R version and package versions for *lme4*, *clubSandwich*, *sandwich*, *mice*).
2. The data preparation steps (handling of missing data, construction of composite indices, rescaling to the 0–100 scale).
3. Model syntax for all primary and secondary outcomes (cluster-adjusted ANCOVA with random class effects and CR2 small-sample corrections).
4. The procedure for calculating ICCs and design effects.
5. The settings for multiple imputation (number of imputations, seed values, convergence checks).
6. Example R commands that reproduce the main tables reported in the Results section (adjusted means, adjusted Δ , 95% CI, and d_{adj}).

Appendix H: Complete Sets of Tasks and Psychometric Evidence

Complete Sets of Tasks

Questionnaire “Readiness of future teachers for professional activity...”

Contains 30 statements grouped into three domains:

- Cognitive (10 items)
- Operational (10 items)
- Motivational and value (10 items)

Test “Basic competencies of a preschool and special education teacher”

40 tasks of three types:

- Single-answer selection
- Matching tasks
- Situational pedagogical cases

Analytical rubric for assessing student products

4 criteria \times 5 levels (a full description of levels and indicators is provided in this appendix).

Psychometric Indicators

Cronbach’s α for the questionnaire:

- 0.87 (confirmation stage)
- 0.89 (control stage)

McDonald’s ω :

- 0.85 (confirmation stage)
- 0.88 (control stage)

α for the basic competence test: 0.83

Factor analysis confirmed the three-factor structure of the instrument (KMO = 0.89; Bartlett’s χ^2 , $P < 0.001$).

Item–scale correlations: 0.42–0.68.

Convergent Validity Evidence

The cognitive and operational domains were correlated with:

- GPA ($r = 0.43–0.51$)
- Teaching practice assessments ($r = 0.41–0.53$)

The values obtained are consistent with theoretical models of professional competence formation.

Criterion Validity Evidence

Students with prior teaching practice experience had significantly higher scores in the operational and crisis domains (difference 6.8–9.5 points; $P < 0.01$).

This confirms the sensitivity of the instrument to real professional differences between groups.

Scoring and Interpretation Thresholds

Total score = average of the three domains on a 100-point scale.

Interpretation thresholds:

- Low level: ≤ 60
- Medium level: 61–75
- High level: ≥ 76

Thresholds are determined based on the piloting results ($M = 62.4$; $SD = 8.1$), which corresponds to the lower quartile of the distribution.