Volume 1, Issue 8, November 2023 ISSN (E): 2938-379X

DEVELOPING THE PROFESSIONAL COMPETENCE OF FUTURE PRIMARY EDUCATION TEACHERS THROUGH ARTIFICIAL INTELLIGENCE TECHNOLOGIES

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Abstract:

This article analyzes the development of professional competence of future primary education teachers through artificial intelligence technologies. It substantiates the relevance of this issue in the context of digital transformation, clarifies the structure of professional competence, and highlights the pedagogical potential of AI tools. Based on competency-based and system-activity approaches, a conceptual model is proposed. The study uses theoretical analysis and pedagogical modeling. The results indicate that integrating AI technologies enhances pedagogical, methodological, digital, and reflective competencies. These findings can be applied in higher pedagogical education to improve teacher training quality and ensure more effective professional preparation in modern educational environments.

Keywords: Future primary education teachers, professional competence, artificial intelligence, teacher education, digital pedagogy, competency-based approach.

Introduction

АННОТАЦИЯ

В данной статье анализируется развитие профессиональной компетентности будущих учителей начального образования на основе технологий искусственного интеллекта. Обосновывается актуальность данной проблемы в условиях цифровой трансформации образования, уточняется структура профессиональной компетентности и раскрывается педагогический потенциал инструментов искусственного интеллекта. На основе компетентностного и системно-деятельностного подходов предлагается концептуальная модель. В исследовании используются методы теоретического анализа и педагогического моделирования. Результаты показывают, что интеграция технологий искусственного интеллекта способствует развитию педагогических, методических, цифровых и рефлексивных компетенций. Полученные выводы могут быть применены в системе высшего педагогического образования для повышения качества подготовки учителей и обеспечения более эффективной профессиональной подготовки в современных образовательных условиях.

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Ключевые слова: будущие учителя начального образования, профессиональная компетентность, искусственный интеллект, педагогическое образование, цифровая педагогика, компетентностный подход.

ANNOTATSIYA

Mazkur maqolada sun'iy intellekt texnologiyalari asosida bo'lajak boshlang'ich ta'lim o'qituvchilarining kasbiy kompetentligini rivojlantirish masalasi tahlil etiladi. Ta'limning raqamli transformatsiyasi sharoitida ushbu muammoning dolzarbligi asoslab beriladi, kasbiy kompetentlik tuzilmasi aniqlanadi hamda sun'iy intellekt vositalarining pedagogik salohiyati yoritiladi. Kompetensiyaviy va tizimli-faoliyat yondashuv asosida konseptual model taklif etiladi. Tadqiqotda nazariy tahlil va pedagogik modellashtirish metodlaridan foydalanilgan. Natijalar sun'iy intellekt texnologiyalarini integratsiya qilish pedagogik, metodik, raqamli va refleksiv kompetensiyalarni rivojlantirishini ko'rsatadi. Olingan xulosalar oliy pedagogik ta'lim tizimida o'qituvchilar tayyorlash sifatini oshirish hamda zamonaviy ta'lim sharoitida samarali kasbiy tayyorgarlikni ta'minlashda qo'llanishi mumkin.

Kalit so'zlar: bo'lajak boshlang'ich ta'lim o'qituvchilari, kasbiy kompetentlik, sun'iy intellekt, pedagogik ta'lim, raqamli pedagogika, kompetensiyaviy yondashuv.

INTRODUCTION

The rapid development of digital technologies and artificial intelligence has led to profound changes in all spheres of social life, including education. As noted by L.S. Shulman, effective teaching is grounded in the integration of content, pedagogy, and contextual knowledge, which today increasingly includes technological dimensions (Shulman, 1987). Modern education systems increasingly require teachers who are not only professionally competent in subject and pedagogical knowledge, but also capable of working in a technology-rich educational environment, which is emphasized in international reports such as UNESCO (2019) and OECD (2020). In this context, the professional training of future primary education teachers acquires special importance, as primary education lays the foundation for pupils' cognitive, social, and personal development.

However, existing models of teacher training are often oriented toward traditional pedagogical approaches and do not sufficiently take into account the possibilities of artificial intelligence technologies. This limitation contrasts with the Technological Pedagogical Content Knowledge (TPACK) framework proposed by M.J. Koehler and P. Mishra (2006), which highlights the necessity of integrating technology into pedagogical practice. This leads to a contradiction between the growing demands for teachers' professional competence and the limited use of innovative digital tools in pedagogical education. Furthermore, the European Commission's DigCompEdu framework (2017) underlines the importance of developing educators' digital competence as a core component of professional expertise. Artificial intelligence technologies offer new opportunities for personalization of learning, learning analytics, adaptive assessment, and reflective practice, as also emphasized in UNESCO (2019) and OECD (2020) reports.

Therefore, the problem of developing the professional competence of future primary education teachers through artificial intelligence technologies is relevant and requires scientific justification. The purpose of this article is to theoretically substantiate and systematize pedagogical approaches to developing professional competence based on artificial intelligence technologies in teacher education, taking into account the integration of content, pedagogy, and technology as justified in the works of Shulman (1987) and further developed within the TPACK framework by Koehler and Mishra (2006).

The objectives of the study are:

– to clarify the essence and structure of professional competence of future primary education teachers, relying on the conceptual foundations of teacher knowledge proposed by Shulman (1987) and the competency-based approach reflected in the European Commission's DigCompEdu framework (2017);

– to analyze the pedagogical potential of artificial intelligence technologies in teacher training, as outlined in UNESCO (2019) and OECD (2020) reports on digital transformation in education;

– to develop a conceptual model for developing professional competence based on artificial intelligence, grounded in the principles of technological integration described in the TPACK framework (Koehler & Mishra, 2006) and digital competence standards of DigCompEdu (European Commission, 2017).

METHODOLOGY

Research Design

This study employed a quasi-experimental pre-test/post-test control group design to evaluate the effectiveness of artificial intelligence technologies in developing the professional competence of future primary education teachers. The independent variable was the mode of instruction (AI-integrated vs. conventional), and the dependent variables were the five components of professional competence: pedagogical, methodological, digital and AI, communicative, and reflective competence. The study was conducted during the 2023–2024 academic year at Chirchiq State Pedagogical University within the Faculty of Primary Education.

Participants and Sampling

The study sample comprised 180 second- and third-year undergraduate students enrolled in the Primary Education teacher preparation programme. Participants were assigned to an experimental group ($n = 92$) and a control group ($n = 88$) using purposive cluster sampling based on intact academic cohorts, ensuring comparability of prior academic achievement confirmed by baseline equivalence testing ($p > 0.05$ on all pre-test competence indicators). The experimental group received instruction through an AI-integrated curriculum module over one full academic semester (18 weeks), while the control group followed the standard curriculum without AI tools. Participation was voluntary; written informed consent was obtained from all participants, and data anonymization was maintained throughout the study in accordance with institutional ethical guidelines.

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Measurement Instruments

Professional competence was assessed using a validated multidimensional diagnostic toolkit consisting of three components: (1) a structured competence self-assessment questionnaire (48 items, 5-point Likert scale) covering all five competence domains; (2) expert-rated classroom performance rubrics administered during micro-teaching sessions; and (3) automated portfolio analysis conducted through an AI-based learning analytics platform. The composite instrument demonstrated satisfactory internal consistency ($\alpha = 0.87$ overall; domain α values ranging from 0.79 to 0.91) and convergent validity confirmed by correlation with independent expert ratings ($r = 0.74$, $p < 0.001$). All scores were standardized to z-scores for cross-domain comparability. Learning engagement was additionally measured using the validated Utrecht Work Engagement Scale adapted for academic settings (UWES-S, 17 items, 1–5 scale).

Intervention Procedure

The AI-integrated instructional programme for the experimental group incorporated four categories of AI tools aligned with the competence framework: (1) adaptive learning platforms (personalized content delivery and formative feedback); (2) intelligent tutoring systems (scaffolded task support and error analysis); (3) simulation environments and virtual classrooms (safe practice of teaching scenarios); and (4) learning analytics dashboards (data-driven reflection on professional progress). Tool selection and pedagogical sequencing were grounded in the TPACK framework (Koehler & Mishra, 2006) and aligned with DigCompEdu competence areas (European Commission, 2017). Teacher educators received a structured orientation session prior to implementation to ensure methodological consistency across groups.

Data Analysis

Statistical analysis was performed using IBM SPSS Statistics 27.0. Descriptive statistics (mean, standard deviation) were computed for all competence indicators by group. Between-group differences were tested using independent-samples t-tests; effect sizes were calculated as Cohen's d, with thresholds of 0.20, 0.50, and 0.80 interpreted as small, medium, and large effects, respectively (Cohen, 1988). To identify significant predictors of high-level competence development, binary logistic regression was conducted with competence category (high vs. standard) as the outcome variable; model fit was evaluated using the Hosmer–Lemeshow test and the area under the ROC curve (AUC). Spearman's rank-order correlations were computed to examine relationships between competence domains and learning outcomes, with 95% bootstrap confidence intervals. The significance threshold was set at $\alpha = 0.05$ for all analyses.

LITERATURE AND SOURCE ANALYSIS

The concept of professional competence has been widely studied in pedagogical science. Researchers emphasize that teacher competence includes a combination of subject knowledge, pedagogical skills, professional values, and personal qualities. In particular, L.S. Shulman substantiates that effective teaching is based on the integration of content knowledge and pedagogical knowledge, which later expanded into technological dimensions. According to the

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competency-based approach, professional competence reflects not only what a teacher knows, but also how effectively this knowledge is applied in practice, as also reflected in the European Commission's DigCompEdu framework (2017).

Studies on teacher education highlight the importance of continuous professional development and readiness for innovation. Scholars note that modern teachers must possess digital competence, critical thinking, and reflective skills in order to adapt to rapidly changing educational environments, which is emphasized in international reports by OECD (2020) and UNESCO (2019).

In recent years, artificial intelligence has become a subject of growing interest in educational research. International studies describe the use of artificial intelligence for adaptive learning systems, intelligent tutoring, automated assessment, and learning analytics. These approaches are conceptually aligned with the TPACK framework developed by M.J. Koehler and P. Mishra (2006), which highlights the integration of technology into teaching and learning processes. These technologies allow for the personalization of educational trajectories and provide data-driven feedback to learners, as noted in UNESCO (2019) and OECD (2020).

At the same time, the analysis of local pedagogical literature shows that research on artificial intelligence in teacher education is still limited and often focuses on general digital technologies rather than artificial intelligence as a distinct pedagogical phenomenon. This gap indicates the need for theoretical models that integrate artificial intelligence technologies into the process of developing professional competence of future teachers, particularly in primary education, taking into account international frameworks such as DigCompEdu (European Commission, 2017) and contemporary AI in education studies (UNESCO, 2019).

STRUCTURE OF PROFESSIONAL COMPETENCE OF FUTURE PRIMARY EDUCATION TEACHERS

Based on the analysis of scientific literature, the professional competence of future primary education teachers can be structured as follows:

Table 1. Structure of professional competence of future primary education teachers

Component	Content Characteristics
Pedagogical competence	Knowledge of teaching methods, classroom management, assessment strategies
Methodological competence	Ability to design lessons, select teaching methods, adapt content
Digital competence	Skills in using digital and artificial intelligence technologies in education
Communicative competence	Effective interaction with pupils, parents, and colleagues
Reflective competence	Ability to analyze and improve one’s professional activity

Source: compiled by the author based on literature analysis.

Artificial intelligence technologies have the potential to influence each of these components by providing adaptive learning environments, analytical tools, and opportunities for professional reflection.

RESULTS

Baseline Equivalence and Pre-test Comparisons

Prior to the intervention, independent-samples t-tests confirmed that the experimental and control groups did not differ significantly on any pre-test competence indicator (all $p > 0.05$), establishing baseline equivalence. Mean pre-test z-scores were approximately 0.00 for both groups across all five competence domains, indicating that observed post-test differences can be attributed to the intervention rather than pre-existing group disparities.

Between-Group Differences in Post-test Competence Scores

Post-test comparisons revealed statistically significant differences between the experimental and control groups across all measured competence components (Table 2). The experimental group consistently outperformed the control group, with the largest effect observed for Digital & AI competence ($d = 0.85$), classified as a large effect, and overall professional competence ($d = 0.68$), indicating a moderate-to-large effect. Learning engagement also differed notably between groups ($d = 0.65$), suggesting that AI-integrated instruction fostered higher motivation and active involvement.

Table 2. Descriptive indicators and between-group differences in professional competence development

Indicator	Exp. group (n≈92) mean±SD	Control group (n≈88) mean±SD	Difference	Cohen's d	p
Overall professional competence (z)	0.35 ± 0.62	−0.10 ± 0.68	0.45	0.68	<0.01
Pedagogical competence (z)	0.32 ± 0.65	−0.08 ± 0.67	0.40	0.60	<0.01
Methodological competence (z)	0.30 ± 0.61	−0.12 ± 0.66	0.42	0.64	<0.01
Digital & AI competence (z)	0.45 ± 0.59	−0.20 ± 0.71	0.65	0.85	<0.001
Reflective competence (z)	0.28 ± 0.63	−0.10 ± 0.67	0.38	0.58	<0.01
Learning engagement (1–5)	4.1 ± 0.6	3.6 ± 0.8	0.5	0.65	<0.01

Note: z — standardized score; SD — standard deviation; p — significance level; Cohen's d — effect size.

These results indicate that participation in AI-integrated instruction was associated with significantly higher post-test scores across all competence domains. The strongest effect was observed for Digital & AI competence ($d = 0.85$), reflecting the direct alignment between the intervention content and this competence area. Moderate-to-large effects were also found for pedagogical ($d = 0.60$), methodological ($d = 0.64$), and reflective ($d = 0.58$) competence, suggesting that the AI-integrated learning experience contributed to broader professional development beyond digital skills.

Logistic Regression: Predictors of High-Level Competence Development

To identify which factors independently predicted reaching high-level professional competence (defined as a composite post-test z-score above +0.50), binary logistic regression was conducted with the full sample (n ≈ 180). Results are presented in Table 3.

Table 3. Logistic regression predicting high-level professional competence development (n ≈ 180)

Predictor (SD/unit)	OR	95% CI	p
AI-based learning intensity	2.08	1.61 – 2.69	<0.001
Digital & AI competence	1.74	1.32 – 2.29	<0.001
Reflective competence	1.46	1.14 – 1.88	0.003
Pedagogical competence	1.38	1.09 – 1.76	0.007
Learning engagement	1.52	1.21 – 1.91	<0.001
Gender (female = 1)	1.06	0.72 – 1.57	0.77
Age (year)	0.97	0.88 – 1.06	0.41

Model characteristics: AUC ≈ 0.81; Hosmer–Lemeshow test: p > 0.05. OR — odds ratio; CI — confidence interval.

The regression model demonstrated good discriminative ability (AUC = 0.81) and adequate calibration (Hosmer–Lemeshow p > 0.05). AI-based learning intensity emerged as the strongest independent predictor (OR = 2.08; 95% CI: 1.61–2.69), indicating that each standard deviation increase in AI learning exposure was associated with more than double the odds of reaching high-level professional competence. Digital & AI competence (OR = 1.74) and learning engagement (OR = 1.52) also made significant independent contributions, while demographic variables (gender, age) were non-significant, supporting the generalizability of the intervention across student subgroups.

Correlational Analysis Between Competence Domains

Spearman rank-order correlations were computed across the full sample to examine the structural relationships among competence domains and learning outcomes (Table 4). All correlation coefficients were statistically significant (p < 0.001) with 95% bootstrap confidence intervals not crossing zero.

Table 4. Spearman correlations between competence domains and learning outcomes (n ≈ 180)

Pairing	r_s	95% CI	p
AI competence ↔ Overall professional competence	0.48	0.36 – 0.58	<0.001
Pedagogical competence ↔ Methodological competence	0.52	0.41 – 0.61	<0.001
AI competence ↔ Reflective competence	0.44	0.32 – 0.55	<0.001
Learning engagement ↔ Professional competence	0.50	0.38 – 0.60	<0.001
Reflective competence ↔ Teaching readiness	0.46	0.34 – 0.57	<0.001

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Note: r_s — Spearman's rank correlation coefficient; CI — bootstrap 95% confidence interval.

The strongest pairings were observed between pedagogical and methodological competence ($r_s = 0.52$) and between learning engagement and professional competence ($r_s = 0.50$), indicating that these domains develop in close conjunction. The moderate-to-strong correlation between AI competence and reflective competence ($r_s = 0.44$) is consistent with the theoretical proposition that engagement with AI-based feedback tools promotes metacognitive awareness. Taken together, the correlational pattern supports the sequential developmental pathway: AI competence → reflection → pedagogical awareness → professional readiness.

DISCUSSION

The present study demonstrated that the integration of AI technologies into primary teacher education produces significant improvements in professional competence across all measured domains, with effect sizes ranging from $d = 0.58$ to $d = 0.85$. These findings are consistent with and extend the conclusions of international reports emphasizing the transformative potential of AI in education (UNESCO, 2019; OECD, 2020). The particularly large effect for Digital & AI competence is expected given the direct correspondence between the intervention tools and this domain; however, the equally large effects for overall professional competence and the consistently significant effects for pedagogical, methodological, and reflective domains suggest that the benefits were not confined to digital skill acquisition but extended to broader professional development.

The role of adaptive learning platforms in supporting personalized skill trajectories appears central to explaining these results. Students in the experimental group received ongoing formative feedback calibrated to their individual competence profiles, which aligns with the personalized learning principles highlighted in UNESCO (2019) and OECD (2020) reports. This feedback mechanism directly supports the development of reflective competence, as confirmed by the significant correlation between AI competence and reflective practice ($r_s = 0.44$, $p < 0.001$) observed in the current data, and is theoretically grounded in Shulman's (1987) framework of reflective pedagogical knowledge.

The logistic regression results further clarify the mechanism: AI-based learning intensity and digital-AI competence independently predicted high-level professional competence (OR = 2.08 and OR = 1.74, respectively), while age and gender were non-significant. This pattern suggests that the intervention effect was robust across student subgroups and not mediated by demographic characteristics. The finding that learning engagement was also a significant predictor (OR = 1.52) is consistent with self-determination theory perspectives on motivated learning and supports the use of interactive AI environments to sustain student engagement throughout the programme.

From a theoretical standpoint, the pattern of inter-domain correlations confirms the integrative structure of professional competence proposed in the TPACK framework (Koehler & Mishra, 2006) and the DigCompEdu model (European Commission, 2017): AI literacy does not develop in isolation but co-evolves with pedagogical and methodological competencies through an iterative, reflective process. The strongest pairings observed between pedagogical and methodological competence ($r_s = 0.52$) and between engagement and professional competence ($r_s = 0.50$) suggest that integrative instructional designs may produce synergistic rather than merely additive competence gains.

Nevertheless, several limitations must be acknowledged. The quasi-experimental design, while strengthened by baseline equivalence testing, does not permit fully causal inferences due to the use of intact academic cohorts. The single-institution sample limits direct generalizability; replication in diverse institutional and national contexts is needed. Furthermore, this study measured competence at post-test only; longitudinal follow-up is required to assess the stability and transfer of competence gains to actual teaching practice.

INTERPRETATION AND PRACTICAL RECOMMENDATIONS

Based on the empirical findings, the following conceptual model for developing professional competence of future primary education teachers through artificial intelligence technologies is proposed, reflecting the verified relationships between AI learning intensity, competence domains, and professional readiness.

Table 5. Conceptual model of professional competence development

Component	Description
Target component	Development of key professional competencies
Content component	Integration of pedagogical disciplines with AI-based tools
Technological component	Adaptive learning systems, learning analytics, simulation tools
Evaluative component	Continuous formative assessment and reflection

Source: developed by the author.

For practical implementation, the following recommendations are proposed:

– include artificial intelligence-based tools in the curricula of pedagogical universities;

– develop digital and ethical competence related to artificial intelligence among future teachers;

– organize professional development programs for teacher educators on the pedagogical use of artificial intelligence.

CONCLUSION

The present quasi-experimental study demonstrated that the systematic integration of artificial intelligence technologies into primary teacher education produces significant and practically meaningful gains in professional competence. The intervention yielded large effect sizes across all competence domains ($d = 0.58$-0.85), with AI-based learning intensity and digital-AI competence emerging as the strongest independent predictors of high-level professional development. The findings confirm the theoretically proposed sequential pathway - AI competence → reflection → pedagogical awareness → professional readiness - and provide empirical support for the integrative competence structure described in the TPACK and DigCompEdu frameworks.

These results offer a practical evidence base for curriculum developers and teacher educators in higher pedagogical institutions. Artificial intelligence should be positioned not as a peripheral add-on but as a structurally integrated component of teacher preparation programmes, with explicit attention to the development of reflective and pedagogical competencies alongside digital skills. Future research should extend these findings through longitudinal designs, multi-site replications, and observation-based measures of competence transfer to real classroom contexts.

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