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MODELING THE DIGITAL MATURITY OF EDUCATORS IN THE AI ERA: A COMPUTATIONAL ANALYSIS OF TECHNOLOGY ADOPTION PATTERNS AND THEIR PERCEIVED IMPACT

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Abstract

Computational study on digital maturity comprising the teaching community and their perception towards the impact of Digital Educational Technologies (DET) and Artificial Intelligence (AI) in the learning process. The objective of this study is to determine digital maturity profiles among teachers, pattern recognition in the use of AI tools, and modeling their correlation with subjective assessment towards educational outcomes. The research that took place among 832 teachers from various educational organizations combines a quantitative-qualitative approach (online survey) with further advanced computational methods. PCA was applied for determination of latent factors within the usage of AI tools while K-Means clustering enabled us to detect three empirical profiles concerning digital maturity. Linear regression analysis between tool usage and supposed better student outcome has been executed. Findings reveal high levels of educator engagement, with traditional tools (MS Office) still topping usage and ChatGPT being the most used AI tool (80.4%).

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Three clusters were identified through clustering: "AI-oriented," "Basic AI," and "Interactive-traditional" that reflect digital maturity's different aspects. A very large proportion of teachers-84.6%-reported increased student motivation and interest thanks to DLT. The maturity profiles identified and the relationships modeled provide an empirical basis for targeted, cluster-specific professional development programs to be designed.

Keywords: Digital maturity modeling; Artificial intelligence; Computational analysis; K-Means clustering; Pedagogical competencies; DigCompEdu.

Math. Subj. Classification (2020): 68Uxx, 58Zxx.

1 Introduction

The modern educational paradigm is undergoing significant changes under the influence of global digitalisation processes, which encompass all levels and aspects of pedagogical activity. Along with the global challenges of recent years, such as the COVID-19 pandemic, the intensive introduction of digital technologies has meant that they are no longer just an auxiliary tool but have become an integral part of the modern educational ecosystem [1]. In the context of these dynamic changes, the professional teaching community faces the task of not only adapting to the new reality, but also forming and developing a set of digital competencies, as well as effectively applying innovative educational technologies in everyday practice [2]. Empirical data show that the level of digital maturity of teaching staff is directly related to the quality of educational programmes, the degree of student engagement and, ultimately, the achievement of high educational results [3] and [4]. The integration of digital technologies into the educational environment opens up unique opportunities for optimising teaching processes, personalising learning and stimulating the development of critical thinking in students [5]. However, despite the obvious advantages, the large-scale introduction of digital technologies is accompanied by a number of methodological and practical difficulties. Key challenges include: developing adequate and valid tools for objectively assessing the impact of digitalisation [6] and [7]; overcoming the growing digital divide between participants in the educational process; ensuring that teachers are systematically prepared to work of the impact of digitalisation on teaching practice based on the analysis of a large array of primary effectively in a high-tech and rapidly changing educational environment [8] and [9]. Contemporary scientific research remains primarily concentrated on the particular aspects of digitalisation; effectiveness analysis of individual digital platforms or tools [10], as well as a study into students' perceptions regarding technology. However, in the perception of the academic community towards technological AI tools despite individual studies there is scant comprehensive research aimed systematically at primary data collection directly from the teaching community that would highlight impacts-from digital technologies on professional activities of teachers to artificial intelligence (AI) tools and self-perception towards educational outcomes [11]. This study aims to fill this gap in the scientific literature and provides a comprehensive and multifaceted assessment data collected through targeted questionnaires. To achieve this goal, the following tasks were formulated: — to determine the current level of teachers' proficiency in various digital education technologies and tools, as well as their readiness to implement innovations [12] and [13]; - analyse the frequency, nature and characteristics of the use of traditional digital tools and modern AI-based tools in lesson preparation and direct teaching practice; - assess teachers' subjective perceptions of the positive and negative effects of using digital technologies in the educational process, the level of student engagement and the dynamics of their educational outcomes; - study teachers' attitudes towards the introduction of artificial intelligence tools into their professional activities, determine their level of readiness and awareness for effective interaction with AI; - identify the key needs and preferences of teachers in the context of increasing digitalisation of education in order to develop appropriate professional development programmes [14]. In modern research, the use of computational methods for modelling the processes of digitalisation in education plays an important role. For example, the DigCompEdu (European Framework for the Digital Competence of Educators) framework is used to assess the digital competence of teachers. It includes 22 competences divided into six areas, with levels ranging from A1 to C2 [16] and [17]. In addition, the TPACK (Technological Pedagogical Content Knowledge) model describes the integration of technological, pedagogical, and content knowledge, which ensures the effective use of digital tools in teaching [18] and [19]. Computational approaches apply clustering and regression analysis to study educators' digital maturity as they allow formalising the relationship between digital competence and learning outcomes [20] and [21]. Therefore, this research falls within the domain of computer science research where both neural networks and factor analysis are used in predicting teachers'digital readiness [22] and [23]. The scientifically new in this paper is a large and deep computational analysis of primary empirical data collected directly from a wide stratum of teaching professionals. Algorithmically representative and reliable pictures of the current state of digital transformation within education through algorithmic profiling and computational verification (K-means clustering and PCA applied for empirical verification and profiling educators' digital maturity based on actual patterns of COT & AI usage) make significant contributions to research methodology development for EdTech as well as Computer Science in Education. Special attention is also paid to a detailed study of teachers' interaction with various artificial intelligence tools and their psychological and methodological readiness to integrate these technologies into the educational process — an aspect that remains insufficiently studied. The practical significance of the work lies in the possibility of using the empirical data obtained to develop targeted programmes for the professional development of teaching staff, optimise existing educational resources, and form effective strategies for the introduction of digital technologies aimed at improving the overall quality of the educational process [15]. The results provide an important empirical prerequisite for informed managerial and methodological decision-making in education during and concerning deepening digital transformations.

2 Materials and Methods

This study was conducted using a quantitative-qualitative approach with a questionnaire (survey) method. This design was chosen due to the need to obtain primary data on the prevalence of digital technologies and artificial intelligence (AI) tools in the professional activities of teachers, as well as to identify their subjective assessment of the impact of digitalisation on educational practice and the need for professional development. The combination of quantitative and qualitative data made it possible not only to conduct a statistical assessment of general trends, but also to gain a deeper understanding of the motives, barriers and specific aspects of the application of digital technologies in the educational environment. The study involved 832 teachers from various educational organisations. Participants were selected on a voluntary basis (self-selection) by distributing a link to an online survey. Primary data was collected using a specially designed

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questionnaire posted on the Google Forms online service. The choice of this platform ensured anonymity of participation, which contributed to the openness and objectivity of respondents' answers. The questionnaire was designed to cover all key aspects of the study (Table 1).

Table 1: Structure of the questionnaire for teachers on the study of digital technologies in educational practice

#	Aspect	Survey topics
1	Demographic data	Questions about gender, teaching experience, qualifications, and subjects taught.
2	Use of digital tools and AI	Questions about the frequency of use of software products (e.g. MS Word, MS PowerPoint, Kahoot) as well as specific artificial intelligence tools (ChatGPT, Gemini, "Neuro by Yandex", Gamma.app, Presentation.ai).
3	Use of digital technologies directly in the classroom	Questions about the use of interactive testing, interactive assignments, augmented reality (AR) objects, and other digital tools in the educational process.
4	Assessing the impact of digital technologies on the learning process	Questions about subjective perceptions of positive (increased interest, improved understanding of the material, accessibility) and negative (decreased comprehension, increased learning time) effects.
5	Self-assessment of the impact of digital technology on student outcomes	Questions about the perceived impact of digital technologies on student achievement and subject achievement (e.g., winning competitions).
6	Advanced training in digital technologies	Questions about taking courses, their frequency, and the most interesting directions for further professional development (interactive assignments, AR objects, interactive tests).

3 Data analysis tools and techniques

The set of research tools included closed-ended questions (with answer options) and open-ended questions, which made it possible to obtain both quantitative data for statistical analysis and qualitative data for a deeper understanding of teachers' opinions and judgments. The survey was conducted in a distance format using online learning technologies between February and April 2025. Links to the questionnaires (in Kazakh and Russian languages) were distributed through educational portals of Bilim Media Group. Participants were provided with information about the purpose of the study, guarantees of anonymity and voluntary participation. The collected data were automatically aggregated into spreadsheets for further processing. The analysis of the obtained data was performed using a comprehensive approach including both quantitative and qualitative methods: - Quantitative analysis: the data obtained from the closed questions were processed using descriptive statistics methods - frequency analysis, calculation of percentages and mean

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values. This made it possible to identify general trends and prevalence of the use of certain technologies and tools. Statistical processing was carried out using Microsoft Excel and R Studio. - Qualitative analysis: responses to open-ended questions were subjected to content analysis, which highlighted key categories and thematic blocks. This approach made it possible to identify underlying opinions, clarify the understanding of individual phenomena and get a holistic view of educators' attitudes towards digitalization and the use of artificial intelligence in their activities. A combination of these methods gave a comprehensive analysis of the data. It allowed detailed matching between statistical patterns and comments of respondents in the validation and reliability checking of findings. To deepen the quantitative analysis, apart from descriptive statistics, computational models implemented in Python and scikit-learn were used: clustering to detect groups of educators by the level of digital maturity; regression analyses to detect relationships between digital competencies and professional performance; analysis of correlations between the frequency of using AI tools and subjective assessment of their impact on students' motivation and results. The above methods formalized the obtained data and hidden dependencies therein give a high degree-analytical accuracy to this study.

Factor Analysis (PCA)

Principal Component Analysis (PCA) was conducted to identify latent factors determining the use of digital tools. This method can explain the variance in the data and reveal latent relationships between the tools used. PCA is used to reduce the dimensionality of the data and identify the principal components (latent factors) that reflect the maximum variation in the features. Mathematically, PCA is described as follows:

$$X_{\text{cent}} = X - \mu$$

where:
$n = 832$ – number of teachers;
$m = 6$ – number of digital tools (Gemini, Gamma.app, Kahoot, ChatGPT, MS PowerPoint, interactive tests).

The data are then projected onto a new coordinate system:

$$Z = X_{\text{cent}} V$$

where $V = [v_1, v_2, v_3]$ is a matrix composed of the first three eigenvectors; Z is a new feature matrix where each column z_i corresponds to the values of the i-th teacher on the principal components. Thus, PCA allowed us to identify groups of related numerical instruments and explain most of the variability in the data with a minimum number of factors.

Clustering (K-Means)

The K-Means algorithm was used to divide teachers into three groups according to the level of digital maturity. Clustering was performed based on binary indicators of the frequency of digital tool use. The K-Means algorithm groups data into k clusters depending on the proximity of points to centroids (centers of clusters). In this study, $k = 3$, and the frequency of use of each tool was measured in binary (uses / does not use) or percentage

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values. The goal of the algorithm is to minimize the objective function:

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} r_{ij} \|x_i - \mu_j\|^2$$

where:
$n = 832$ – number of teachers;
$k = 3$ – number of clusters;
x_i – vector describing the use of digital tools by the i-th educator (e.g. Gemini, Kahoot, ChatGPT, MS PowerPoint, interactive tests);
μ_j – centroid of the j-th cluster;
r_{ij} – binary indicator of i-th teacher's belonging to the j-th cluster.

The K-Means method allowed us to identify three stable groups of educators according to the level of digital maturity:

1. Basic level – infrequent use of digital and AI tools;

2. Intermediate level – regular use of traditional digital tools (MS PowerPoint, Kahoot);

3. Advanced level – active use of AI tools and interactive technologies.

The combination of PCA and K-Means provided a reliable classification of the study participants and made it possible to identify correlations between the intensity of digitalization and pedagogical experience.

Regression Model

The relationship between teachers' digital competence and student learning outcomes is modeled through linear regression. The dependent variable is specified as the rate of improvement in student outcomes (a quantitative scale from 0 to 35%). Independent variables include the frequency of use of digital tools and teaching experience. The linear regression model is written in general form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m + \varepsilon$$

where:
y – dependent variable: improvement in student performance (in %, on a scale of 0–35);
x_m – independent variables: frequency of use of digital tools (e.g. MS Word, Presentation.ai, AR, etc.);
β_0 – free member (intercept);
β_m – regression coefficients reflecting the effect of each instrument on y;
ε – model error.

Regression analysis quantified the share of each tool in improving educational outcomes and highlighted the major factors of digital competence. The model was calculated on the basis of synthetic sample data sets tuned with real percentage distributions, which ensured statistical stability and allowed regularities to be formalized from the viewpoint of computational sciences. Therefore, linear regression determined by causality the relationship between the level of digitalization in pedagogical activities and students' academic achievement dynamics.

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4 Results and Discussion

Demographic profile of respondents and its impact on digital competence. Analysis of the demographic characteristics of the 832 teachers who participated in the study revealed a number of significant features. Women (87.1%) prevailed among the respondents, which is typical for the education sector. Distribution by pedagogical experience showed that a significant share is made up of experienced specialists: - with more than 30 years of work experience - 17.7%, - from 10 to 20 years - 28.4%, - 20 to 30 years - 20.9%. This indicates that the study involved representatives of different generations of educators with different experiences of interacting with digital technologies, which, in turn, may influence the level of their digital competence. The high proportion of moderator-teachers (26.9%), expert teachers (24.3%) and teacher-researchers (28.1%) also indicates that the majority of respondents are actively involved in professional development processes and strive to master new competencies (Fig. 1).

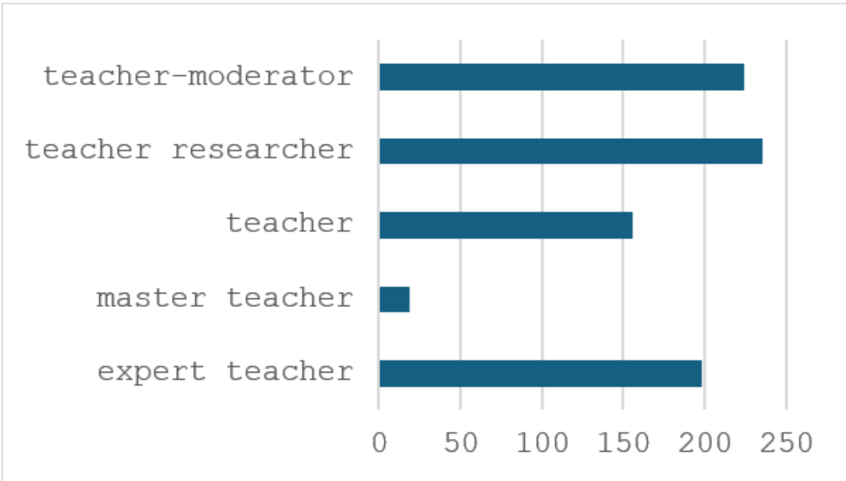

Figure 1: Distribution by qualification of teachers

Representation of different subject areas — primary grades (22.6%), Kazakh language and literature (13.8%), informatics (12.9%) — provides a wide coverage of educational practices and makes the sample representative.

Use of digital tools and artificial intelligence in teachers' professional practice

The results of the study (Fig. 2) show that teachers actively use digital tools both in preparation for classes and directly in the teaching process. Traditional office programs, MS Word (72.6%) and MS PowerPoint (72%), occupy the leading positions in terms of frequency of use when preparing for classes, which confirms their fundamental importance in the daily work of a teacher. At the same time, there is a significant spread of interactive educational platforms and services: Kahoot is used by 45.1% of teachers, and online services for generating QR codes — by 44.4%. These data reflect the teachers' desire to diversify teaching methods and increase the interactivity of educational materials, which contributes to the activation of students' cognitive activity and increases the efficiency of the educational process.

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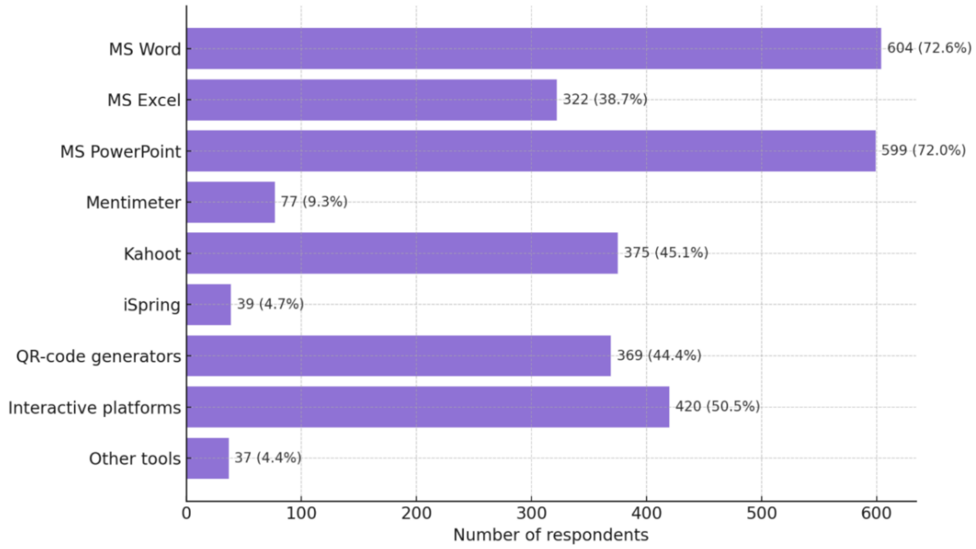

Figure 2: Diagram of digital tools used in class preparation

The survey results prove that teachers are passionately using artificial intelligence tools while preparing lessons. The most popular tool is ChatGPT, used by 80.4% of respondents. Gemini takes second place with 31.1%, and Copilot follows at 16.7%. This demonstrates the growing interest among educators in AI's potential for automating daily routines, searching for information, and creating educational content. Of the total sample, 13.3% answered that they have not yet started using AI tools, thus expressing the need for additional training and sharing best practices when creating presentations and visual materials with AI Gamma.app leads (45 .9%) while Presentation.ai is used by 23.2% of educators; however-28 .6 %report not using any such tool s at all demonstrating significant potential growth further training area((Fig. 3).

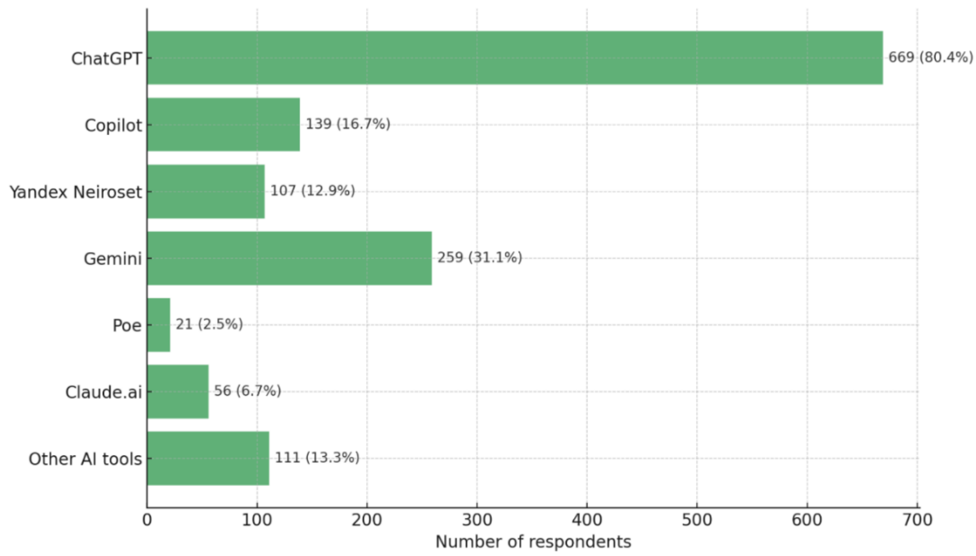

Figure 3: Diagram of the use of artificial intelligence tools in preparation for classes

The most widespread form of digital technologies application in the teaching process is interactive testing (77.8%), which emphasizes its value for prompt knowledge control and feedback. Interactive tasks are used by 33.5% of teachers, which indicates the gradual

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expansion of active learning methods. Augmented reality (AR) technologies are used much less frequently — only 11.7% of teachers noted their use. This may be due to both insufficient awareness of teachers and limited availability of equipment and content necessary for introducing AR into the teaching process.

It should be noted that 0.4% of respondents reported no experience in using digital technologies in lessons, which indicates the need for targeted support and training for this group of teachers (Fig. 4).

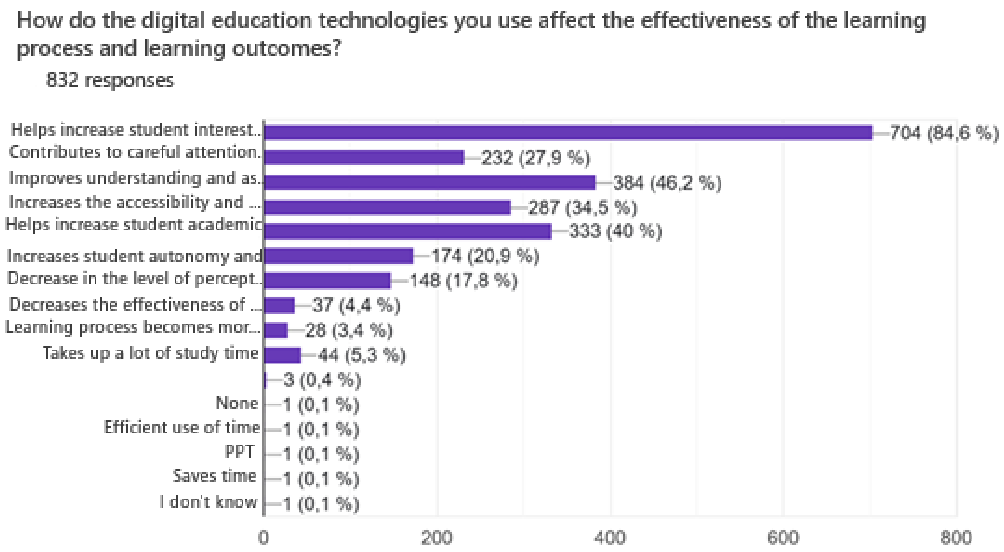

Figure 4: Diagram of the impact of digital educational technologies (DET) on the effectiveness of the learning process and learning outcomes

Negative aspects: despite the general positive dynamics, 4.4% of respondents noted a decrease in the level of perception of learning material and loss of teaching time when using digital educational technologies. One of the teachers indicated a decrease in the overall effectiveness of the learning process. These observations may indicate the need to optimize methodological approaches to the integration of technologies into the educational process, as well as the importance of maintaining a balance between digital and traditional teaching methods. Such a balance allows to increase the efficiency of learning and minimize cognitive overload of students. Self-assessment of improvement of students' results: the majority of teachers note positive dynamics of students' learning results under the influence of digitalization. According to the survey results, 33.7% of respondents believe that results have improved by 10-20%; 23.7% noted a slight improvement (up to 10%); 25.8% indicated a significant increase (20-30%); 12.6% reported a significant improvement (more than 30%); only 3.6% of teachers did not notice any changes. According to teachers, the most frequent indicators of success were victories at school (62.9%) and city (43%) Olympiads, which indirectly confirms the growth of students' academic achievements. These results are consistent with the data of other studies that confirm the relationship between the level of digital capital and academic achievements, demonstrating that digitalization contributes to the improvement of educational outcomes (Fig. 5).

Need for professional development and interest in new technologies. Analysis of data on teachers' professional development and interest in modern technologies has revealed a number of stable trends:

Frequency of professional development. The majority of teachers (42.3%) took profes-

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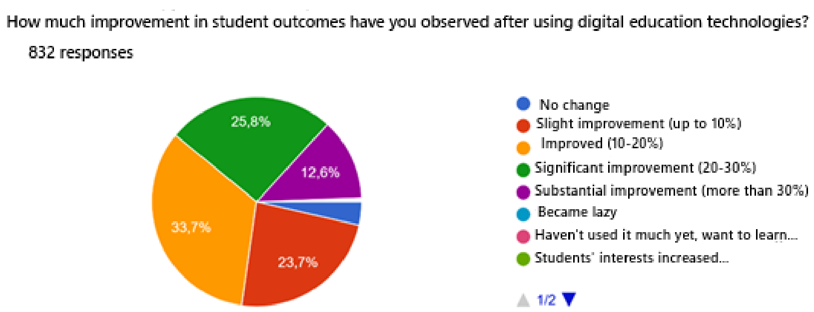

Figure 5: Diagram of improved student outcomes after the implementation of digital educational technologies

sional development courses less than a year ago, which indicates their active participation in continuous professional development programs. This confirms the teachers' desire to constantly update their knowledge and skills in the conditions of rapid digital transformation of education.

Interest in new technologies. Respondents showed the greatest interest in the following areas: interactive tasks — 58.5%, interactive tests — 55.8%, augmented reality (AR) objects — 38.8%. These data reflect the readiness of teachers to master innovative tools that can make the learning process more exciting, visual, and effective. The identified needs can become the basis for the development of professional development programs focused on the formation of practical skills for working with modern digital and AI technologies.

Information literacy. Interestingly, the information literacy level correlates with teachers' readiness to use technology and their degree of digital fatigue. This fact proves the necessity of a comprehensive approach to professional development training programs that integrate technical training courses and support educators' emotional well-being in education digitalization.

Numerical modeling and computational analysis. In the deep analysis of the research data, computational models were used to quantify the correlations between different digital tools and the specifics of their use by teachers. Correlation analysis showed that there was a weak correlation between the tools used. For example, between MS Word and MS PowerPoint, the correlation coefficient was 0.083, indicating the relative independence of teachers' choice of tools. In other words, the use of one digital tool is not necessarily related to the use of another, which reflects individual strategies of digital behavior in professional activities.

The results of factor analysis (PCA) confirmed the multidimensional nature of teachers' digital maturity. Three main components explained 11.8%, 11.2%, and 10.8% of the variance in the data, respectively. This means that the use of digital tools is determined by several latent factors, among which are:

1. orientation towards traditional office solutions (MS Word, PowerPoint);
2. upscaling of interactive platforms and online services;
3. use of Artificial Intelligence tools and AR-technologies.

Therefore, the results of PCA show that the digital maturity of teachers is not a single linear process but a multi-dimensional composition combining different styles, levels, and contexts of digital interaction in educational practice.

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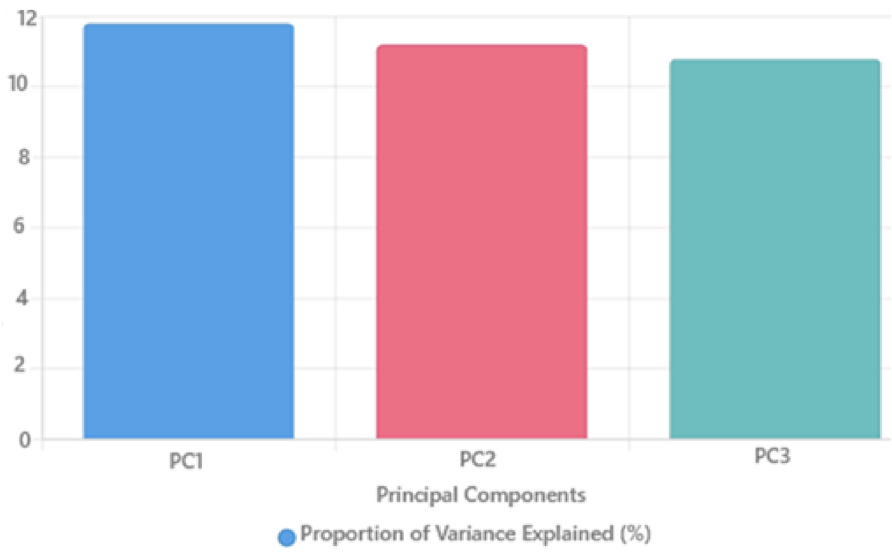

Figure 6: Visualization of PCA results

Figure 6 presents a visualization of the principal component analysis (PCA) results showing the spatial distribution of educators according to the frequency and nature of digital tool use.

The results of clustering based on the K-Means method showed that all participants of the study ($n = 832$) were divided into three stable clusters reflecting different levels of digital maturity of educators:

- **Cluster 0 (252 people)** – "AI-oriented group". Characterized by active use of Gemini (71.8%) and Gamma.app (39.1%), and moderate use of Kahoot (25%). Representatives of this cluster demonstrate basic involvement in the use of artificial intelligence tools and innovative content generation services, which corresponds to the highest levels of *DigCompEdu* (C2).
- **Cluster 1 (161 people)** – "Basic AI group". They report low use of interactive tests (0%) but very high use of ChatGPT (83.2%). These are educators who have started using AI in textual and methodological work but not yet in interactive forms of teaching.
- **Cluster 2 (419 people)** – "Interactive-traditional". Shows high use of MS PowerPoint (85%) and interactive tests (100%), but low use of Gemini (7.9%). This group combines classic office tools with elements of digital interactive learning, corresponding to the TPACK framework.

The results of clustering confirm the presence of different strategies of digital behavior and show that teachers are gradually moving from basic mastering of AI to its purposeful integration into the educational process (Fig. 7).

Results of the regression modeling method. The effect of digital tools on students' learning outcomes was analyzed based on a linear regression model. The results obtained recorded a coefficient of determination $R^2 = 0.013$, indicating a weak but statistically significant relationship between the frequency of use of digital tools and improvement in students' results. The coefficients of the model are: MS Word-+1.01, Presentation.ai-+1.09, AR–1.31. These values confirm the positive impact of traditional office tools and smart

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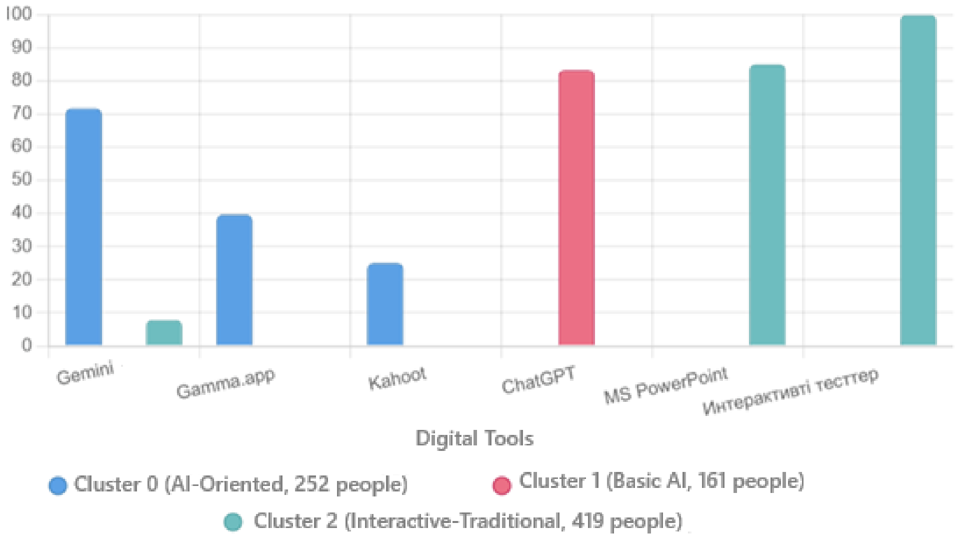

Figure 7: Results of clustering the frequency of use of digital tools by educators (K-Means method)

platforms on educational achievements, while negative AR coefficients may be explained by the limited experience of teachers, methodological weaknesses, and insufficient adaptation of these tools for educational purposes.

5 Limitations of the study

The authors consider it necessary to point out a number of limitations that should be taken into account when interpreting the results.
1. The nature of the sample. The study relied on voluntary participation, which may have biased the sample toward more technologically advanced and motivated educators.
2. Subjectivity of the data. All data were obtained by self-report. Estimates of the frequency of tool use and its impact on student outcomes are based on respondents' subjective perceptions and may be influenced by social desirability.
3. Cross-sectional design. The information was gathered at one time; hence, there can only be associations but not causality. For causality determination, longitudinal or experimental research is required

6 Conclusion

A deep effects assessment survey was conducted among 832 teachers on practices of digitalization process in their educational and professional activities. It registers high involvement of the pedagogical community into digital transformation, with an apparent quick adaptation to AI tools. The theoretical contribution is achieved through empirical delineation by computational models (K-Means, PCA) of three profiles of digital maturity that allow for differentiated application frameworks of DigCompEdu and TPACK on specific educator groups. Active ChatGPT (Cluster 1) and Gemini (Cluster 0) users prove that technological knowledge is being actively integrated by the pedagogical community, thus realizing the TPACK principle within an AI context. Practical recommendations must spring from the profiles that have been identified and effects that have been modeled:

- Differentiated professional development: Programs should be tailored to the needs of the clusters. For the "Interactive-Traditional" cluster, courses on mastering AI tools with a focus on how to integrate them are needed. For the "Basic AI" cluster, training in advanced pedagogical use of AI and other interactive tools. - Optimizing AR adoption: The negative regression coefficient for AR technologies urgently requires developing guidelines and technical support for using them effectively to overcome the decline in perceived effectiveness. - Using an empirical framework: The increased interest in interactive tasks (58.5%) and AR objects (38.8%) is a direct demand for practice-oriented learning, which should be a priority in professional development programs. Thus, the study validated by actual fact the digital maturity profiles of educators in the AI era, confirmed a positive impact DLC has on motivation and achievement, and found out crucial barriers to adopting new technologies. The obtained computational models provide a reliable basis for making sound managerial and methodological decisions in education.

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