

The object of the study is the method for assessing the level of digital competencies of higher education teachers. Teachers with a high level of digital competencies can create more interactive, interesting and more effective learning materials, which has a positive impact on education quality. The ability to ensure the continuity and quality of the educational process in remote conditions is relevant. To improve the qualification level of teachers, it is necessary to form a measuring system of indicators. A method for calculating the potential for changing the digital competency level was developed and trajectories of forming digital competencies of higher education teachers based on the project-vector methodology were formed. The method was implemented and verified as part of the state project in the Republic of Kazakhstan with the participation of the Higher Education Development National Center and Astana IT University. Testing of 62 teachers of Astana IT University, Karaganda Buketov University and Toraighyrov University was taken as a basis. The analysis involved measuring the achievement of their competency level in four categories: didactic, design, monitoring, and personal. The results obtained allow a systematic approach to the process of assessing and forming the competencies of higher education teachers. The result obtained is due to integrating the project-vector management methodology into the process of digital competency assessment. The value of the method is the possibility of using it both personally by teachers to track the level of competency achievement, and by the management of higher educational institutions for motivation and when signing contracts. In the future, the results of the pilot project are planned to be distributed to other higher education institutions in the Republic of Kazakhstan. And then extend its results to higher education institutions in Central Asia and Eastern Europe

Keywords: digital competencies, higher education, competency assessment, multidimensional polytope, project-vector management

UDC 04.032.26

DOI: 10.15587/1729-4061.2024.308983

DEVELOPMENT OF A METHOD FOR ASSESSING THE LEVEL OF DIGITAL COMPETENCIES OF HIGHER EDUCATION TEACHERS BASED ON THE CALCULATION OF THE MULTIDIMENSIONAL POLYTOPE VOLUME

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Received date 10.05.2024
Accepted date 12.07.2024
Published date 30.08.2024

How to Cite: Mukhatayev, A., Omirbayev, S., Kuchanskyi, O., Biloshchytskyi, A., Biloshchytska, S., Omarova, S. (2024). Development of a method for assessing the level of digital competencies of higher education teachers based on the calculation of the multidimensional polytope volume. *Eastern-European Journal of Enterprise Technologies*, 4 (4 (130)), 26–34. <https://doi.org/10.15587/1729-4061.2024.308983>

1. Introduction

Over the past decade, there has been a rapid increase in the number of different methods, tools, and concepts for

measuring the level of digital competencies in different target groups. This direction has become especially relevant in higher education during the COVID-19 pandemic. Since for successful mastering of knowledge by students, as well as improving

the qualification level of teachers of higher education institutions, it is necessary to form a measuring system of indicators to determine the level of achievement of learning outcomes. In the context of distance learning and advanced training, the process of achieving learning outcomes may differ.

To improve teachers' digital skills and ensure a high level of digital literacy, digital competency frameworks are being created. The creation of digital competency frameworks has an important impact on the higher education system, contributing to raising teachers' digital competencies and improving education quality. Research in this area is important for the development of digital competencies in terms of creating tools and methods for competency assessment, integrating digital technologies and introducing innovative teaching methods. The study also aims to bring the national education system closer to international standards, reduce the digital divide and stimulate the development of the digital economy in the country.

An important task in building digital competency assessment methods is to study the reliability and validity of the methods and tools that implement them. The task is also to ensure the versatility of the developed competency assessment method, because for the most part, existing approaches are rigidly tied either to the international digital competency system, or to one's own system. Moreover, changing the components of the system often leads to a restructuring of the entire method. It is also important to take a systematic approach to assessment with a detailed understanding of all the processes associated with acquiring appropriate digital competencies. Therefore, it is urgent to develop a method for assessing the level of digital competencies of teachers of higher educational institutions and masters studying in pedagogical specialties. This is important for building the digital literacy of citizens. Such a method should be versatile, that is, flexible to changes in the digital competency framework. This is due to the fact that the digital competency framework is updated regularly. Some competencies lose their relevance, while others need to be included in the system for measuring the level of digital literacy of citizens.

2. Literature review and problem statement

Significant development of competency-based learning, measuring the level of digital competencies began about twenty years ago. The concept of digital competencies was formed gradually with the development of information technology, cyber security, etc. At the moment, this concept is identical to the concepts of digital literacy, information literacy, e-skills, e-competencies, and so on. To unify this area, digital competency frameworks have been developed for different target groups. In particular, DigComp Frameworks for Citizens [1] were developed in the European Union, which are updated periodically, and the digital competency strategy for teachers ISTE [2] and the NETS model for students' digital skills were created in the USA. The UNESCO ICT Competency Framework for Teachers [3] was also published, which forms general digital competency standards for teachers. Similar standards are defined in the DigCompEdu framework [4], which is based on European educational standards. Overall, each country, in addition to the general framework, has its own digital competency frameworks. These frameworks are formed and adjusted according to the needs of the IT industry, social, age and other characteristics

of the population in these countries. There are also attempts to adapt the European digital competency frameworks to the needs of these countries. In particular, the process of implementing the DigComp standard in Ukraine is described in [5, 6]. So, at the moment, there are dozens of digital competency frameworks in force, and the formation of policies for ensuring citizens' digital competencies is a complex process that is not only in the methodological, but also in the legislative field. That is why there is a shift in emphasis from forming new frameworks and editing existing ones to directly creating specific competency evaluation indices and interpreting them. This is described in more detail in [7, 8], which provide an overview of solutions for digital competency assessment. However, an unsolved part of the problem is to assess the level of digital competencies of higher education teachers, which allows tracking their progress over time and calculating the potential for their change. Competency assessment is often based on subjective opinions of experts, and the mathematical apparatus is insufficient in terms of scientifically based assessment of the digital competency level of higher education teachers.

Most competency assessment methods are based on a quantitative survey, testing or interview, as well as working in focus groups. For example, in [9], the validity of digital competency assessment based on modeling is investigated. The study involved 4,048 senior students who were selected in January 2005 for the ETS ICT Literacy Assessment. However, this paper used the author's system of competencies, which is not reflected in international assessment systems. [10] examines the relationship between age and ICT competencies. The study involved 2,000 teachers interviewed at the University of British Columbia, Canada, between 2001 and 2004. As a result, no differences were found in digital skills in different age groups. The advantage of the study is that it is based on the ISTE international competency system, but the assessment was conducted through a survey that did not provide for a formal assessment of respondents' knowledge. The most comprehensive survey in terms of the number of respondents was conducted in 2015 and described in [11]. The study [11] was based on the competency system «The framework of 21st century skills» and included 35,000 respondents. Tests were also developed for competency level assessment according to DigComp. In particular, [12] attempted to integrate digital competency into teacher training programs. However, the study [12] has clear limitations, especially in the variation of questionnaire responses received from higher education institutions. Accordingly, to make a correct analysis, it is necessary to adjust the questionnaire and develop its more balanced structure. In [13], teachers were tested to assess their level of digital competencies. The results show moderate digital competency levels among primary school teachers, but also significant differences between their self-perception and outcomes in objective evidence. So, this means that the test may not correlate well with the objective level of teachers' digital competencies. This needs to be investigated in more detail. The paper [14] also describes the assessment of teachers' digital competency. However, it should be noted that the students who participated in the testing, as described in [14], have not completed their training yet. Accordingly, this may affect the assessment of the final level of digital competencies. A common drawback of [12–14] is the limited number of survey participants from 44 in [14] to 316 in [13].

In general, the concept of digital competency assessment does not imply binding to international digital competency

systems or frameworks. Therefore, many studies are based on national qualifications frameworks or form their own vision of evaluation criteria. In particular, [15] describes a study conducted at two Spanish universities and concerned identifying gender differences in the acquisition of digital skills. The «University Students' Basic Digital Competences 2.0» questionnaire was formed and verified. The aim of the study described in [16] is to determine the importance of the environment and teachers in digital literacy development, in particular age, gender, and socio-economic status. This study was conducted in the Slovak Republic. Similar studies on profiling and assessing digital literacy, particularly in the context of the COVID-19 pandemic, are described in [17]. In [17], the researchers recommend using digital readiness data in tandem with a well-tuned LMS system and advanced training. However, these studies are not based on the international competency system or frameworks, or using the proposed methods makes it impossible to adjust the structure of the competency framework they are based on.

The study [18] substantiates the importance of developing innovative ecosystems and learning environments in the context of rapid technology development in the digital age, in particular, digital competency as an integral part of educational technologies. The findings of the study indicate the need for specific training of teachers, with a focus on the pedagogical use of technology. The authors also note the need for further research to validate tools for teachers' digital competency assessment.

The study [19] emphasizes the importance of developing digital competencies in modern society. The importance of developing digital competencies among teachers to improve their professional activities is substantiated. The need for further research to identify effective methods for developing digital competencies and preparing universities for new challenges of the digital age and integrating new technologies into the educational process is shown.

The results of the study [20] on using Blockchain technology to create a new generation of scientometric indices show prospects in assessing the digital competency of teachers. In particular, the use of Blockchain allows you to create a reliable and transparent system for recording the scientific achievements of teachers, where all data on citation and impact of works will be stored unchanged. This will ensure a more objective and fair assessment of the scientific productivity and competency of teachers. Teachers who actively use digital technologies, such as open access publications, participation in digital scientific communities, can be better evaluated with a new system that takes these aspects into account. This will contribute to the recognition of digital competency importance in modern scientific activities. Thus, the implementation of research results can significantly improve the process of assessing teachers' digital competency, providing a more fair, transparent and objective system that promotes the development of scientific and educational activities.

The study [21] substantiates the importance of developing digital competencies for teachers in the context of the Fourth Industrial Revolution. The authors emphasize the need to train a competent society, especially in the field of education. It is revealed that university teachers have a moderate level of technological competencies, which determines the need for continuous training to improve teachers' digital competencies and the importance of adapting and applying DigCompEdu Check-in to unify digital competencies in the university environment.

The authors of the study [22] substantiate the need to develop digital competencies among teachers in Kazakhstan. They identify the main problems of digitalization in Kazakhstan: weak infrastructure, cybersecurity problems, lack of competent specialists and lack of a clear regulatory framework and legislation in the field of digital education. The need to solve the above problems, develop strategies and action plans, attract investments and develop human capital in the field of digital technologies is determined.

In [23], a modern approach of pedagogy is applied to form not only basic and professional competencies, but also to educate a comprehensively developed person with a broad worldview and creative approach to problem solving. The need to adapt the current trends of European and American educational systems to the features of the education system in the Republic of Kazakhstan is shown. It is determined that teachers should be able to integrate these technologies into the educational process and constantly adapt to changes in the field of education and technology. The need to improve the methods of automating the management of the educational system, selecting content and organizational forms of training, methods for monitoring and evaluating students' academic performance is indicated. The authors of the study emphasize that the introduction of ICT in education is a complex and multifaceted process that requires constant research and improvement to achieve efficiency and meet modern requirements.

In other words, an important task is to create a versatile comprehensive method for calculating an estimate for the level of digital competencies among higher education teachers. This method should be flexible to changes or adjustments in the competency system, as with the rapid growth of information technology, such a system is not sustainable. This is an important function, since it allows using the method with a certain frequency, exploring the dynamics of changes in the competency level among respondents. For example, [24] describes the approach to calculating the competency level in dynamics, but if the components in the assessment system change, it will be impossible to continue the research. Another shortcoming of the studies is the lack of recommendations and assessments for building a personal trajectory for acquiring digital competencies by higher education teachers. Also, no methods for assessing the teachers' potential in mastering necessary competencies are given. This is important both for teachers' personal development and motivation raising, and for improving the reputation of the higher education institution these teachers are affiliated with. However, an unsolved part of the problem is to assess the level of digital competencies of higher education teachers, which allows tracking their progress over time and calculating the potential for their change.

3. The aim and objectives of the study

The aim of the study is to develop a method for assessing the level of digital competencies of higher education teachers based on calculating the volume of a multidimensional polytope. Scientifically based determination of the digital competency level will make it possible to increase the efficiency of higher education institutions. Such an increase can occur at several levels: improving the quality of educational services, ensuring the professional development of teachers, institutional and social influences on higher education in general.

To achieve the aim, the following objectives were set:

- to describe the principles of calculating a complex estimate for the level of digital competencies of higher education teachers based on calculating the volume of a multidimensional polytope;
- to develop a procedure for assessing the potential for changing the level of digital competencies and building a trajectory of forming digital competencies of higher education teachers based on the project-vector methodology.

4. Materials and methods

The object of the study is the processes related to assessing changes in the digital competency level of higher education teachers.

The hypothesis of the study is that assessing the level of digital competencies of teachers can identify gaps in the training and professional development of teachers, which contributes to their professional growth.

Technological tools and methods used by researchers to assess teachers' digital competency were analyzed and reviewed. The results of the meta-analysis are shown in Table 1.

As shown by the meta-analysis of digital competency assessment methodologies, the authors apply two approaches. The first is to adapt the known competency assessment methodology. Another approach is to develop an author's methodology. The most common form of assessment is testing.

The work is based on the structure of the European Framework for the Digital Competence of Educators. In the current version, the framework includes 22 teacher competencies, which are included in 6 blocks. The framework is based on the fact that it aims to detail how digital technologies can be used to improve and innovate education and training. Accordingly, each of the six blocks can be evaluated for a particular higher education teacher. In addition, the assessment of the teachers' competency potential can be extended to assessing the potential of higher education institutions these teachers are affiliated with. The framework was adjusted to assess the competency level that meets the needs of higher education in the Republic of Kazakhstan.

To verify the proposed method for calculating the level of competencies, the activities of more than 60 teachers of Astana IT University, Karaganda Buketov University and Toraighyrov University were analyzed. The analysis involved measuring the achievement of their competency level in four categories: didactic, design, monitoring, and personal. The analysis provided for testing in these areas, which was conducted from September 20 to October 7, 2023 and from May 1 to May 15, 2024. Based on the results of counting correct answers, estimates were generated for each category in the interval [0, 100].

5. Development of a method for assessing the level of digital competencies of higher education teachers

5. 1. Principles of calculating a complex estimate for the level of digital competencies of higher education teachers

To calculate a complex estimate for the level of digital competencies of higher education teachers, it is necessary to form a teacher's information competency environment. The teacher's information competency environment includes a set of resources, technologies, tools and methods that support and develop the teacher's information and digital competencies. It promotes the effective use of information technology in the educational process, which improves education quality and raises the professional level of teachers. The main components of the teacher's information competency environment are technological infrastructure (computer hardware, software), digital resources (educational platforms, multimedia resources, electronic libraries). The components also include training and professional development (advanced training courses, seminars, conferences, self-training), methodical support (methodical recommendations and technical support), information security (cybersecurity, data protection). Given the different digital competency frameworks taken as a basis, a different list of competencies is formed, which is the basic level for working in higher education.

Let $Q = \{q_1, q_2, \dots, q_n\}$ be the set of teachers (professors, associate professors, assistants) of a higher education institution involved in educational and scientific activities, n – the number of teachers. The competency approach is based on the idea that each competency can be measured and a numerical estimate can be set for each competency or group of competencies. Let the list of competencies that higher education teachers should have be grouped into four categories: didactic, design, monitoring, and personal. Each category includes a certain number of competencies, which may vary depending on the needs of the higher education institution. Estimates of these categories can be as follows:

$$K(q_i, t) = (R_1(q_i, t), R_2(q_i, t), R_3(q_i, t), R_4(q_i, t)), \quad (1)$$

where $K(q_i, t)$ is the vector for assessing the competency level of a higher education teacher q_i at time t , $i = 1, n$, $R_j(q_i, t)$ are the components of the vector for assessing the competency level of a higher education teacher q_i at time t , corresponding to a specific competency category $j = 1, 4$, $t \in T$, $T = \{t_1, t_2, \dots, t_m\}$, t_1 is the initial time at which the teacher competency level is calculated. For ease of notation, the components $R_j(q_i, t)$ were designated by $R_j^{i,t}$.

Table 1

Meta-analysis of digital competency assessment methodologies

Methodology of digital competency assessment	Form of assessment	Number of respondents	Year	Source
Author's	Testing	4,048	2005	[9]
ISTE	Sociological survey	2,000	2001–2004	[10]
The framework of 21st century skills	Testing	35,000	2015	[11]
DigComp	Control survey	1,381	2014	[12]
Author's	Testing	316	2017	[13]
Author's	Control survey	351	2016	[16]
GRCU Digital Competency Framework	Testing	279	2017	[17]

Each estimate corresponding to a certain competency category $R_j^{i,t}$ can be normalized on the interval $[0, 1]$. Accordingly, each normalized value obtained can be represented by a point on the numerical axis, $R_j^{i,t} \in [0,1]$. Since this representation considers four competency categories, we define a four-dimensional space. Moreover, the numerical estimate for each category will be placed on a separate numerical axis. Due to such arrangement of points, the space between these points can form a spatial figure called a multidimensional polytope. In a four-dimensional space, a polytope can be denoted as Δ^3 . The construction of polytopes and their use for evaluation problems are described in detail in [25].

Without limiting generality, we can assume that the number of competency categories for evaluating teachers of a higher education institution is k . Then the $(k-1)$ -dimensional polytope in this case at time $t \in T$ for the teacher q_i , $i = 1, n$ will have vertices at points $r_j^{i,t} \in \mathbb{R}^k$:

$$\begin{aligned} r_1^{i,t} &= (R_1^{i,t}, 0, \dots, 0) \\ r_2^{i,t} &= (0, R_2^{i,t}, 0, \dots, 0) \\ &\dots \\ r_k^{i,t} &= (0, 0, \dots, 0, R_k^{i,t}), \end{aligned} \tag{2}$$

the $(k-1)$ -dimensional polytope will then be defined as a set of points $\Delta^{k-1} \in \mathbb{R}^k$:

$$\Delta^{k-1} = \left\{ \sum_{j=1}^k \theta_j^{i,t} r_j^{i,t} \mid \left(\sum_{j=1}^k \theta_j^{i,t} = 1 \right) \wedge \left(\theta_j^{i,t} \geq 0, j = \overline{1, k}, i = \overline{1, n} \right) \right\}, \tag{3}$$

$\theta_j^{i,t} \in \mathbb{R}$ are some real numbers, Δ^{k-1} is the definition of the $(k-1)$ -dimensional polytope at time $t \in T$ for the teacher q_i , $i = 1, n$.

To form a complex estimate for the quality of higher education based on the identifiers of the information environment of a higher education institution, we will put the $(k-1)$ -simplex in accordance with a numerical characteristic that determines the volume of the part of space bounded by this $(k-1)$ -simplex. The volume can be denoted by $V(\Delta_{i,t}^{k-1})$:

$$V(\Delta_{i,t}^{k-1}) = \sqrt{\frac{\det(F) \cdot (-1)^{k-2}}{2^{k-1} ((k-1)!)^2}},$$

where

$$F = \begin{pmatrix} 0 & 1 & 1 & 1 & \dots & 1 \\ 1 & 0 & (w_{11}^{i,t})^2 & (w_{12}^{i,t})^2 & \dots & (w_{1k}^{i,t})^2 \\ 1 & (w_{11}^{i,t})^2 & 0 & (w_{12}^{i,t})^2 & \dots & (w_{2k}^{i,t})^2 \\ 1 & (w_{12}^{i,t})^2 & (w_{21}^{i,t})^2 & 0 & \dots & (w_{3k}^{i,t})^2 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & (w_{k1}^{i,t})^2 & (w_{k2}^{i,t})^2 & (w_{k3}^{i,t})^2 & \dots & 0 \end{pmatrix}, \tag{4}$$

$(w_{ij}^{i,t})^2 = (r_n^{i,t})^2 + (r_j^{i,t})^2$ is the distance between the points $r_n^{i,t}$ and $r_j^{i,t}$, $h, j = \overline{1, h}$.

To numerically calculate the determinant, the Cholesky method can be used [26], and to numerically calculate the volume of the $(k-1)$ -simplex at time $t \in T$ for the teacher q_i , $i = \overline{1, n}$ you can use the formula [27, 28]:

$$V(\Delta_{i,t}^{k-1}) = \frac{a^{2(k-2)}}{2^{k-2} ((k-2)!)^2} \times \left[\frac{2}{a^4} \sum_{h=1}^k \sum_{j=i+0}^{k-1} (w_{hk}^{i,t})^2 w(w_{jk}^{i,t})^2 + \frac{2}{a^2} \sum_{h=1}^k (w_{hk}^{i,t})^2 - \frac{k-1}{a^4} \sum_{h=1}^k (w_{hk}^{i,t})^4 - k + 1 \right], \tag{5}$$

where a is the distance from the vertices $\Delta_{i,t}^{k-1}$ to the origin.

Thus, the resulting complex estimate of the volume $V(\Delta_{i,t}^{k-1})$ will indicate the competency level of the teacher $q_i \in Q$ at time $t \in T$, given that the list of competencies is divided into k categories. Of course, if there are not many competencies to be evaluated, then the categories are replaced by competencies. In general, calculating volume estimates with a small number of polytope vertices is not a difficult task, and on modern processors, the calculation takes seconds.

5. 2. Procedure for assessing the potential for changing the level of digital competencies and building a trajectory of their formation

Based on the values of complex estimates $V(\Delta_{i,t}^{k-1})$ for each teacher $q_i \in Q$, a time series for each $t \in T$ can be constructed. Since time is discrete, we can set a time series as follows:

$$E_i^{k-1} = \{V(\Delta_{i,1}^{k-1}), V(\Delta_{i,2}^{k-1}), \dots, V(\Delta_{i,p}^{k-1})\}, \tag{6}$$

where E_i^{k-1} is the time series of complex digital competency estimates for the teacher $q_i \in Q$, $V(\Delta_{i,t}^{k-1})$ is a complex competency estimate for the teacher $q_i \in Q$ at time points $t = \overline{1, p}$.

The potential for changing the level of digital competencies will be defined as the ratio of the current complex estimate value to the estimate obtained s points ago, i.e.:

$$P_i^{k-1}(t_p, t_{p-s}) = \frac{V(\Delta_{i,p}^{k-1})}{V(\Delta_{i,p-s}^{k-1})}, \tag{7}$$

where $P_i^{k-1}(t_p, t_{p-s})$ is the potential for changing the level of digital competencies of the teacher $q_i \in Q$.

If the value $P_i^{k-1}(t_p, t_{p-s}) > 1$, then the potential for changing competencies has a positive trend, if $P_i^{k-1}(t_p, t_{p-s}) < 1$, then negative.

To measure the trajectory of forming digital competency indicators, the project-vector methodology can be used. A matrix for each teacher $q_i \in Q$ can be formed:

$$\Omega_i = \begin{pmatrix} R_1^{i,1} & R_2^{i,1} & \dots & R_k^{i,1} \\ R_1^{i,2} & R_2^{i,2} & \dots & R_k^{i,2} \\ \vdots & \vdots & \ddots & \vdots \\ R_1^{i,p} & R_2^{i,p} & \dots & R_k^{i,p} \end{pmatrix}, \tag{8}$$

where Ω_i is the vector of competency estimates for the teacher $q_i \in Q$.

Let a planned motion vector be defined for each competency category and each teacher $q_i \in Q$ at time t :

$$\tilde{E}^{i,t} = (\tilde{R}_1^{i,t}, \tilde{R}_2^{i,t}, \dots, \tilde{R}_k^{i,t}), \tag{9}$$

$\tilde{E}^{i,t}$ is the planned teacher's motion vector in the direction of acquiring competencies.

Then the real motion vector is determined from the matrix Ω_i for fixed t and is equal to:

$$E^{i,t} = (R_1^{i,t}, R_2^{i,t}, \dots, R_k^{i,t}), \tag{10}$$

$E^{i,t}$ is the real teacher's motion vector in the direction of acquiring competencies.

As a result, the administrative teacher's motion vector to the desired competency level was obtained:

$$\bar{E}^{i,t} = (\tilde{R}_1^{i,t} - R_1^{i,t}, \tilde{R}_2^{i,t} - R_2^{i,t}, \dots, \tilde{R}_k^{i,t} - R_k^{i,t}), \tag{11}$$

$\bar{E}^{i,t}$ is the administrative motion vector of the teacher $q_i \in Q$ to the desired competency level.

Motion resistance $L_j^{i,t}$, which prevents the achievement of the appropriate competency level is calculated by the formula:

$$L_j^{i,t} = c_j^i \left(\frac{\partial(\tilde{R}_j^{i,t} - R_j^{i,t})}{\partial t} \right), \tag{12}$$

c_j^i is the coefficient of motion resistance.

Fig. 1 shows a conceptual scheme of the method for assessing the level of digital competencies of higher education teachers. This scheme shows that the increase in the polytope volume in the space of assessing teacher competency categories corresponds to the motion in the space of the complex estimate. According to the method of building the trajectory of forming digital competencies of higher education teachers based on the project-vector methodology, the management of this motion is carried out by determining the vector of administrative influence.

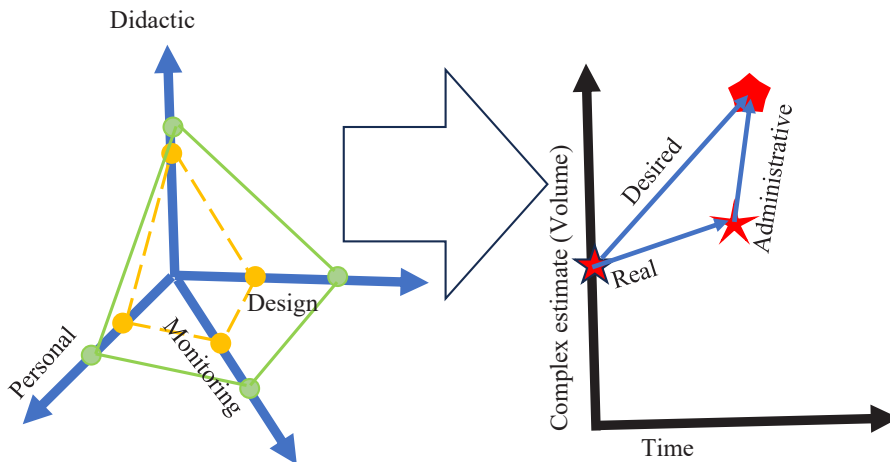


Fig. 1. Conceptual scheme of the method for assessing the level of digital competencies of higher education teachers

Based on the analysis (Table 1), it was decided that in order to validate the procedure for assessing the potential for changing the level of digital competencies and building a trajectory of forming digital competencies of higher education teachers by the project-vector methodology, competency assessment of the research and teaching staff was carried out. The first competency assessment was held from September 20 to October 7, 2023 and involved 62 teachers from Astana IT University, Karaganda Buketov University and Toraighyrov University. Four competency groups were studied, namely didactic, design, monitoring and personal. All results were normalized.

To assess the competencies of the research and teaching staff, testing was conducted, which included 45 questions. The questionnaire was developed during a grant research.

The survey met a number of requirements to ensure its reliability, validity, and utility. All the questions were clearly formulated. The questions directly related to four groups of teacher's competencies and professional activities. Pilot surveys were also conducted on smaller samples, which showed that the survey produced stable results when repeated, and questions related to the same competency agreed with each other.

The survey included various types of questions, although the vast majority of them are open-ended. That is why the survey results were interpreted to make further decisions.

Based on this study, complex estimates for the quality of higher education were determined based on the identifiers of the information environment of institutions according to formula (4). Further, by formula (10), a real motion vector is determined for each competency category and each teacher at the time of the study. Next, the administrations of higher education institutions determined the planned motion vector (9), which set the development of competencies and on its basis, by formula (11), determined the administrative motion vector of the teacher to the desired competency level.

To check the effectiveness of the method, from May 1 to May 15, 2024, a re-assessment of the research and teaching staff competencies was carried out with the same 62 teachers. The results of applying the digital competency assessment method are shown in Table 2.

It was found that the proposed method of building the trajectory of forming digital competencies of higher education teachers allowed determining the potential for changing the level for each of the teacher's digital competency groups in the range from 1.869 to 1.770. That is, the potential for changing the level of teacher digital competencies is greater than 1, so the potential for changing competencies has a positive trend.

The study showed that didactic competencies significantly outweigh design, monitoring and personal ones. Based on this study, the vector of administrative influence aimed at developing the design, monitoring and personal competencies of teachers was determined.

The potential of the complex digital competency estimate of higher education teachers based on calculating the volume of a multidimensional polytope shows a 6-fold increase.

Table 2

Results of applying the digital competency assessment method

No.	Competency group	Average 1 monitoring	Average 2 monitoring	Potential
1	Didactic	0.393	0.735	1.869
2	Design	0.356	0.630	1.770
3	Monitoring	0.347	0.638	1.842
4	Personal	0.337	0.603	1.788
5	Volume of the 4-dimensional polytope	$2.704 \cdot 10^{-3}$	$16.243 \cdot 10^{-3}$	6.006

6. Discussion of the method for assessing the level of digital competencies of higher education teachers

The calculation of a complex estimate for the level of digital competencies of higher education teachers based on calculating the volume of a multidimensional polytope was carried out using formulas (2)–(5). The study showed that didactic competencies significantly outweigh design, monitoring and personal ones. The results were based on the procedure for assessing the potential for changing the level of digital competencies and building a trajectory of forming digital competencies of higher education teachers based on the project-vector methodology. This allowed the administrations of higher education institutions to determine the administrative motion vector of the teacher to the desired competency level using formulas (9)–(11). This made it possible to determine the potential for changing the level for each of the teacher's digital competency groups in the range from 1.869 to 1.770, and the potential of the complex digital competency estimate of higher education teachers based on calculating the volume of a multidimensional polytope – by 6 times. That is, the potential for changing the level of teacher digital competencies is greater than 1, so the potential for changing competencies has a positive trend.

The creation of a versatile comprehensive method for calculating an estimate for the level of digital competencies among teachers of higher education institutions allows flexible changes and adjustments to the competency system. This allows using the method to study the dynamics of changes in the competency level among respondents. In contrast to the study [17], the author's methodology for assessing teacher digital competencies was applied, which includes four components. Unlike [9], in this study, digital competency assessment was carried out twice, which allows building a trajectory for changing the level of competencies. This makes it possible to assess the potential of each teacher in the process of achieving the appropriate competency level. The obtained research result is due to the integration of the project-vector management methodology into the process of digital competency assessment. The results obtained are also due to the fact that the competency assessment involved 62 teachers from 3 universities of the Republic of Kazakhstan. The small sample size made it possible to apply an individual approach when applying the vector of administrative influence.

The developed method for assessing the level of digital competencies of higher education teachers based on calculating the volume of a multidimensional polytope makes it possible to scientifically reasonably determine the level of digital competencies, which contributes to improving the efficiency of higher education institutions.

The limitations of this study are related to the fundamental difficulty of determining teacher competencies. The survey used in the study contains open-ended questions and therefore requires interpretation of the answers.

The main drawback of the study is the small sample size of validation of the procedure for assessing the potential for changing the level of digital competencies and building a trajectory of forming digital competencies of higher education teachers based on the project-vector methodology. To eliminate it, procedures should be carried out to assess the potential for changing the level of digital competencies of

teachers in other universities of the Republic of Kazakhstan and abroad.

This study is pilot and demonstrates the main advantages of the teacher competency assessment method. In the future, it is planned to test and apply this approach for use in other higher education institutions in the Republic of Kazakhstan.

7. Conclusions

1. The principles of calculating a complex estimate for the level of digital competencies of higher education teachers based on calculating the volume of a multidimensional polytope are described. A complex estimate of the level of teacher digital competencies is calculated as the volume of a multidimensional polytope with vertices, which are determined based on normalized competency estimates for various categories. The polytope dimensionality is determined by the number of competency assessment categories.

2. A procedure for assessing the potential for changing the level of digital competencies was developed and trajectories of forming digital competencies among higher education teachers were formed. For verification, the results of testing 62 teachers of Astana IT University, Karaganda Buketov University and Toraighyrov University were taken as a basis. The analysis involved measuring the achievement of their competency level in four categories: didactic, design, monitoring, and personal. Testing in these areas was conducted from September 20 to October 7, 2023 and from May 1 to May 15, 2024. The results obtained show that the didactic competencies of teachers of higher educational institutions of the Republic of Kazakhstan significantly outweigh design, monitoring and personal ones. Based on this study, the vector of administrative influence aimed at developing the design, monitoring and personal competencies of teachers was determined. The potential of the complex digital competency estimate of higher education teachers based on calculating the volume of a multidimensional polytope shows a 6-fold increase. This procedure does not need to form a separate list of weight factors to take into account a particular category of competency estimates to a greater or lesser extent in the overall estimate. Competency levels are equally important. In addition, if the list of competencies for each category is changed, the form of calculating a complex competency estimate will not change, since the polytope dimensionality will not change.

The obtained verification results allowed us to determine the potential for changing the level for each of the teacher's digital competency groups in the range from 1.869 to 1.770. That is, the potential for changing the level of teacher digital competencies is greater than 1, so the potential for changing competencies has a positive trend. This information can be used directly by teachers to understand the level of personal growth and professional development. It is also important for the management of universities teachers are affiliated with, since the trajectory of competency formation allows teachers to be motivated accordingly and take this into account in the terms of contracts. A thorough understanding of the principles of changing the level of competencies of the teaching staff of higher education institutions and their assessment is a necessary component of ensuring the sustainable development of the university.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This paper was written in the framework of the state order to implement the science program for budget program 217 «Development of Science», IRN No. AP14870918 with the topic: «Cre-

ating a system for developing the methodological competence of teachers of IT disciplines based on continuous education».

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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