The qualimetric aspect of digitalization in the formation of professional competencies of university graduates

Belevitin V.A.
South Ural State Humanitarian Pedagogical State University
Chelyabinsk, Russian Federation
belevitinva@cspu.ru

Rudnev V.V.
South Ural State Humanitarian Pedagogical State University
Chelyabinsk, Russian Federation
belevitinva@cspu.ru

Giss E.I.
Russian Academy of National Economy and Public Administration, Chelyabinsk branch
Chelyabinsk, Russia
belevitinva@cspu.ru

Abstract — **The digitalization of the economy, state, and municipal management, as well as all spheres of society, poses new global challenges for the education system. In the new context of the relationship between business, the state and citizens, there is a demand for specialists who not only possess theoretical knowledge, but also big data processing methods, the basics of business analytics, the ability to systematically improve their competencies and develop new software products. It is possible to ensure the training of such specialists only through innovative changes in the educational paradigm when "analog" education is increasingly pressured by digital education. The authors analyzed the system of the qualimetric approach (SEC) in terms of mathematical modeling and mathematical statistics of a phased assessment of the results of quantitative measurements of pedagogical studies of the degree of formation of professional competencies (SSPK) of university graduates using new information and communication technologies (ICT). The program implementation of the described SEC algorithm will allow when it is implemented for various disciplines and training directions, to eliminate the subjective approach and minimize economic and didactic risks.**

Keywords — training, educational paths, classification of competencies, modeling

I. INTRODUCTION

In October 2017, at the Moscow International Forum of Innovative Development "Digital Economy. Challenges for global transformation" experts from various sectors of the Russian and foreign economies discussed the digital future, which, in fact, is already beginning to take over [1]. Among the priorities in the Decree of the President of the Russian Federation dated May 9, 2017 No. 203 "On the Strategy for the Development of the Information Society in the Russian Federation for 2017–2030", the need to ensure national interests in the field of the digital economy is noted.

Due to significant changes in the rapid development of the global Internet in highly efficient production, the whole new, -

efficient and flexible approach of Industry 4.0 is gradually capturing the whole world. with the use of new ICT, which, according to the forecasts of leading experts regarding its promising capabilities, will allow developing managerial, technical, technological and educational resources to ensure the achievement of the main goals laid down in the list of the main directions of strategic development of the Russian Federation until 2018 and for the period until 2025, in accordance with the provisions Programs for the development of the digital economy in Russia until 2024 [2-3]. At the same time, it is quite logical that to create new digital technologies, masses of the highest level will be needed in mass, having perfect professional digital and research competencies, as well as technological groundwork for supporting applied research in the field of digital economy (search infrastructure of digital platforms). That is why the improvement of the education system and the creation of key conditions for the training of competent personnel in the digital economy are included in the framework of the five basic directions of the Program for the Development of the Digital Economy in Russia until 2024.

Within this approach, it is completely justified to receive education under the new master's program of the Federal State Educational Standard of Higher Education (hereinafter FSEHE3++) "Information Security Management in Vocational Education" in the training direction 44.04.44 Vocational Training (by industry). This circumstance is also relevant because of the human factor, as the main cause of technological disasters in the vast majority of cases [4], and the unsatisfactory training of personnel for working with new ICTs due to the insufficient effectiveness of the educational resources used [5]. Effectively leveling existing and potential threats, without exaggeration, is possible only through innovative changes in the educational paradigm, when "analog" education is increasingly crowding digital [1]. Of particular relevance is the competency-based solution to the problem of digital assessment among graduates of professional educational organizations (GOEO) of the level of formation, especially practice-oriented

professional competencies, as the leading quality characteristic of higher education (HE) [6-7].

II. FORMULATION OF THE PROBLEM

The current situation of digitalization of the economy actualizes the problem of developing innovative principles of educational training of specialists in vocational education. A methodically competent assessment of the GOEO in the field of ICT and the level of their human capital [8–12] is the key to an effective response to the requests of society, employers and students themselves, who need to know the criteria for assessing their readiness for the profession as a whole, and for the qualitatively efficient performance of their work in conditions specific workplace, ability to quickly respond to changes in different areas of public life. The problem is conditioned by the objective need to develop innovative pedagogical tools for an objective quantitative assessment of the GOEO, as a set of interconnected tools (methods, techniques, techniques, and tools) of the pedagogical interaction of subjects and objects of the educational process [13-14]. Training based on the conceptual principles and methods of pedagogy, quantitative measurements, mathematical modeling and mathematical statistics of the qualimetric approach with the widespread use of ICTs makes it possible to study and analyze the influence of various factors on the learning process, choose optimal strategies, teaching methods and methods for generating educational trajectories [8; 15-17]. In light of this approach, the special relevance of the qualimetric assessment of students' academic achievement (QASA) has been updated since 2000 by conceptual studies within the framework of the "Program for International Student Assessment, PISA" [18].

III. MATERIALS AND METHODS

The subject of the research is the system of the qualimetric approach in terms of mathematical modeling and mathematical statistics of a phased assessment of the results of quantitative measurements of pedagogical studies of the GOEO using new ICT.

The socio-economic transformations taking place today as a result of the transition to market relations, and the urgent need to mitigate the negative consequences of our country's stay under the conditions of the application of Western sanctions, necessitating the urgent need for high-tech technical and technological solutions, a number of priorities objectively put forward the problem of high-quality training of professional personnel with a higher GOEO in ICT, an increased level of their human capital [9–12, 23]. An analysis of the preparation of the GOEO is convincing evidence of a "chronic" lag behind the necessary needs of the modern post-information society [25], the requirements of the sixth level of the National Qualifications Framework of the Russian Federation [26].

The effectiveness of raising the level of human capital at GOEO and the more successful formation in the field of ICT of their professional competencies, including motivational, value and operational components, is largely determined by taking into account the interconnections and methodically competently scientifically-based objective quantitative assessment of these components [27–30, etc.].

Most notable initiative digital assessment in the field of the innovative aspect of pedagogical control of the GOEO are ideas of I. Stolbovoy and A. Danilova with co-authors of their articles, D. Miroshina [19–21], O. Shikhova and J. Shikhova [22] and M. Potapova [13]. At the same time, as in the vast majority of cases, the digital assessment of the professional competencies of HSE is traditionally carried out taking into account only one parameter — KODO, which is detected by the results of their control measurement materials (CMM). Meanwhile, the final value of the KODO, and, consequently, of the GOEO of HSE is a function of several phenomenologically dominant factors. As a result of this situation, there are economic (redundancy) and didactic (insufficiency) threats to the high-quality preparation of the HSE because of the high percentage of errors in planning the development vector of the principles of modernization and innovative development of a professional educational organization [31]. Conclusions about the "magnitude of measurement error" of the level of knowledge, skills and errors of KODO, the rationality of various testing systems (for example, SAT, ACT, APP), the formats of test tasks "multiple choice", "free response", and the use of recalculation of "raw points" to "true points" using the Item Response Theory models [32–33], for example, can only be made on the basis of experimental data analyzed using objective mathematical and statistical methods.

The research material was modern approaches, algorithms, and models of qualimetric monitoring (V. Gorb, L. Davidova, N. Efremova, N. Kulemin, A. Mayorov, D. Matros, etc.) KODO in educational institutions. The main research methods were the theoretical analysis of materials published in the scientific literature on the problem of digital assessment of the secondary vocational education and system of higher education in the field of ICT, first of all, their practice-oriented professional competencies [22; 34]. The main goal of pedagogical measurement (Educational Measurements), as an applied theory of scientific pedagogy [35], is to develop tests of objective control of the knowledge of students. Qualitatively made research results V. Avanesov [36–37] are, according to A. Mayorov [38], qualimetrically verified tests with pre-designed technologies for standardized procedures for conducting, processing and analyzing results [39–40], unlike a set of control tasks, they allow solving the problem of objectification of pedagogical measurements and, on this basis, improving modern education through direct communication controlling methods and teaching aids with education, training and upbringing [41]. Obtaining complete and objective information for taking reasonable measures to improve the quality of modern education, bringing its level into line with the needs of the modern labor market largely depends on the correctness of expert assessments of the level of difficulty of test tasks, objectivity of the content of tests, their high scientific validity and representativeness, first of all, as well as validity, latency, cognition, discriminatory power and, in general, reliability, which determines the reproducibility of the result testing, their accuracy [42–43].

IV. RESULTS OF THE STUDY

The results of expert assessments, as the practice of recent decades shows, can be significantly improved by applying not only mathematical statistics, but also a systematic approach that implements, according to V. Glushkov [44], the transfer of problems into a structured category, the solution of which is scientifically justified by the apparatus of mathematical modeling and the selection of optimal solutions [45–48].

At the first stage of the study, eight experts with a professional qualification in ETC from the 14th category, whose consensus was previously identified by calculating the Kendall concordance coefficient (multiple rank correlation W), it was proposed to rank selected according to the results of the analysis of the opinions of researchers from literary sources, factors according to the degree of their influence on the value of objectivity of pedagogical tests (PT) [32–33], namely, such factors of influence of PT as their content S, R-representative structure and latency L [40]. As a result of applying the method of group expert assessment, which provides the opportunity to increase the level of objectivity in the estimates and judgments of expert experts (two or more), the procedure for bringing their individual opinions to a single group has been implemented. At the same time, differences in the knowledge, competence, and objectivity of experts were taken into account with a real leveling of their "inequality" and statistical processing of the results of surveys among independent experts. For the extreme values of the "importance" coefficients c_i, $i = 1, 2, 3$ of the factors S, R and L of the PT, the values of the degree of their influence on the value of ò PT are obtained: $0.67 \leq S \leq 0.85$; $0.73 \leq R \leq 0.87$; $0.50 \leq L \leq 0.60$. At the same time, the final (group, collective) assessment of Y_i of expert experts was determined as the average competence of expert knowledge:

$$Y_i = g_j Y_{11} + g_j Y_{12} + g_j Y_{13} + \ldots + g_j Y_{ij}, \quad (1)$$

where: Yi - final, group assessment of the ranking of the i-th factor of PT; Yij - an individual assessment of the ranking of the i-th PT factor by the j-th expert; gj - competence, knowledge of the j-th expert.

To assess the degree of influence of factors S, R, and L of the PT on the value of the indicator ò in the form of the dependence = ò (S, R, L), mathematical design of the experiment was used according to the type of Latin 4x4 square (Table 1). Each factor S, R and L were assigned at four levels, as a result of which planning is called by the type of Latin 4x4 square. The levels of variation of the S-factor of the PT (bi = 0.67; ..., 0.85) correspond to the rows of Table 1, the columns correspond to the levels of the R-factor of the structure of the PT (ai = 0.73; ...; 0.87); The L-factor PT varied from ci = 0.51 to ci = 0.60 (in the cells of Table 1). The total values of ò PT are also presented in the cells of Table 1: ò = 0.834; …., 0.989.

The average values $\tilde{o}_i$ of the ò PT indicator calculated from the corresponding columns, equal to 0.910; ...; 0.951, reflect the degree of influence of the R-factor of the structure of the PT on the value of the indicator ò. By the values of $\tilde{o}_j$, as the result of the calculation by rows, one can judge the degree of influence of the S-factor of PT: $\tilde{o}_j$, equal 0.872;…; 0.988. In the rightmost column are the values of the indicator ò for different latencies L PT: $\tilde{o}_k$, equal 0.912; …; 0.988.

In the case of changes in the L-factor of PT from $c_i = 0.59$ to $c_i = 0.71$ at similar levels of variation of the s-factor of PT ($bi = 0.67$; ..., 0.85) and the R-factor of PT ($a_i = 0.73$; ...; 0.87) calculated on the corresponding columns of the identical design of the model experiment according to the type of Latin 4x4 square, the average values $\tilde{o}_i$ of the indicator ò PT, reflecting the degree of influence of the R-factor, are 0.777; ...; 0.813. A comparison of these average values with those given in Table 1 indicates a lower objective objectivity value in the

range of 14...17% than the best interval of changes in the L-factor of the identified factors by independent experts. Comparison of the average values $\tilde{o}_i$ of the indicator ò PT, reflecting the degree of influence of the S-factor, for the same changes in the L-factor of the PT from $c_i = 0.59$ to $c_i = 0.71$ are equal to 0.872; ...; 0.988 also confirms the results performed by expert experts assessment.

TABLE I. Ò STUDY PLAN AND RESULTS

LATIN SQUARE 4X4 TYPE

$S(b_i)$	R(a_i)				$\tilde{o}_j$	$\tilde{o}_k$ where c_i
	$a_1 = 0.73$	$a_2 = 0.78$	$a_3 = 0.83$	$a_4 = 0.88$		
$b_1 = 0.67$	$c_1 = 0.51$	$c_2 = 0.54$	$c_3 = 0.57$	$c_4 = 0.60$	0.872	$c_1 = 0.51$
	ò = 0.834	ò = 0.860	ò = 0.884	ò = 0.909		$\tilde{o} = 0.912$
$b_2 = 0.73$	$c_2 = 0.54$	$c_1 = 0.51$	$c_4 = 0.60$	$c_3 = 0.57$	0.912	$c_2 = 0.54$
	ò = 0.884	ò = 0.886	ò = 0.934	ò = 0.942		$\tilde{o} = 0.924$
$b_3 = 0.79$	$c_3 = 0.57$	$c_4 = 0.60$	$c_1 = 0.51$	$c_2 = 0.54$	0.950	$c_3 = 0.57$
	ò = 0.938	ò = 0.960	ò = 0.937	ò = 0.964		$\tilde{o} = 0.938$
$b_4 = 0.85$	$c_4 = 0.60$	$c_3 = 0.57$	$c_2 = 0.54$	$c_1 = 0.51$	0.988	$c_4 = 0.60$
	ò = 0.985	ò = 0.987	ò = 0.988	ò = 0.989		$\tilde{o} = 0.947$
$\tilde{o}_i$	0.910	0.908	0.936	0.951	$\tilde{o} = 0.930$	

To conduct a variance analysis of the research results, a general calculation scheme for calculating such quantities as: the sum of the squares of all experiments s_1^2, the results for rows s_2^2 and columns s_3^2; the results of the alternate summation of s_4^2 and the corrective term s_5^2, equal to the square of the total divided by the total number of experiments. From comparing the mean square values according to the F-criterion, it follows that the S-factor of the PT has a greater effect on the value of: $F_S = 0.227/0.037 = 6.16 > F_{\text{critical } 0.05(3;6)} = 4.76$. Significant should be recognized and the influence of the R-factor of the structure of the PT: $F_R = 0.221/0.037 = 6.00$ and latency L PT: $F_L = 0.220/0.037 = 5.97$. An analysis of the changes in ò indicates that it significantly increases with increasing values of the S factor, while the influence of R and L factors of PT is less than the influence of factor S of PT.

An integrated assessment of the degree of influence on the objectivity value of PT of factors of their content S, representativeness of the structure R, and latency L was carried out using the desirability function or Harrington's criterion [24], which is calculated by the formula:

$$D = \sqrt[4]{d_1 d_2 d_3 d_4}, \quad (2)$$

where d_1, d_2, d_3, d_4 are partial functions of the desirability of the value of objectivity of the PT.

Reference points for establishing a relationship between the values of y_i of the degree of influence of PT factors on the value ò of different types of PTs and the particular values of the desirability function of the quantity ò objectivity of PTs are given in Table 2. Test modes 1 and 2 differ in values of k_t of the coefficient of the degree of difficulty of 1.0 and 0.5, respectively. The characteristic parameters of the options for PT are the following: the values of the influence factors S, R

and *L*of the PT for options 1–3, respectively, at the maximum, average and minimum levels of the interval established by experts $0.67 \leq S \leq 0.85$; $0.73 \leq R \leq 0.87$; $0.50 \leq L \leq 0.60$ and for option 4 it is lower than the minimum level of all influencing factors *S*, *R* and *L* PT (no more than 10%).

TABLE II. REFERENCE POINTS FOR TRANSLATING YI PT VALUES

DEGREE OF INFLUENCE OF FACTORS IN PARTICULAR VALUES

DESIRABILITY FUNCTIONS (HARRINGTON CRITERION)

Test mode	Reference points for PT options							
	Number 1		Number 2		Number 3		Number 4	
	y_i	d_i	y_i	d_i	y_i	d_i	y_i	d_i
1	0.690	0.37	0.570	0.37	0.490	0.37	0.410	0.37
	0.910	0.8	0.860	0.8	0.770	0.8	0.680	0.8
2	0.520	0.37	0.490	0.37	0.410	0.37	0.380	0.37
	0.830	0.8	0.780	0.8	0.700	0.8	0.640	0.8

∗ Numerator - min., Denominator - max.

The transition of the results of mathematical modeling of the degree of influence on the objectivity of the PT of the factors of their content *S*, the representativeness of the structure *R*, the latency *L* and the degree of difficulty *K* into the particular values of the desirability function d_i, $i = 1–4$ was carried out according to the *S*-shaped curve of the desirability function [24] followed by calculation by formula (2) of the integral desirability function (Harrington criterion) of objectivity *D* ò PT (Table 3).

TABLE III. HARRINGTON CRITERION (D) FOR VARIOUS

OPTIONS FOR THE INFLUENCE OF FACTORS AND MODES

OF IMPLEMENT PT TESTING

Test options	Objectivity ò PT (y_i) and particular values of the desirability function (d_i) for S, R and L, k_τ=var.								D
	S		R		L		k_τ		
	y_i	d_i	y_i	d_i	y_i	d_i	y_i	d_i	
1-1	0.85	0.63	0.87	0.64	0.60	0.58	1.0	0.95	0.69
1-2	0.85	0.63	0.87	0.64	0.60	0.58	0.5	0.54	0.59
2-1	0.76	0.61	0.80	0.62	0.55	0.56	1.0	0.95	0.67
2-2	0.76	0.61	0.80	0.62	0.55	0.56	0.5	0.54	0.57
3-1	0.67	0.59	0.73	0.60	0.50	0.54	1.0	0.95	0.65
3-2	0.67	0.59	0.73	0.60	0.50	0.54	0.5	0.54	0.56
4-1	0.60	0.50	0.65	0.58	0.45	0.51	1.0	0.95	0.61
4-2	0.60	0.50	0.65	0.58	0.45	0.51	0.5	0.54	0.52

Since the values of the desirability function from 0.63 to 0.8 correspond to a "good" degree of influence [24], the obtained values of the Harrington criterion *D* indicate that the values of the influence factors *S*, *R*, and *L* of the PT in options 1–3, respectively, at the maximum, average and minimum levels of the interval established by experts of $0.67 \leq S \leq 0.85$; $0.73 \leq R \leq 0.87$; $0.50 \leq L \leq 0.60$ for values for k_τ of the coefficient of degree of difficulty of 1.0, leading to good objectivity ò PT. Test cases with identical values of the influence factors *S*, *R* and *L* of the PT for options 1-3, but with values of k_t of the coefficient of difficulty degree of 1.0 result in "satisfactory" objectivity ò PT. The lowest objectivity ò PT in all studied cases occurs in the case of using test cases with values of influence factors *S*, *R* and *L* for options 4-1, 4-2 for both k_t values of the coefficient of difficulty degree 1.0 and 0.5.

V. CONCLUSION

The data obtained from the results of the study show that the phased implementation of science-based planning and the implementation of pedagogical experiments with the combined use of methodically and qualimetrically correctly pro-

cessed quantitative measurements of the degree of formation of professional competencies of GOEO contributes to the digitalization of forecasting with increased accuracy of the potential for preventive meeting society's needs and employers while minimizing Economic and didactic risks in planning vector of development of the principles of modernization and innovative development of professional educational organizations.

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