Qualimetric Assessment of Pedagogical Factors in the Formation of Professional Environmental and Economic Competence of University Graduates

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Abstract. The current situation of green economy digitalization actualizes the problem of developing innovative principles of professional training in universities. The key conditions for the training of highly qualified personnel in accordance with the needs of society and employers as participants of educational relations are of particular importance due to the qualimetric assessment of educational achievements of students (QAA), which has been actualized since 2000 by conceptual research within the framework of the Programme for International Student Assessment (PISA). The material for the study was modern approaches, algorithms and models of QAA in higher education institutions. The main methods of research were theoretical analysis of published scientific literature on the problem of digital assessment of the level of professional competence of university graduates in the field of green economy- sustainable development, primarily, their professional environmental and economic competence (PEEC) based on a ranking analysis of expert information on the impact of different factors. At the same time, the problems which are the result of multifactor dependencies typical for pedagogy are put into the structured category and the apparatus of mathematical modelling and selection of optimal solutions is scientifically grounded to solve them. The most significant pedagogical factors were selected according to their influence on the level of PEEC formation as a result of using the method of expert group evaluation and ranking the selected opinions of experts, the consistency of which was previously revealed by calculating the Kendall's concordance coefficient. Theprinciples of the systematic approach applied in the pedagogical research, using the conceptual provisions of quantitative measurements, numerical modelling and mathematical statistics based on factor planning allowed us to present the results of the experiment to identify the final dependence of the level of PEEC formation as a regression model as the initial step in the developed platform (underlying concept) of qualimetric assessment of the dominant factors of PEEC formation. The initial principles of such a concept are formulated, providing opportunities for studying and analyzing the influence of various pedagogical factors and organizational and pedagogical conditions, choosing the ways of generating educational trajectories.

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1 Introduction

Among the priorities in the Decree of the President of the Russian Federation of May 9, 2017 No. 203 "On the Strategy for Development of Information Society in the Russian Federation for 2017-2030" noted the need toensure national interests in the field of digital economy (DE) for the development of knowledge society in the Russian Federation by creating conditions for improving digital literacy of the Internet use among citizens of the country, their awareness of the urgency of green business and green economy development instead of traditional polluting, resource- and energy-intensive The concept of the Seventh EU Environment Action Plan is based on the priority application of the direction "Green technologies" for innovative and sustainable creation of a green economy with a synergistic effect [1; 2; 3; 4].

Thanks to significant changes in its rapid development, the Internet is gradually taking over the world through a new approach of Industry 4.0, which allows efficient and flexible, using new hardware and software information and communication technologies (ICT), to develop managerial, technical, technological and educational resources to ensure achievement of the main objectives laid down in the list of main directions of strategic development of the Russian Federation for the period until 2025 [5], including with a predominant At the same time, it is quite logical that ensuring the national interests in the field of DE as an integral part of the sustainable development of modern society necessitates the development of ecological and economic knowledge in the Russian Federation in order to significantly increase the professional training of personnel possessing important ecological and economic competencies along with digital and research competencies andtechnological reserves to support applied research in DE (search infra-structure). That is why the improvement ofthe education system and the creation of key conditions for the training of competent DE personnel are includedin the five basic directions of the Programme for the Development of the Digital Economy in Russia until 2024. In the light of this approach, a qualimetric solution to the problem of digital assessment in university graduates of the level of PEEC formation as the initial step of the developed platform (underlying concept) of qualimetric assessment of the dominant factors of PEEC formation acquires special relevance [6].

2 Formulation of the problem

The modern situation of green economy digitalization actualizes the problem of developing innovative principles of professional training of specialists in higher education institutions. Methodologically competent assessment of the level of PEEC of university graduates as a component of their human capital [7-9] is the key to an effective response to the needs of society, employers and students themselves, who need to know the criteria to assess their readiness for the profession in general, qualitative effective performance of their work in a particular workplace, ability to respond quickly to changes in different spheres of social life. The adequate approach to such an effective response is largely due to the objective need to develop innovative pedagogical tools as a set of interrelated tools (methods, techniques, methods, means) of pedagogical interaction between the subjects and objects of the educational process. Professional education based on the conceptual provisions, methods and techniques of pedagogy, quantitative measurements, digital modelling and mathematical statistics, tools of qualimetric approach with extensive use of ICT allows you to study and analyze the impact of different factors on the learning process, choose the best strategies, training methods and ways of generating educational trajectories [10; 11].

3 Materials and methods

The analysis of practice-oriented professional training materials shows not so much insufficient, fragmented coverage of the subject area of modern post – information society, as the "chronic" lagging behind its necessary needs [12], the requirements of the sixth level of the RF National Qualification Framework [13]. The effectiveness of improving the level of human capital of university graduates and more successful formation of PEEC, which includes motivational, value and operational components, is largely determined by taking into account the relationship and methodologically competent, scientifically grounded objective quantitative assessment of these components [14; 15; 16].

In the vast majority of cases, traditionally numerical assessment of professional competencies is carried out taking into account only one parameter – QAA, which is revealed by results of qualimetric monitoring (V.G. Gorb, L.N. Davydova, N.F. Efremova, N.A. Kulemin, A.N. Mayorov, D.S. Matros, etc.) of their performance on control measuring materials. At the same time, the final QAA value and hence PEEC is a function of several phenomenologically dominant factors. As a consequence, there are economic (redundancy) and didactic (insufficiency) threats to quality training due to high error rates. The conclusions about the "magnitude of measurement error" of knowledge, skills and abilities or the errors of QAA, the rationality of various testing systems (SAT, ACT, APP), "multiple choice" and "free response" test-task formats, and the use of "raw scores to true scores" using Item Response Theory models [17; 18], for example, can only be made based on experimental data analyzed using objective mathematical-statistical methods.

Experimental research plays an essential role in all sciences. The less rigorous the science, the more important is the role of experiment [19]. In the strong sciences, which use a mathematical apparatus, many results can be obtained and justified theoretically, on the basis of existing empirical material. In weak sciences, such as pedagogy, experimentation is often the only way to confirm the validity of hypotheses and theoretical results, since the lack of a generally accepted axiomatic and an adequate formal apparatus does not allow for proper justification without the use of experimentation with statistical methods. At the same time, statistical methods are either not used at all in pedagogics are often used incorrectly without the mathematical rigor of the applied evaluation of research results. The aim of any experimental study is to establish objective regularities that - are expressed by the dependencies of different factors, including their interaction, for the subsequent use of the identified dependencies in the management of the processes under study [20].

In order to identify the most pedagogically characteristic multifactorial relationships [21], it is necessary to choose experimental designs that minimize experimental errors and adequately assess the influence of controlling factors, based on clear scientific rules. The material for the study was modern approaches, algorithms, and models of QAA in educational organizations, and the main methods of research were theoretical analysis of published scientific literature and ranked analysis of expert information on the level of influence of various factors on the formation of PEEC [11; 22]. Since the formal characteristics of expert candidates, such as specialty, academic degree, work experience and their other indicators on a competency scale, do not always allow for the selection of a truly professional focus group, the use of standardized procedures for the selection of experts in the group has become a pressing need [23; 24]. In order to identify the most significant factors and to check the convergence of the results of the ranking of professional focus group experts against them, the cloud-based data development and analysis service Google Colaboratory [25] in the Random Forest Classifier model [26] was used. The results of expert ranking, as practice shows, can be significantly improved by applying not only mathematical statistics or the Random Forest Classifier model, but also the systematic approach, which, as defined by V.M. Glushkov [27], transforms problems into the category of structured ones, which can be solved using mathematical modeling and optimal solution selection [28; 29].

4 Results of the study

At the first stage of the research, the experts of the professional focus group consisting of its leader and four experts, the consistency of whose opinions has been preliminary revealed by calculating Kendall's concordance coefficient (multiple rank correlation W), were proposed to rank the factors (disciplines) according to their influence on PEEC formation (selected as a result of analysis of professional education content for university students - future managers). Such disciplines with the same workload (72 hours) included: ecology (X_0), law (X_1), economic theory (X_2), applied economics (X_3), information technologies in management (X_4), mathematical modeling (X_5), basics of life safety (X_6), basics of information security (X_7), organizational management (X_8), basics of scientific research (X_9).

The analysis of works on qualimetry shows that the expert method is not limited only to the opinion of expert specialists, and that at the present stage of pedagogical sciences development "the scope of the expert method should be expanded". Therefore, based on the results of using and objectivity of experts were taken into account, with their "inequalities" actually leveled out and the results of interviews with independent experts statistically processed.

For the extreme values of the factors "importance" coefficients X_0, X_1, ..., X_9, the values of the degree of their influence on the value of the PEEC formation are obtained, first of all $0.65 \le X_0 \le 0.97$; $0.68 \le X_1 \le 0.94$; $0.61 \le X_2 \le 0.79$; $0.72 \le X_3 \le 0.99$; $0.61 \le X_4 \le 0.99$; $0.63 \le X_5 \le 0.93$; $0.68 \le X_6 \le 0.98$; $0.55 \le X_7 \le 0.90$; $0.85 \le X_8 \le 0.98$; $0.63 \le X_9 \le 0.93$. The group score Y_i of the expert experts was determined as a competency-weighted average of the preparedness of the expert experts:

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

where: Y_i is the group ranking score of the i-th factor X_i;
Y_{ij} is the individual ranking score of the i-th factor X_i by the j-th expert;
g_j is the competence, preparedness of the j-th expert.

The highest value of the values of the PEEC in its lowest range of variation is inherent in such factors as: $0.65 \le X_0 \le 0.97$; $0.72 \le X_3 \le 0.99$ and $0.85 \le X_8 \le 0.98$. This indicates the predominant role of the resource in the formation of the PEQ of such educational disciplines as "Organization Management", "Ecology" and "Applied Economics".

To identify the level of dominance of factors X_0, X_3 and X_8 in terms of their influence on the value of PEEC formation in order to develop mathematical models for the detailed study of ways to address the problems of green economy, it is appropriate to apply the methodology of factor experiment planning with variation of variables at only two levels (Table 1).

Table 1. Conditions for a factor experiment to investigate the degree of influence The subjects "Organizational Management", "Ecology" and "Applied Economics" on the level of PEEC

Varying factors	Designation factors	Levels		Interval of variation
		lower	top	
Discipline "Organizational Management"(D1)	$\tilde{x}_1$	0,85	0,98	0,065
Discipline “Ecology” (D2)	$\tilde{x}_2$	0,65	0,97	0,160
Discipline “Applied Economics” (D3)	$\tilde{x}_3$	0,72	0,99	0,135

In order to simplify the recording of the conditions of a factor experiment, it is rational to represent the variables in coded form by means of a conversion

$$Xi = (\tilde{x}i – \tilde{x}io)/Ji,$$

where Xi is the coded value of the factor (the upper level corresponds to +1, the lower level to 1 and the middle level to zero);

x̃i is the natural value of the factor at the relevant level; x̃io is the natural value of the factor at the average level; Ji is the interval of variation;

i is the recoded number of the factor.

The full factor experiment methodology requires setting up eight experiments at two levels of variation of the three factors x̃1, x̃2 and x̃3 respectively to the disciplines (see Table 1). The order of the eight experiments was carried out by selecting randomized sampling fragments of the PEEK indicators from a total sample of 174 graduates over a number of academic years, using a randomized number table.

The plan of the three-factor experiment in the form of a matrix in which the rows correspond to the different experiments and the columns to the values of the factors, and the results of the experiments to identify the degree of influence of the disciplines "Organizational Management", "Ecology" and "Applied Economics") on the level of the formation of PEEC are shown in Table 2.

Table 2. Outline of a three-factor experiment and results of experiments to identify the extent The impact of the disciplines "Organizational Management", "Ecology" and "Applied Economics" on the level of PEEC

Experience number	Random order of experiments	D1		D2		D3		Experimental results (PEEC = P_{ki})			
		X_1 coded value	The natural value of X_1	Coded value ofX_2	The natural value of X_2	X_3 coded value	The natural value of X_3	Repeated experiments			Average result
1	4	+1	0,98	+1	0,97	+1	0,99	0,97	0,99	0,98	0,98
2	1	– 1	0,85	+1	0,97	– 1	0,72	0,78	0,91	0,66	0,78
3	6	+1	0,98	– 1	0,65	– 1	0,72	0,96	0,63	0,68	0,76
4	3	– 1	0,85	– 1	0,65	+1	0,99	0,82	0,64	0,97	0,81
5	7	+1	0,98	+1	0,97	– 1	0,72	0,94	0,93	0,65	0,84
6	5	– 1	0,85	+1	0,97	+1	0,99	0,80	0,95	0,99	0,91
7	8	+1	0,98	– 1	0,65	+1	0,99	0,97	0,61	0,96	0,85
8	2	– 1	0,85	– 1	0,65	– 1	0,72	0,83	0,62	0,71	0,72

The results of the experiment can be represented as a regression equation

$$P_k = b_0 + \sum_{i=1}^{3} b_i X_i \sum_{i<j} b_{ij} X_i X_j + b_{123} X_1 X_2 X_3, \quad (2)$$

where b_0 is the arithmetic mean value of the level of PEEC formation (R_k) in all experiments;

bi are regression coefficients showing the magnitude of the influence and direction of the effect of the factors under study on R_k;

b_{ij} are regression coefficients taking into account the interaction effects of the variables (presence of a factor interaction effect).

Using the method of least squares, the values of the regression coefficients of equation (2) can be calculated using the formula:

$$b_i = \frac{1}{k}\sum_{k=1}^{8} X_{ik} P_{ki},$$

where k is the number of experiments in the planning matrix (k = 8); Rci is the arithmetic mean value of the level of PEEC development; Xiq is the value of the i-th factor in the k-th experiment.

In the case in question:

$b_0 = [(+1)\cdot P_{k1} + (+1)\cdot P_{k2} + (+1)\cdot P_{k3} + (+1)\cdot P_{k4} + (+1)\cdot P_{k5} + (+1)\cdot P_{k6} + (+1)\cdot P_{k7} + (+1)\cdot P_{k8}]/8 = =0,831$

$b_1 = [(+1)\cdot P_{k1} + (-1)\cdot P_{k2} + (+1)\cdot P_{k3} + (-1)\cdot P_{k4} + (+1)\cdot P_{k5} + (-1)\cdot P_{k6} + (+1)\cdot P_{k7} + (-1)\cdot P_{k8}]/8 = =0,026$

$b_2 = [(+1)\cdot P_{k1} + (+1)\cdot P_{k2} + (-1)\cdot P_{k3} + (-1)\cdot P_{k4} + (+1)\cdot P_{k5} + (+1)\cdot P_{k6} + (-1)\cdot P_{k7} + (-1)\cdot P_{k8}]/8 = =0,046$

$b_3 = [(+1)\cdot P_{k1} + (-1)\cdot P_{k2} + (-1)\cdot P_{k3} + (+1)\cdot P_{k4} + (-1)\cdot P_{k5} + (+1)\cdot P_{k6} + (+1)\cdot P_{k7} + (-1)\cdot P_{k8}]/8 = =0,056$

According to the principles of the method of least squares, to quantify the interaction effects of factors x̃1, x̃2 and x̃3 respectively of disciplines D1, D2 and D3, the product columns of these factors should be generated, after which the calculated formulae for the interaction effects of these factors will be as follows:

$$b_{12} = [(+1)\cdot(+1)\cdot P_{k1} + (-1)\cdot(+1)\cdot P_{k2} + (+1)\cdot(-1)\cdot P_{k3} + (-1)\cdot(-1)\cdot P_{k4} + (+1)\cdot(+1)\cdot P_{k5} + (-1)\cdot(+1)\cdot P_{k6} +(+1)\cdot(-1)\cdot P_{k7} + (-1)\cdot(-1)\cdot P_{k8}]/8 = 0,006;$$

$$b_{13} = [(+1)\cdot(+1)\cdot P_{k1} + (-1)\cdot(-1)\cdot P_{k2} + (+1)\cdot(-1)\cdot P_{k3} + (-1)\cdot(+1)\cdot P_{k4} + (+1)\cdot(-1)\cdot P_{k5} + (-1)\cdot(+1)\cdot P_{k6} +(+1)\cdot(+1)\cdot P_{k7} + (-1)\cdot(-1)\cdot P_{k8}]/8 = 0,001;$$

$$b_{23} = [(+1)\cdot(+1)\cdot P_{k1} + (+1)\cdot(-1)\cdot P_{k2} + (-1)\cdot(-1)\cdot P_{k3} + (-1)\cdot(+1)\cdot P_{k4} + (+1)\cdot(-1)\cdot P_{k5} + (+1)\cdot(+1)\cdot P_{k6} +(-1)\cdot(+1)\cdot P_{k7} + (-1)\cdot(-1)\cdot P_{k8}]/8 = 0,011;$$

The calculated formula for the triple interaction effect of the factors x̃1, x̃2 and x̃3 respectively would look as follows in this case:

$$b_{123}=[(+1)\cdot(+1)\cdot(+1)\cdot P_{k1}+(-1)\cdot(+1)\cdot(-1)\cdot P_{k2}+(+1)\cdot(-1)\cdot(-1)\cdot P_{k3}+(-1)\cdot(-1)\cdot(+1)\cdot P_{k4}+(+1)\cdot(+1)\cdot(-1)\cdot P_{k5}+(-1)\cdot(+1)\cdot(+1)\cdot P_{k6} + (+1)\cdot(-1)\cdot(+1)\cdot P_{k7} + (-1)\cdot(-1)\cdot(-1)\cdot P_{k8}]/8 = 0,001;$$

Analysis of the obtained results allows us to note that all linear effects of the disciplines "Organization Management", "Ecology" and "Applied Economics" by degree of influence on the level of PEQ formation are arranged in the form of a ranked series

|b3| > |b2| > |b1|.

The use of factor planning makes it possible to present the results of the experiment as providing the maximum result of the final P_k dependence of the level of PEEC formation without taking into account the effects of the interaction of the factors studied in the form of a regression equation.

$$P_k = 0{,}831 + 0{,}026 \times \frac{Д1 - 0{,}915}{0{,}065} + 0{,}046 \times \frac{Д2 - 0{,}810}{0{,}160} + 0{,}056 \times \frac{Д3 - 0{,}855}{0{,}135}. \quad (3)$$

The values of coefficients b3, b2, b1 of the regression equation (3) show that among the dominating factors of PEEC formation the discipline of "Applied Economics" has the highest level of influence, followed by the discipline of "Ecology", and then by the discipline of "Organization Management" with the proportions |0.056| > |0.046| > |0.026|.

The resulting regression model is the initial step in developing a platform (underlying framework) for the qualitative assessment of factors for the successful formation of PEECC, following on from earlier work [29]. The underlying principles of such a framework include:

- to identify the factors whose influence on the value of the model response under study is to be determined;
- determining the range of boundaries of the factors, the intervals of variation in the values of the variables;
- selecting a pedagogical research design according to the research object model;
- determining the order of experiments (experiments, sample analyses, questionnaires, expert procedures, etc.) using random number tables in order to randomize the pedagogical study;
- statistical processing of the results of pedagogical research with calculation of average values of the studied response of the model of the object of research, determination of dispersion in groups of parallel experiments, calculation of error of experiment to ensure accuracy and adequacy of the obtained results and screening of doubtful results, qualimetric evaluation of confidence intervals and degree of influence of the studied factors on the model response values of the object of research;
- anticipating practical decision-making.

5 Conclusion

In this study, the principles of systemic approach, using conceptual provisions of quantitative measurements, numerical modelling and mathematical statistics based onto identify the final dependence of PEEC level as a regression model as the initial step in the developed platform (underlying concept) of qualimetric evaluation of the factors of successful PEEC formation. The initial principles of such a concept were formulated, providing opportunities to study and analyze the influence of different pedagogical factors and choose the ways of generating educational trajectories.

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