http://dx.doi.org/10.18623/rvd.v23.n4.4837

CONCEPTUAL OPTIONS OF THE METHODOLOGICAL APPROACH TO DIGITAL TRANSFORMATION OF EDUCATIONAL ACHIEVEMENTS

OPÇÕES CONCEITUAIS DA ABORDAGEM METODOLÓGICA PARA A TRANSFORMAÇÃO DIGITAL DOS RESULTADOS EDUCACIONAIS

Article received on: 10/9/2025
Article accepted on: 1/9/2026

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The authors declare that there is no conflict of interest

Abstract
The article aims to substantiate the conceptual and methodological options for digital transformation of educational achievements, focusing on how ICT tools and mathematical modeling contribute to sustainable human capital development and competitiveness. Particular emphasis is placed on aligning educational assessment practices with the requirements of the digital economy and the Sustainable Development Goals (SDGs). The study employs a combination of systemic and comparative analysis, statistical modeling (geometric mean, Harrington scale, Monte Carlo method), and pedagogical measurement techniques. These approaches allow the authors to evaluate the limitations of traditional assessment systems, demonstrate the advantages of digital assessment models, and classify their contribution to sustainable educational outcomes. Unlike studies that address digital education primarily through technological adoption, this research highlights the methodological dimension of assessment as a decisive factor in shaping competitive, future-

Resumo
O artigo tem como objetivo fundamentar as opções conceituais e metodológicas para a transformação digital dos resultados educacionais, com foco em como as ferramentas de TIC e a modelagem matemática contribuem para o desenvolvimento sustentável do capital humano e a competitividade. É dada especial ênfase ao alinhamento das práticas de avaliação educacional com os requisitos da economia digital e os Objetivos de Desenvolvimento Sustentável (ODS). O estudo emprega uma combinação de análise sistêmica e comparativa, modelagem estatística (média geométrica, escala de Harrington, método de Monte Carlo) e técnicas de medição pedagógica. Essas abordagens permitem aos autores avaliar as limitações dos sistemas de avaliação tradicionais, demonstrar as vantagens dos modelos de avaliação digital e classificar sua contribuição para resultados educacionais sustentáveis. Ao contrário de estudos que abordam a educação digital principalmente por meio da adoção tecnológica, esta pesquisa

ready human capital. By integrating ICT with advanced mathematical modeling, the paper bridges educational measurement, competitive intelligence, and sustainable development. The digital transformation of assessment systems enhances both the accuracy and reliability of competency evaluation, thereby supporting the formation of 21st-century skills. Beyond measuring academic success, digital assessment becomes a driver of innovation, competitiveness, and sustainability by ensuring the adaptability of human capital to continuously changing labor market demands. The article contributes to the theory of sustainable competitive intelligence in education by refining assessment models, expanding methodological tools for evaluating competencies, and demonstrating how digital intelligence can strengthen educational systems as strategic resources for sustainable development.

Keywords: Information and Communication Technologies (ICT). Mathematical Modeling Options. Data Determination. Forecasting Trend.

destaca a dimensão metodológica da avaliação como um fator decisivo na formação de capital humano competitivo e preparado para o futuro. Ao integrar as TIC com modelagem matemática avançada, o artigo faz a ponte entre a medição educacional, a inteligência competitiva e o desenvolvimento sustentável. A transformação digital dos sistemas de avaliação aumenta a precisão e a confiabilidade da avaliação de competências, apoiando assim a formação de habilidades do século XXI. Além de medir o sucesso acadêmico, a avaliação digital se torna um impulsionador da inovação, competitividade e sustentabilidade, garantindo a adaptabilidade do capital humano às demandas em constante mudança do mercado de trabalho. O artigo contribui para a teoria da inteligência competitiva sustentável na educação, refinando modelos de avaliação, expandindo ferramentas metodológicas para avaliar competências e demonstrando como a inteligência digital pode fortalecer os sistemas educacionais como recursos estratégicos para o desenvolvimento sustentável.

Palavras-chave: *Tecnologias da Informação e Comunicação (TIC). Opções de Modelagem Matemática. Determinação de Dados. Previsão de Tendências.*

1 INTRODUCTION

Digitalization of the most popular platform of the education system for a radical reconfiguration of the technological sphere of industry and, especially, its economic sector inevitably and constantly requires an objective assessment, adjustment and digital transformation of management in professional and educational organizations (Belevitin *et al*., 2023; Brown *et al*., 2015; Kaplan & Haenlein, 2016; Nielsen *et al*., 2015; Watson *et al*., 2015).

The relevance of the priority of scientifically based reliability of the forecast data of quantitative integration-resource assessment of results within the framework of the registry system of the organization of the process of obtaining education and management of professional educational activities is due to the urgent need to use innovative approaches that most fully implement the resources of mathematical methods in terms of

scientifically correct increase in the accuracy and reliability of processing educational content in the pragmatically oriented digital transformation of the professional education system (Tarasova *et al*., 2026; Ismagilova *et al*., 2025).

Due to the complexities of the many methods of competencies formation initiated by the introduction of various methods, various models for assessing the formation of competencies in the field of pedagogical measurements come to the fore (Belevitin *et al*., 2020).

Due to the possibility of obtaining a more objective assessment of the competencies formation by using the approach of statistical processing of latent (cognitive) and deeply latent (competency) variables, which, however, cannot be considered finally formed, but provides additional information when using digital clustering tools, for example, the initial data of current and final monitoring of educational achievements. Ensuring reliable and valid assessment of various components of educational results for the development of 21st century skills in the form of a qualitative, quantitative or other degree of competencies formation requires certain approaches to the creation of not individual indicators, but a system of criteria, scales and digital assessment tools (Strokov, 2020).

In Russian educational practice today, the traditional four-point (2, 3, 4 and 5) system of assessing students' academic achievements is used almost everywhere. But employers' demand for scientifically based evidence of the validity and reliability of criteria for assessing the degree of development of key competencies of the 21st century for graduates of professional educational organizations is growing every year, which is becoming increasingly important and significant for the digital economy in a rapidly changing global environment. In this regard, the quality assessment system of education is in need of fundamental changes, which cause an urgent need, first of all, for digital transformations both in the training of teachers of professional educational organizations to design educational materials of a new format, and technologies for scientifically evidence-based assessment of objective criteria for the degree of competencies formation. The assessment reform has become a key factor for ensuring the education quality: all the best global educational practices are based on independent highly professional assessment systems and processes.

The aim of the study is to substantiate the conceptual and intellectual options of the combined information and digital toolkit (CIDT) of the digital transformation of the quantitative assessment of educational achievements (theoretical knowledge, practical skills and abilities – the fundamental basis for the formation of competencies) of subjects of professional education as a measure of mastering the resource potential of the readiness of the human capital of an individual for its successful and effective inclusion in professional activities.

2 LITERATURE REVIEW

The practical application in Russian educational practice of statistical methods that have real potential for leveling random errors of continuous and discrete influence (as a result of the action of a large number of factors that are not interconnected with each other) and correcting the limits of their change according to the normal law, respectively, the results of the analysis of dissertation research on pedagogical sciences within the framework of the most typical cases of their implementation in pedagogy is not implemented at all or is often used incorrectly (Yessengulova *et al*., 2026). Cases of the highest order of use of calculations of the simple average parameter from the appropriate position of ensuring the correctness and significance of their application in pedagogical research are not confirmed (Korshunova & Rakipova, 2020).

At the same time, the direction that is rapidly revolutionizing the development of new conceptual and intellectual options of ICT (information and communication technologies) serves as an innovative source of acceleration of digital transformation of scientifically based accuracy in combination with the reliability of determination data (a pedagogical construct that guarantees practical opportunities for understanding the problem being solved as an engine of progress) of quantitative resource-integration assessment of the results of forecasting trends and prospects for modernization of the management system of the educational organizations activities in terms of improving the organization of the process of the education quality improving (Titova *et al*., 2025).

The combination of innovative information and digital resources of ICT and mathematical modeling with the use of potential resources of conceptual and intellectual options of the CIDT (statistical processing of the interval-point scaling regulations

(changes in the type of assessment scale with the transformation of qualitative or quantitative certainty corresponding to the identified scale mark (Bratishchenko, 2019)) of primary and initial data, their subsequent ranking, approximation, flattening, determination of mathematical expectation, standard deviation, etc.) provides new opportunities for expanding the range of digital transformation of determination content to an acceptable level of guaranteed reliability of general indicators.

The transition from linear mathematical operations of addition and division in the case of calculating arithmetic mean parameters to calculation operations of determining geometric mean parameters that have an integration resource has a positive effect on the final result of determining generalizing characteristics. Confirmation of this is contained in numerous publications of the results of research by scientists in assessing and optimizing multi-criteria problems in various fields: economics, engineering and technology, medicine, management, ecology, education, etc. (Efremova, 2019).

The problem of uncertainty and narrowness of intervals of the most popular, due to its simplicity, five-point system of assessing the educational achievements of students as a method of one-dimensional scaling makes it difficult to use as an accurate pedagogical tool. In a number of countries, a 12-point scale is used to assess the educational achievements of educational entities with the following regulations: 12, 11 and 10 points, respectively, 5+, 5 and 5 −; 9, 8 and 7 points – 4+, 4 and 4 −, etc. This reduces the narrowness of the scoring intervals and increases its differentiability. The introduction of the calculation operation of the geometric mean parameter of the “raw” scores of the initial information reformatted by the “advanced” statistical Mote-Carlo method (Pan'gina & Pan'gina, 2002) into a specific substance of quantitative results corresponding to the identified marks of the Harrington scale (Chernaya, 2017; Rodionov *et al*., 2019) (Table 1) in pedagogical research contributes to the expansion of the real capabilities of the CIDT for the quantitative assessment of students' academic achievements during digitalization.

Table 1

Standard harrington scale marks

Interpretation	Very good	Good	Satisfactory	Bad	Very bad
Interval	1,00–0,80	0,80–0,63	0,63–0,37	0,37–0,20	0,20–0,00

In light of the approach that provides for the relationship between the academic success of educational activities and the positive motivation for its achievement by students (D. McClelland, H. Heckhausen, T.O. Gordeeva, etc.) (Kateyeudo & De Souza, 2022; Mareque & De Prada-Creo, 2018; Rychen, 2016), the necessary pedagogical conditions are reduced to one of the most important current conditions, which provides for the dominant importance of increasing the objectivity of assessing the educational achievements through the most valuable resources of our time.

3 MATERIALS AND METHODS

The study is based on the application of quantitative pedagogical measurement methods combined with mathematical and statistical modeling of educational assessment data. The empirical material consists of existing results of current (border) and final academic control in bachelor's degree programs of vocational education. Discrete academic grades obtained within standard assessment procedures were used as initial numerical data for further analytical processing. The research applies comparative analysis to examine differences between traditional arithmetic mean aggregation and geometric mean aggregation of assessment results in order to evaluate their impact on accuracy and error levels in measuring academic achievement.

To improve the objectivity and reliability of assessment, the study employs advanced statistical tools, including geometric mean modeling as an integrative indicator for multi-criteria evaluation, Monte Carlo simulation to reduce random errors and stabilize distributions, and Harrington's desirability function to transform discrete grades into continuous interval-scale values. The accuracy of the applied models was assessed by calculating and comparing error indicators ($\Delta_1 K$ and $\Delta_2 K$) for arithmetic and geometric aggregation methods, using an acceptable error threshold of 5–7% consistent with pedagogical measurement standards. In addition, a digital transformation algorithm was

developed, including grade differentiation, scale transformation, weighting procedures, and weighted geometric mean calculation, forming a combined information and digital toolkit (CIDT) for the quantitative assessment of educational achievements.

4 RESULTS AND DISCUSSION

The analysis by the method of comparison of the assessment results of the representative samples of the border and final test control of the success of students' knowledge acquisition in the bachelor's degree programs “Vocational Education” (profile “Transport”, “Economics and Management”) using the geometric mean indicator ($S_G = (g_1 \cdot g_2 \cdot g_3 \cdot \ldots \cdot g_n)^{1/n}$) and the arithmetic mean indicator S_A, made it possible to identify a critically significant difference in the calculated accuracy of academic success rate – the arithmetic mean indicators S_{A1K}, S_{A2K} and the geometric mean S_{G1K}, S_{G2K}, as well as the error values Δ_{1K} и Δ_{2K} in % (Table 2):

$$\Delta_{1K} = (S_{1A} - S_{2G})/(S_{1A} \cdot 10^{-2}),$$
$$\Delta_{2K} = (S_{2AK} - S_{2AGK})/(S_{2AK} \cdot 10^{-2}),$$
$$S_{2AG} = (S_{1G} \cdot S_{2GK})^{1/2}. \qquad (1)$$

Table 2

Results of comparative analysis

No.	Result of the border control	S_{1A}	S_{1G}	Δ_{1K}, %	S_{2AK}	S_{2GK}	S_{2AGK}	Δ_{2K}, %
1	3, 4, 4, 4, 5, 5, 5, 5, 5	4,44	4,39	1,13	4,63	4,60	4,49	3,02
2	3, 3, 4, 4, 4, 5, 5, 5, 5	4,22	4,14	1,90	4,57	4,54	4,34	2,84
3	3, 3, 3, 4, 4, 4, 5, 5, 5	4,00	3,91	2,25	4,50	4,47	4,18	4,50
4	3, 3, 3, 3, 4, 4, 4, 5, 5	3,78	3,70	2,12	4,40	4,37	4,06	7,41
5	3, 4, 4, 5, 5	4,20	4,13	1,67	4,50	4,47	4,33	3,09
6	3, 3, 4, 4, 5	3,80	3,73	1,84	4,33	4,30	4,00	5,26
7	3, 3, 3, 4, 5	3,60	3,52	2,22	4,50	4,47	4,01	11,39
8	4, 4, 4, 4, 4	4,00	4,00	0,00	4,00	4,00	4,00	0,00
9	4, 4, 4, 4, 5	4,20	4,18	0,50	4,20	4,18	4,18	0,50

As a consequence of choosing the geometric mean S_G instead of the arithmetic one S_A as a generalizing parameter, the advantage of the S_{G2K} value is revealed in the qualitative success of students’ knowledge acquisition for individual samples of the midterm and final test control with an acceptable error Δ_{2K} of less than 5–7%. At the same

time, an increase in the value of S_{G2K} of the qualitative knowledge acquisition success in the test control samples is also observed, with a proportion of satisfactory grades in the range of 0.37–0.63 marks on the Harrington scale (Table 1).

The successes of the rapid development of ICT hardware and software tools contribute to the expansion of the range of their potential resources for the development of options for the CIDT for digitalization of the educational achievements quantitative assessment, in particular, in ensuring the direct objectification of the results of multifactorial studies, to which pedagogical research is related in an unambiguous manner.

One of such variants of the CIDT digital transformation includes the author's development and evidentiary testing of the following algorithmic components sequence:

1. Differential addition of the composition of marks “3”, “4” and “5” with the values “3–” (three minus), “3+” (three plus), “4–” (four minus), “4+” (four plus), “5–” (five minus), “5+” (five plus);
2. Establishing the relationship between the upgraded marks composition and the parametric characteristics of the Harrington scale: $3^{-} = 0.37$, $3 = 0.50$ ((0.37 + 0.63)/2), $3^{+} = 0.63$, $4^{-} = 0.63$, $4 = 0.72$ ((0.63 + 0.80)/2), $4^{+} = 0.80$, $5^{-} = 0.80$ и $5 = 0.9$ ((0.80 + 1.00)/2), 5 + = 1.00;
3. Assignment of weighting coefficients to the components of the re-updated marks composition, taking into account the parametric characteristics of the Harrington scale, depending on the level of the proportion of “3” in the total number of marks of the studied samples as a percentage (in particular);
4. Calculation and analysis of the geometric mean parameter of the Harrington’s desirability function (utility, practicality) reformatted by the Mote-Carlo method, taking into account the weighting coefficients of the components of the re-updated marks composition of the studied samples into a specific substance of quantitative results (Table 3).

Table 3

Results of comparative analysis of reformatted Table 2 samples of using the digital transformation toolkit

No.	Result of the border control	S_{1A}	S_{1G}	Δ_{1K}	S_{2AK}	S_{2GK}	S_{2AGK}	Δ_{2K}
1	0,62; 0,80; 0,85; 0,90; 0,95; 0,95; 0,95; 0,95; 0,95	0,881	0,874	0,80	0,913	0,911	0,891	2,18
2	0,59; 0,61; 0,72; 0,79; 0,80; 0,80; 0,90; 0,95; 0,95	0,790	0,780	1,27	0,844	0,856	0,819	3,67
3	0,37; 0,50; 0,62; 0,63; 0,72; 0,78; 0,80; 0,85; 0,90	0,691	0,663	4,05	0, 669	0,807	0,747	8,10
4	0,37; 0,39; 0,45; 0,56; 0,69; 0,74; 0,77; 0,80; 0,84	0,623	0,597	4,17	0,454	0,766	0,691	10,91
5	0,60; 0,72; 0,72; 0,90; 0,90	0,768	0,759	1,17	0,810	0,810	0,789	2,73
6	0,37; 0,41; 0,63; 0,72; 0,76	0,578	0,554	4,15	0,703	0,701	0,623	7,79
7	0,37; 0,42; 0,55; 0,66; 0,81	0,620	0,594	4,19	0,743	0,675	0,647	11,39
8	0,72; 0,72; 0,72; 0,72; 0,72	0,720	0,720	0,00	0,720	0,720	0,720	0, 00
9	0,72; 0,72; 0,72; 0,72; 0,90	0,756	0,753	0,40	0,756	0,753	0,753	0, 40

Expanding the potential of the resource capabilities of the five-point system of the academic achievements assessing, which is the most popular due to its simplicity, by reducing the narrowness of the assessment intervals and increasing the level of its differentiability helps to support, on the one hand, a more uniform stabilization of the identification of the error values Δ_{1K} and Δ_{2K}, and, on the other hand, an additional increase in accuracy in identifying a critically significant difference in errors (> 5–7%) in the process of calculating the academic success rate. This increases the range of pragmatic possibilities for determining pedagogical tools through the objectification of digital integration assessment by improving the resources of conceptual and intellectual options of the CIDT for digital transformation of educational achievements quantitative assessment (theoretical knowledge, practical skills and abilities – the fundamental basis for the formation of the 21st century competencies) as a measure of: the readiness of the human capital for its successful inclusion in professional activity; effective and progressive results of forecasting trends and prospects for modernization of the educational activities management system in terms of improving the organization of the process of improving the quality of education in accordance with the continuously changing requirements of the labor market.

The propagation in general or selectively of the options of the CIDT of digital transformation of the educational achievements quantitative assessment to the obvious transformation into a specifically measurable result of the objectification of many

different factors of influence (Amin & Mirsa, 2020; Calero Lopez & Rodriguez-Lopez, 2020; Garcia-Valcarcel Munoz-Repiso *et al*., 2020; Sturing *et al*., 2011) on the increase in the range of boundaries of the processability of education and science is nothing more than a trigger for the growth of the country's technological sovereignty.

5 CONCLUSION

The study demonstrates that traditional approaches to assessing educational achievements, based on discrete grading scales and arithmetic averaging, have limited capacity to ensure objective and differentiated evaluation in the context of digital transformation. The results show that integrating ICT with mathematically grounded assessment models significantly improves the accuracy and reliability of educational measurement.

The application of geometric mean aggregation, interval-scale transformation using Harrington’s desirability function, and Monte Carlo–based data processing reduces random errors and enhances the differentiation of assessment outcomes, particularly for borderline and heterogeneous achievement levels. The proposed combined information and digital toolkit expands the analytical capabilities of existing assessment systems without replacing them institutionally.

Overall, the findings confirm that the digital transformation of assessment practices is essential for improving the quality of educational measurement, supporting the formation of 21st-century competencies, and strengthening the role of education in the development of competitive and sustainable human capital.

ACKNOWLEDGMENTS

The authors express their gratitude to the Mordvinian State Pedagogical University, which sponsored this research work within the framework of the scientific project “Development of scientific foundations of digital tools for improving innovative and professional training of teaching staff”.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

How to cite this article (APA)

Belevitin, V., Gafarova, E., Dmitriyev, M., & Litke, S. (2026). CONCEPTUAL OPTIONS OF THE METHODOLOGICAL APPROACH TO DIGITAL TRANSFORMATION OF EDUCATIONAL ACHIEVEMENTS. *Veredas Do Direito*, *23*(4), e4837. https://doi.org/10.18623/rvd.v23.n4.4837