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THE PLACE OF KNOWLEDGE MANAGEMENT IN THE QUALITY ASSURANCE SYSTEM OF INDUSTRY 4.0: A VIEW FROM THE POINT OF VIEW OF SUSTAINABILITY AND COMPETITIVENESS

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A B S T R A C T

The article is devoted to solving the problem of the imperfection of the existing approach to knowledge management in the quality assurance system of Industry 4.0 products, due to the fact that the place of knowledge management outside the quality assurance system of industry 4.0 products, characteristic of this approach, hinders the achievement of sustainability and competitiveness. The authors have compiled an econometric model based on the international experience of the top 40 leading countries of the world with the most developed industry 4.0 for 2023, which mathematically describes and justifies the significant contribution of knowledge management to the product quality of industry 4.0 from the standpoint of sustainability and competitiveness. The model has identified key factors of sustainability (implementation of SDGs 8 and SDGs 9) and competitiveness, namely knowledge capital, research, development and innovation outputs and impact, as well as information and communications technology usage. To solve this problem, an alternative, new approach to knowledge management in the product quality assurance system of industry 4.0 has been developed, which makes it possible to simultaneously and fully achieve sustainability and competitiveness. The originality of the approach is that it considers quality as a result of sustainability and competitiveness; and knowledge management is interpreted as the embodiment of quality, located inside the quality assurance system of products in industry 4.0.The theoretical significance of the authors' conclusions is that they rethought the place of knowledge management in the product quality assurance system of industry 4.0, which should be inside this system in the interests of sustainability and competitiveness. The practical significance of the developed approach is due to the fact that it will improve the practice of ensuring the product quality of industry 4.0 through the integrated achievement of sustainability and competitiveness through the optimization of knowledge management.

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1. INTRODUCTION

Knowledge management is one of the most pressing issues of business management because of the clearly expressed social consequences. In industry 4.0, the urgency of this issue is increased, since social risks are especially high: from the need for lifelong learning in order to fill the constantly emerging knowledge deficit to the release of personnel as automation progresses.

From the perspective of sustainability, which is based on the Sustainable Development Goals (SDGs) formulated by the UN, knowledge management in industry 4.0 implies fitting workplaces with advanced equipment, providing employees with access to the latest knowledge and technologies available to the organization, promoting the development and disclosure of human potential, as well as creating additional jobs for highly qualified specialists for strengthening the guarantees of their employment and increasing the value of higher education and digital competencies in the socio-economic system.

Modern managers are professionals in their field who share progressive social values and actively support the implementation of the SDGs. They clearly understand, accept and bear social responsibility for their HRM. However, unfortunately, high and increasing digital competition often forces them to shift their focus from the SDGs to strengthening competitiveness.

From the standpoint of competitiveness, knowledge management in industry 4.0 implies, firstly, a rigorous competitive selection of the best personnel both in the labor market and in the labor collective of the organization, inevitably creating a certain psychological pressure on potential and existing employees associated with the risk of being an outsider of a fierce race, in which the goal is often even not building a career, but the jobs themselves.

Secondly, strict requirements for the set of knowledge and competencies that employees should have, going beyond providing them with the opportunity to obtain them and reaching the level of mandatory conditions for employment This is the reason that the development of knowledge is perceived by employees as an undesirable additional burden to the main employment, which does not guarantee career growth Investment in knowledge – from higher education to further professional development – in many cases do not pay off and therefore are unprofitable for employees.

Thirdly, forced automation increases the tension in the social and labor collective of the organization of industry 4.0.Human-machine communications are replacing social communications in the workplace. Total control of artificial intelligence and machine vision increases openness, transparency and predictability of knowledge management, but reduces employee satisfaction with working conditions.Staff reduction and meaningful transition of knowledge-intensive work from the disclosure of human potential through team building and labor stimulation to the disclosure of the potential of automation tools through machine learning and their maintenance.

Thus, sustainability and competitiveness come into conflict in industry 4.0.The described contradiction in the practice of modern business is usually resolved in the interests of quality, which is a business priority. The problem is that with the existing approach to knowledge management in the quality assurance system of industry 4.0, this contradiction is resolved either in favor of sustainability, or in favor of competitiveness, or at the same time to the detriment of both sustainability and competitiveness.

In this regard, the scientific search for an alternative approach to knowledge management in the product quality assurance system of industry 4.0 is relevant, which will make it possible to simultaneously and fully achieve sustainability and competitiveness. The development of this approach is the purpose of this article. Further, the article provides a review of the literature. It reveals the view of the available literature on the place of knowledge management in the product quality assurance system of industry 4.0.The existing approach to knowledge management in the product quality assurance system of industry 4.0 is described. The identified gaps are analyzed, a research question (RQ) is posed and a hypothesis is formulated.

After that, the materials of the methodological apparatus of the study are described: the sample and the system of the considered indicators are explained, and the methodology and procedure of the research are prescribed. The main results are given below. They include determining the contribution of knowledge management to the product quality of industry 4.0 from the perspective of sustainability and competitiveness. The results also develop a new approach to knowledge management in the product quality assurance system of industry 4.0. The authors' recommendations on improving knowledge management to increase the product quality of industry 4.0 in Russia are proposed.

2. LITERATUREREVIEW

2.1. The view of the available literature on the place of knowledge management in the product quality assurance system of industry 4.0

The fundamental basis of this research is the concept of knowledge management within the framework of the theory of management information systems (Memon et al., 2022; Mohamad et al., 2022; Nguyen et al., 2023; Shrestha and Saratchandra, 2023). The specifics of the product quality of industry 4.0, according to this concept, are described in detail in the publications of Popkova et al. (2021), Popkova (2019), Sergi

and Popkova (2022), Sharma (2023), Woźniak et al. (2022). The concept under consideration notes the important role of knowledge management to ensure the product quality of industry 4.0 (Nwasuka et al., 2022; Zimon et al., 2022).

The interpretation of the relationship of quality with sustainability and competitiveness given in the existing literature by Dyakov et al. (2022), Handayani et al. (2022) defines quality as a factor of sustainability and competitiveness. That is, the organization of industry 4.0 systematically takes measures aimed at maintaining and improving the quality of products within the framework of its normal functioning (Othman and Elwazer, 2023; Rambe and Khaola, 2023). At the same time, sustainability and competitiveness are secondary and are achieved according to the residual principle (Papademetriou et al., 2023; Ružbarský and Gašpár, 2023).

There are also suggestions in the existing literature regarding the possible place of knowledge management in the product quality assurance system of industry 4.0.In the works of Campos and Silva (2022), Dovleac et al. (2021),knowledge management is interpreted as a source of product quality in industry 4.0, occupying a place outside the quality assurance system of these products. This means that knowledge management is perceived as a management process separate from quality management, but influencing it (Montoya-Quintero et al., 2022).

2.2. The existing approach to knowledge management in the product quality assurance system of industry 4.0

The provisions of the existing approach to knowledge management of the product quality assurance system in industry 4.0 can be found in the published scientific literature and are as follows. First, the important role of higher education for knowledge management (Alvesand de Carvalho, 2023; Sabherwal et al., 2023). In the existing approach, it is important for employees to have higher education, since it is assumed that thanks to employees with higher education, the greatest increment of knowledge is achieved in the organization of industry 4.0, which creates the most favorable opportunities for improving product quality (Przhedetskaya and Borzenko, 2019; Vanchukhina et al., 2022).

Secondly, the great importance of AI competencies for knowledge management. The established approach proceeds from the fact that AI competencies in industry 4.0 are more important and more valuable than other competencies for increasing knowledge and improving quality (Khakimova and Kayumova, 2022; Ma et al., 2022). Thirdly, knowledge is considered as the most valuable property of intellectual resources. In the existing approach, it is believed that knowledge in itself is valuable in industry 4.0, as it allows an organization to gain and strengthen unique digital competitive advantages in the field of product quality (Bogoviz, 2020; Capasso and Umbrello, 2022).
Fourth, the essence of the approach to knowledge management is to attract and retain leading digital staff (Binsaeed et al., 2023). That is, this approach involves the acquisition of ready, standard (developed within the framework of standard educational programs at universities) knowledge (Gagliardi et al., 2023). Fifth, the uncertainty and inconsistency of the consequences of knowledge management in the quality assurance system for sustainability and competitiveness (Turginbayeva and Abildaev, 2013).

Thus, the result of knowledge management with the existing approach is that quality increases, but the consequences for sustainability and competitiveness can be both positive and negative (Mamyralieva et al., 2022). Thus, in the existing approach, the main and most important factors of knowledge management in the product quality assurance system of industry 4.0 are: 1) AI skills penetration (Pokharel, 2023) and 2) higher education outputs (Nguyen et al., 2023).

2.3. Gap analysis, research question (RQ) and hypothesis

The literature review has shown that the scientific provisions of the concept of knowledge management are deeply developed and detailed in the available literature, which provides a high degree of elaboration of the problem. However, a serious disadvantage of the existing approach to knowledge management in the product quality assurance system of industry 4.0 is the separation of quality, sustainability and competitiveness of products in industry 4.0.

It is not clear from the published literature how to systematically achieve high product quality in industry 4.0 simultaneously with the sustainability and competitiveness of products. In this regard, the place of knowledge management in the product quality assurance system of industry 4.0 from the standpoint of sustainability and competitiveness is uncertain. This is a gap in the literature and raises the following research question. RQ: How to manage knowledge in Industry 4.0 to simultaneously achieve both sustainability and competitiveness embodying quality?

Some literature sources (Jatiningsih et al., 2023; Vătămănescu et al., 2023) indicate that it is not necessary to switch completely to digital personnel during the transition to industry 4.0, also that the value of pre-digital personnel remains in it.As potential factors of knowledge management that can improve quality, as well as have a beneficial effect on sustainability and competitiveness, the following are given:

- knowledge capital (AlQershi et al., 2023);

- research, development and innovation outputs (Ilina et al., 2019);
- research, development and innovation impact (Al-Sous et al., 2023);
- information and communications technology usage (Karrieva, 2019).

Based on the above works, this article hypothesizes that in order to simultaneously achieve both sustainability and competitiveness embodying quality, it is necessary to manage knowledge in industry 4.0 through the disclosure of talents. Using the terminology of official statistics, we can formulate a hypothesis as follows. H: knowledge capital, research, development and innovation outputs and impact, as well as information and communications technology usage are key factors of sustainability (implementation of SDGs 8 and SDG9) and competitiveness.

To test the hypothesis put forward in this article, a factor analysis of sustainability (implementation of SDGs 8 and SDGs 9) and competitiveness is carried out. This analysis compares the impact on the sustainability and competitiveness of alternative sets of factors: AI skills penetration and higher education outputs, on the one hand, and knowledge capital, research, development and innovation outputs and impact, as well as information and communications technology usage, on the other hand.

3. MATERIALSANDMETHODOLOGY

3.1. Sample and system of studied indicators

The sample consists of the top 40 leading countries of the world with the most developed industry 4.0. As a justification for the inclusion of countries in the sample is their presence in the "Global Industry 4.0 Market Report 2023" (Globe Newswire, 2023), as well as in the "Cross-Country AI Skills Penetration 2022" (OECDAIPolicyObservatory, 2023). The system of studied indicators includes, firstly, the results of quality assurance:

- "Economic competitiveness" as an indicator of competitiveness according to Knowledge for all (2023) (the dependent variable: Q1);
- Goal 8 Score as an indicator of HRM sustainability result in terms of the implementation of SDG 8 according to UN (2023) (the dependent variable: Q2);
- Goal 9 Score as an indicator of the sustainability of Industry 4.0 in terms of the implementation of SDG9 according to UN (2023) (the dependent variable: Q3).

Secondly, a set of potential quality factors from the perspective of knowledge management:

- "AI Skills Penetration" as an indicator of the prevalence of workers with artificial intelligence skills according to the LinkedIn participants themselves in 2022 in comparison with the OECD average according to the OECD AI Policy Observatory (2023) (the factor variable: AIsk). The arithmetic mean of the sample is indicated for countries for which statistics are not kept;
- Knowledge capital according to Knowledge for all (2023) (the factor variable: KnCap);
- Higher education outputs according to Knowledge for all (2023) (the factor variable: HEotp);
- Research, Development and Innovation outputs according to Knowledge for all (2023) (the factor variable: RDIotp);
- Research, Development and Innovation impact according to Knowledge for all (2023) (the factor variable: RDIimp);
- Information and Communications Technology Usage according to Knowledge for all (2023) (the factor variable: ICTusg).

Time period of the study: 2023 based on data for 2022. The data table is shown in Appendix, with statistics in tabular form, which allows rechecking the results by all interested parties.

3.2. Methodology and procedure of the study

The article sets and consistently solves the following three tasks. The first task is to determine the contribution of knowledge management to the product quality of industry 4.0 from the standpoint of sustainability and competitiveness. To solve it using regression analysis, econometric modeling of the dependence of each of the results of quality assurance on a set of potential quality factors from the standpoint of knowledge management is carried out. The research model is written as follows:

$$Q=a+b_1*AIsk+b_2*KnCap+b_3*HEotp+b_4*RDIotp+b_5*RDIimp+b_6*ICTusg \quad (1)$$

The quality of the model (1) is evaluated by correlation analysis, Fisher's F-test and Student's t-test. During the formulation of the authors' conclusions, only those variables are taken into account, according to which all tests will be successfully passed, which will guarantee their validity and reliability. Hypothesis (H) will be proven if the regression coefficients (b_2, b_4, b_5, b_6) for the factor variablesKnCap, RDIotp, RDIimp and ICTusg take larger values than the regression coefficients ($b_1$andb_3) at factor variables AIsk and HEotp.

The second task is to determine the prospects for improving knowledge management in the product quality assurance system of industry 4.0.To solve it, a new approach to this management is developed. The authors' approach is presented graphically and described in detail. It reveals the authors' vision of the

place of knowledge management in the product quality assurance system of industry 4.0 from the standpoint of sustainability and competitiveness.

The third task is to unlock the potential of improving the product quality of industry 4.0 in Russia through the improvement of knowledge management. To solve it, the maximum possible values of the selected statistically significant factor variables are substituted into the research model (1) and the expected values of the dependent variables are determined. Based on this, the authors' recommendations for improving knowledge management to increase the product quality of industry 4.0 in Russia are compiled. The change in all variables (trend) compared to their baseline values in 2023 is determined by the method of trend analysis.

4. RESULTS

4.1. Contribution of knowledge management to the product quality of industry 4.0 from the perspective of sustainability and competitiveness

To solve the first task of this study, related to determining the contribution of knowledge management to the product quality of industry 4.0 from the standpoint of sustainability and competitiveness, the authors define the dependencies of each of the results of quality assurance on a set of potential quality factors from the standpoint of knowledge management through the method of regression analysis. The obtained results of the regression analysis are shown in Tables 1-3.

Table 1. Regression analysis of the dependence of economic competitiveness on potential quality factors from the perspective of knowledge management

Regression statistics	
Multiple R	0.7616
R-Square	0.5801
Adjusted R-Square	0.5037
Standard Error	5.8463
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Signifi-cance F*
Regression	6	1558.0128	259.6688	7.5973	$3.6*10^{-5}$
Residual	33	1127.9130	34.1792		
Total	39	2685.9258			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	18.1110	10.6296	1.7038	0.0978	-3.5150	39.7370
AIsk	-1.1698	2.3612	-0.4954	0.6236	-5.9737	3.6340
KnCap	0.2605	0.1724	1.5108	0.1404	-0.0903	0.6114
HEotp	0.0967	0.1598	0.6051	0.5492	-0.2285	0.4219
RDIotp	0.2094	0.1040	2.0136	0.0523	-0.0022	0.4210
RDIimp	0.1513	0.1335	1.1338	0.2651	-0.1202	0.4228
ICTusg	0.1057	0.1452	0.7280	0.4717	-0.1897	0.4012

Source: calculated and compiled by the authors.

The results from Table 1 mean that the cumulative impact of the studied quality factors from the standpoint of knowledge management by 76.16% explains the change in economic competitiveness in the top 40 leading countries of the world with the most developed industry 4.0 in 2023This is evidenced by the obtained value of the multiple R (0.7616). The coefficient of determination (R^2) also assumed a rather large value (0.5801), which indicates a close relationship of the variables under study.

The significance F=3.6*10-5, hence the results of the regression analysis in Table 1 correspond to the highest significance level of 0.01. The observed F=7.5973. With 40 observations (n=40) and 6 factor variables (m=6), k_1=m=6, k_2=n-m-1=40-6-1=33. In this case, the critical F=3.4059. Since the observed F has exceeded the critical F (7.5973>3.4059), the Fischer's F-test has been passed.

At 39 degrees of freedom, the Student's t-test has been passed only for three factor variables: 1) for KnCap (observed t=1.5108) at a significance level of 0.15, where critical t=1.4685; 2) for RDIotp (observed t=2.0136) at a significance level of 0.1, where critical t=1.6849; 3) for RDIimp (observed t=1.1338) at a significance level of 0.3, where critical t=1.0504.

Table 2. Regression analysis of Goal 8 Score dependence on the potential quality factors from the perspective of knowledge management

Regression statistics	
Multiple R	0.7571
R-Square	0.5733
Adjusted R-Square	0.4957
Standard Error	4.0019
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Signifi-cance F*
Regression	6	709.9332	118.3222	7.3882	$4.6*10^{-5}$
Residual	33	528.4984	16.0151		
Total	39	1238.4316			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	39.8200	7.2761	5.4727	0.0000	25.0167	54.6234
AIsk	-2.3304	1.6163	-1.4418	0.1588	-5.6187	0.9580
KnCap	0.4110	0.1180	3.4816	0.0014	0.1708	0.6511
HEotp	-0.0169	0.1094	-0.1543	0.8783	-0.2395	0.2057
RDIotp	0.0283	0.0712	0.3969	0.6940	-0.1166	0.1731
RDIimp	0.0380	0.0914	0.4161	0.6800	-0.1478	0.2239
ICTusg	0.1364	0.0994	1.3719	0.1794	-0.0659	0.3386

Source: calculated and compiled by the authors.

The results from Table 2 mean that the cumulative impact of the studied quality factors from the standpoint of knowledge management by 75.71% explains the change in Goal 8 Score in the top 40 leading countries of the world with the most developed industry 4.0 in 2023.This is evidenced by the obtained value of the multiple R (0.7571). The coefficient of determination (R^2) has also assumed a rather large value (0.5733), which indicates a close relationship of the studied variables.

The significance is F=4.6*10-5, hence the results of the regression analysis in Table 2 correspond to the highest significance level of 0.01. The observed F=7.3882. Since the observed F has exceeded the critical F (7.3882>3.4059), the Fischer's F-test has been passed. At 39 degrees of freedom, the Student's t-test has been passed only for three factor variables: 1) for KnCap (observed t=3.4816) at a significance level of 0.01, where critacal t=2.7080; 2) for ICTusg (observed t=1.3719) at a significance level of 0.2, where critacal t=1.3036.

Table 3. Regression analysis of Goal 9 Score dependence on the potential quality factors from the perspective of knowledge management

Regression statistics	
Multiple R	0.8714
R-Square	0.7594
Adjusted R-Square	0.7157
Standard Error	6.4564
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Signifi-cance F*
Regression	6	4342.0540	723.6757	17.3607	$6*10^{-9}$
Residual	33	1375.5918	41.6846		
Total	39	5717.6458			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	3.6287	11.7388	0.3091	0.7592	-20.2540	27.5113
AIsk	-0.2579	2.6076	-0.0989	0.9218	-5.5630	5.0473
KnCap	0.6428	0.1904	3.3756	0.0019	0.2554	1.0303
HEotp	-0.0483	0.1765	-0.2739	0.7859	-0.4075	0.3108
RDIotp	0.3969	0.1149	3.4561	0.0015	0.1633	0.6306
RDIimp	0.2118	0.1474	1.4367	0.1602	-0.0881	0.5116
ICTusg	0.1598	0.1604	0.9965	0.3263	-0.1665	0.4861

Source: calculated and compiled by the authors.

The results from Table 3 mean that the cumulative impact of the studied quality factors from the standpoint of knowledge management by 87.14% explains the change in Goal 9 Score in the top 40 leading countries of the world with the most developed industry 4.0 in 2023.This is evidenced by the obtained value of the multiple R (0.8714). The coefficient of determination (R^2) has also taken a rather large value (0.7594), which indicates a close relationship of the studied variables.

The significance is F=6*10-9, hence the results of the regression analysis in Table 3 correspond to the highest significance level of 0.01. The observed F=17.3607. Since the observed F has exceeded the critical F (17.3607>3.4059), the Fischer's F-test has been passed. At 39 degrees of freedom, the Student's t-test has been passed only for three factor variables: 1) for KnCap (observed t=3.3756) at a significance level of 0.01, where critical t=2.7080; 2) for RDIotp (observed t=3.4561) at a significance level of 0.01, where critical t=2.7080; 3) for RDIimp (observed t=1.4367) at a significance level of 0.2, where critical t=1.3036.

The conducted tests have confirmed the validity and reliability of the results of the regression analysis, which makes it possible to compile an econometric model mathematically describing the impact of the studied quality factors from the standpoint of knowledge management on the target results of quality assurance in industry 4.0:

$$\begin{cases} Q_1=18.1110-1.1698*AIsk+0.2605*KnCap+0.0967*HEotp+0.2094*RDIotp+0.1513*RDIimp+0.1057*ICTusg, \\ Q_2=39.8200-2.3304*AIsk+0.4110*KnCap-0.0169*HEotp+0.0283*RDIotp+0.0380*RDIimp+0.1364*ICTusg, \\ Q_3=3.6287-0.2579*AIsk+0.6428*KnCap-0.0483*HEotp+0.3969*RDIotp+0.2118*RDIimp+0.1598*ICTusg. \end{cases} \quad (2)$$

Model (2) means that economic competitiveness increases by 0.2605 points, Goal 8 Score – by 0.4110 points, Goal 9 Score – by 0.6428 points with an increase in knowledge capital by 1 point. Economic competitiveness increases by 0.2094 points, Goal 8 Score – by 0.0283 points, Goal 9 Score – by 0.3969 points with the growth of research, development and innovation outputs by 1 point.

Economic competitiveness rises by 0.1513 points, Goal 8 Score – by 0.0380 points, Goal 9 Score – by 0.2118 points with an increase in research, development and innovation impact by 1 point. Economic competitiveness grows by 0.1057 points, Goal 8 Score – by 0.1364 points, Goal 9 Score – by 0.1598 points with an increase in information and communications technology usage by 1 point.

At the same time, AI skills penetration does not have a positive impact on either sustainability or competitiveness as aspects of the product quality of industry 4.0. The impact of higher education outputs on Goal 8 Score and Goal 9 Score is negative, therefore, this factor does not provide an increase in the sustainability of products in industry 4.0 and has a contradictory effect on quality.

Thus, the regression coefficients (b_2, b_4, b_5, b_6) for the factor variables KnCap, RDIotp, RDIimp and ICTusg have assumed non-negative and larger values than the regression coefficients ($b_1$andb_3) for the factor variables AIsk and HEotp, most of which have taken negative values. This proves hypothesis (H) and confirms that the key factors of sustainability (SDG8 and SDG9 implementation) and competitiveness are knowledge capital, research, development and innovation outputs and impact, as well as information and communications technology usage.

4.2. The new approach to knowledge management in the product quality assurance system of industry 4.0

To solve the second task, which is to determine the prospects for improving knowledge management in the product quality assurance system of industry 4.0, a new approach to this management has been developed. The authors' approach is presented graphically in Figure 1; it reveals the authors' vision of the place of knowledge management in the product quality assurance system of industry 4.0 from the standpoint of sustainability and competitiveness.

As shown in Figure 1, the new approach to knowledge management in the product quality assurance system of industry 4.0 assumes the central place of knowledge management in the product quality assurance system of industry 4.0.In the new approach, basic knowledge capital is attracted from the labor market, the potential of which is built up and implemented using a mechanism of knowledge management. This mechanism is activated through: 1) disclosure of the talents of employees; 2) generation of unique knowledge and their diffusion in the organization; 3) stimulation of innovative activity of employees.

As a result of the implementation of the mechanism of knowledge management, the increased knowledge capital, research, development and innovation outputs, research, development and innovation impact, information and communications technology usage contribute to sustainability and competitiveness, which together ensures the product quality of the enterprise of industry 4.0.

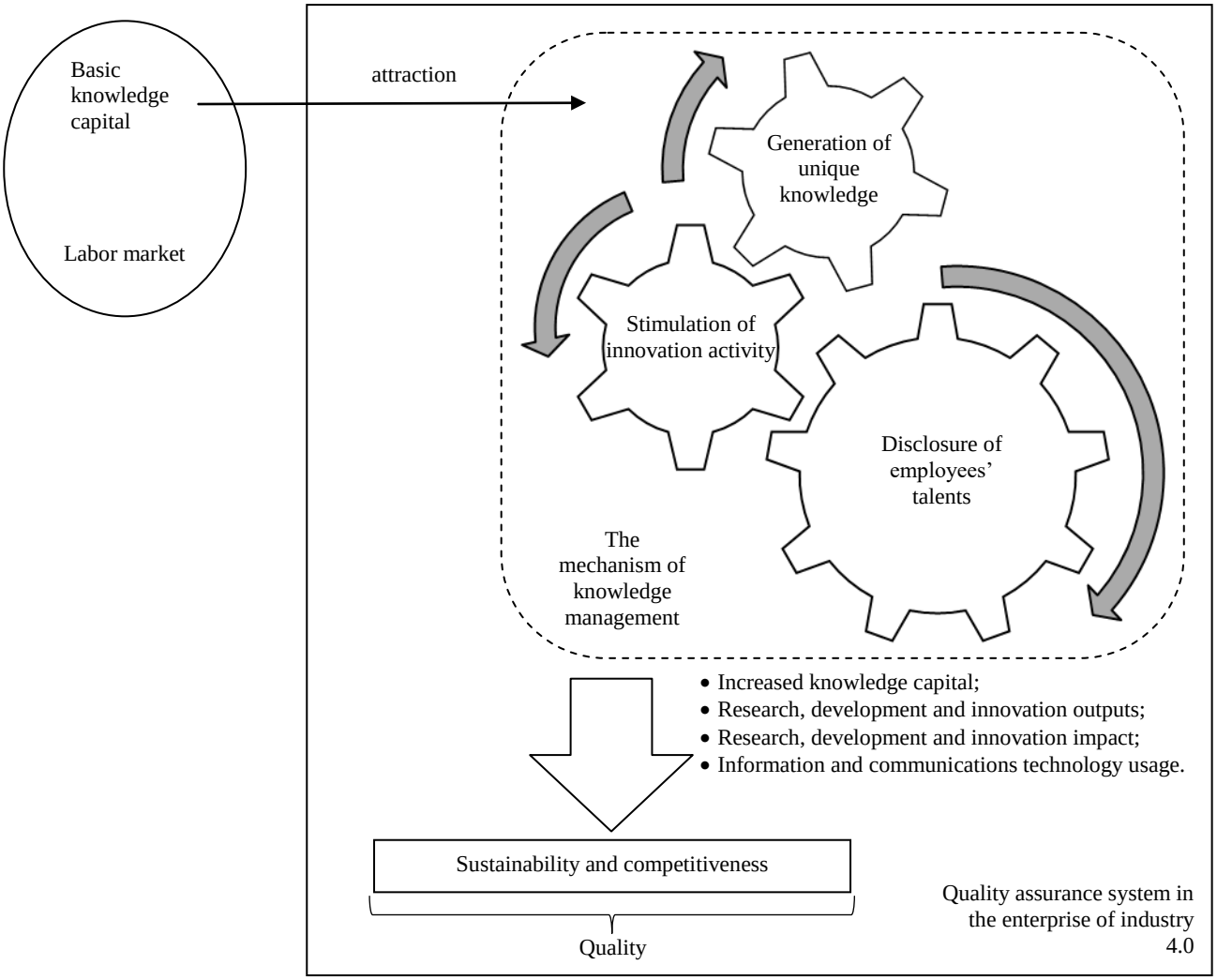


Figure 1. The new approach to knowledge management in the product quality assurance system of industry 4.0
Source: developed and compiled by the authors.

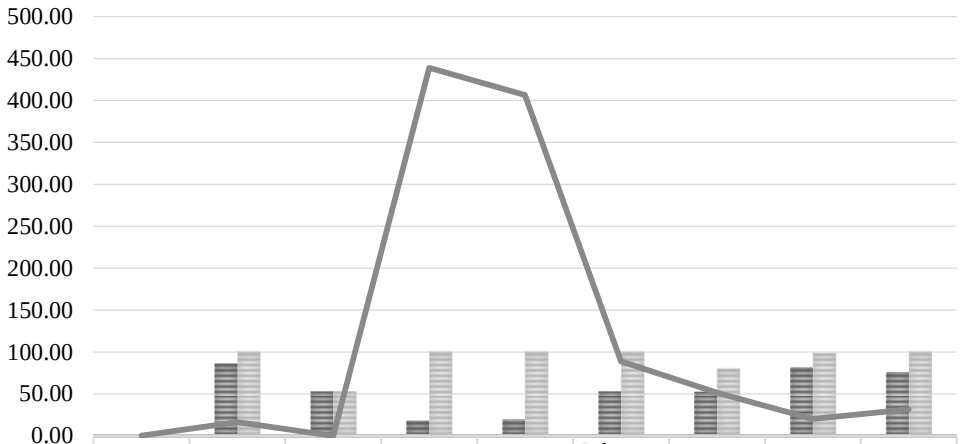
4.3. Recommendations for improving knowledge management to increase the product quality of industry 4.0 in Russia

To solve the third task, which consists in unlocking the potential for increasing the product quality of industry 4.0 in Russia through improving knowledge management, the maximum possible values of statistically significant factor variables selected by the authors are substituted into model (2) and the expected values of the dependent variables are determined. Based on this, the authors' recommendations for improving knowledge management to increase the product quality of industry 4.0 in Russia are compiled. The authors have applied the method of trend analysis in order to determine changes in all variables (trend) compared to their baselines in 2023 (fig. 2).

As shown in Figure 2, the growth of the product quality of industry 4.0 in Russia through the improvement of knowledge management potentially allows to increase, firstly, economic competitiveness by 51.61% to 79.89 points compared to 52.69 points in 2023.Secondly, Goal 8 Score increases by 20.30% to 98.18 points compared to 81.61 points in 2023. Third, Goal 9 Score rises by 31.67% to 100 points compared to 75.95 points in 2023.To unlock this potential, a set of authors' recommendations for improving knowledge management to increase the product quality of industry 4.0 in Russia is proposed, including:

- Increase of knowledge capital by 16,14%;
- Increase of research, development and innovation outputs by 438,79%;
- Growth of research, development and innovation impact by 406,33%;
- Growth of information and communications technology usage by 88,89%.

At the same time, AI skills penetration and higher education outputs remain unchanged at the level of 2023 and amount to 0.84 and 52.81 points, respectively.



	Cross-Country AI Skills Penetration	Knowledge capital	Higher education outputs	Research, Development and Innovation outputs	Research, Development and Innovation impact	Information and Communications Technology Usage	Economic competitiveness	Goal 8 Score	Goal 9 Score
Baseline values in 2023, points	0.84	86.10	52.81	18.56	19.75	52.94	52.69	81.61	75.95
Recommended values, points	0.84	100.00	52.81	100.00	100.00	100.00	79.89	98.18	100.00
Recommended increase in values compared to 2023, %	0.45	16.14	0.00	438.79	406.33	88.89	51.61	20.30	31.67

Figure 2. The potential for increasing the product quality of industry 4.0 in Russia through the improvement of knowledge management

Source: calculated and constructed by the authors.

5. DISCUSSION

The article contributes to the literature by developing the concept of knowledge management within the framework of the theory of management information systems (Memon et al., 2022; Mohamad et al., 2022; Nguyen et al., 2023; Shresthaand Saratchandra, 2023) through rethinking the place of knowledge management in the quality assurance system of industry 4.0 from the standpoint of sustainability and competitiveness. The main scientific result of this article has been the development of a new approach to knowledge management in the quality assurance system of industry 4.0, a comparative analysis of which with the existing approach based on the available literature has been made in Table 4.

As shown in Table 4, the fundamental differences between the new approach to knowledge management in the product quality assurance system of industry 4.0 and the existing approach are the following. Firstly, it is a refined interpretation of the relationship of quality with sustainability and competitiveness. Unlike Dyakov et al. (2022), Handayani et al. (2022), it has been proven that quality is not a factor, but the result of the sustainability and competitiveness of the products of enterprises in industry 4.0

Secondly, it is a rethought place of knowledge management in the quality assurance system of Industry 4.0.Unlike Campos and Silva (2022), Dovleac et al. (2021), it has been proven that knowledge management is not a source, but the embodiment of the product quality of industry 4.0. That is, knowledge management is not outside the quality assurance system of industry 4.0, but inside it.

Third, it is the new role of higher education for knowledge management. Alves and de Carvalho(2023), Sabherwal et al. (2023) have proven that it is not important whether employees have higher education, but the very sufficiency of intellectual resources – their knowledge capital.

Fourth, it is a revised value of AI competencies for knowledge management. Unlike Khakimova and Kayumova(2022), Ma et al. (2022),it has been proven that basic knowledge is significant, and AI competencies as extra-knowledge are not significant.

Fifthly, these are the revised most valuable properties of intellectual resources. Unlike Bogoviz (2020) Capasso and Umbrello (2022), it has been proven that knowledge is valuable not in itself, but as a source of innovation.

Sixthly, it is the renewed essence of the approach to knowledge management. In contrast to Binsaeed et al. (2023), Gagliardi et al. (2023),it has been proven that it is necessary not to recruit and retain leading digital personnel, but to reveal talents and increase the knowledge of employees. That is, it is preferable not to acquire ready, standaed knowledge, but to generate unique knowledge in the practice of enterprises in industry 4.0.

Table 4. Comparative analysis of the existing and new approach to knowledge management in the product quality assurance system of industry 4.0 proposed in this article

Criteria for comparing approaches	Approach to knowledge management in the product quality assurance system of industry 4.0	
	The existing approach presented in the literature	The new approach proposed in this article
Interpretation of the relationship of quality with sustainability and competitiveness	Quality as a factor of sustainability and competitiveness Dyakov et al. (2022), Handayani et al. (2022)	Quality as a result of sustainability and competitiveness
The place of knowledge management in the product quality assurance system of industry 4.0	Knowledge management as a source of product quality in industry 4.0, occupying a place outside the systemCampos and Silva (2022), Dovleac et al. (2021)	Knowledge management as the embodiment of the product quality of industry 4.0, located inside the system
The role of higher education for knowledge management	It is important for employees to have a higher education (Alves and de Carvalho, 2023; Sabherwal et al., 2023)	It is important for employees to have sufficient intellectual resources – their knowledge capital
The significance of AI competencies for knowledge management	AI competencies are the most significant ones (Khakimovaand Kayumova, 2022; Ma et al., 2022)	Basic knowledge is significant, and AI competencies as extra knowledge are not significant
The most valuable properties of intellectual resources	Knowledge is of value in itself (Bogoviz, 2020; Capassoand Umbrello, 2022)	Knowledge is of value as a source of innovation
The essence of the approach to knowledge management	Recruitment and retention of leading digital personnel: acquisition of ready, standard knowledgeBinsaeed et al. (2023), Gagliardi et al. (2023)	Disclosure of talents and increment of knowledge of employees: generation of unique knowledge in practice
Implications of knowledge management in the quality assurance system for sustainability and competitiveness	As a result of knowledge management, quality increases, but the implications for sustainability and competitiveness can be both positive and negative (Mamyralieva et al., 2022; TurginbayevaandAbildaev, 2013)	Knowledge management, aimed at increasing sustainability and competitiveness, ensures quality improvement

Source: developed by the authors.

Seventhly, these are other implications of knowledge management in the quality assurance system for sustainability and competitiveness. Unlike Mamyralieva et al. (2022), Turginbayeva and Abildaev (2013),it has been proven that quality increases not as a result of knowledge management, but knowledge management aimed at increasing sustainability and competitiveness, which, in turn, ensures quality improvement

Thus, the article continues the scientific discussion (Jatiningsih et al., 2023; Vătămănescu et al., 2023) on knowledge management in the product quality assurance system of industry 4.0 in the interests of sustainability and competitiveness. The new scientific results obtained in the article have revealed four key factors (in which the arithmetic mean of regression coefficients with all dependent variables has taken positive values) of knowledge management in the product quality assurance system of industry 4.0 in the interests of sustainability and competitiveness:

- knowledge capital (the arithmetic mean of the regression coefficients has been 0.44in confirmation of the position of AlQershi et al., 2023);
- research, development and innovation outputs (the arithmetic mean of the regression coefficients has been 0.21 in support of the position of Ilina et al., 2019);
- research, development and innovation impact (the arithmetic mean of the regression coefficients has been 0.13 in confirmation of the position ofAl-Sous et al., 2023);
- information and communications technology usage (the arithmetic mean of the regression coefficients has been 0.13 in support of the position of Karrieva, 2019).

It has also been found that the knowledge management factors used in the existing approach in the product quality assurance system of industry 4.0 are in fact insignificant for sustainability and competitiveness. Thus, the arithmetic mean of regression coefficients with AI skills penetration has been -1.25 (in contrast to Pokharel, 2023), and the arithmetic mean of regression coefficients with higher education outputs has been near zero and equal to 0.01 (in contrast to Nguyen et al., 2023).

6. CONCLUSION

The main conclusions based on the results of the study are as follows. The current place of knowledge management outside the quality assurance system of industry 4.0 hinders the achievement of sustainability and competitiveness. The econometric model, compiled based on the international experience of the top 40 leading countries of the world with the most developed

industry 4.0 for 2023, has mathematically described and justified the significant contribution of knowledge management to the product quality of industry 4.0 from the standpoint of sustainability and competitiveness.

The model has identified key factors of sustainability (the implementation of SDGs 8 and SDGs 9) and competitiveness, namely knowledge capital, research, development and innovation outputs and impact, as well as information and communications technology usage. In order to simultaneously achieve both sustainability and competitiveness embodying quality, it is recommended to manage knowledge in industry 4.0 through the disclosure of talents (hypothesis H has been proven).To solve this problem, an alternative, new approach to knowledge management in the product quality assurance system of industry 4.0 has been developed, which allows to fully achieve sustainability and competitiveness simultaneously.

The features of the new approach are the following: quality is considered in it as a result of sustainability and competitiveness; knowledge management is interpreted as the embodiment of the product quality of industry 4.0 located inside the system; the very sufficiency of intellectual resources is important – employees' knowledge capital; basic knowledge is significant, and AI-competencies as extra-knowledge are not significant; knowledge is valuable as a source of innovation; the disclosure of talents and the increment of knowledge of employees is carried out, that is, the generation of unique knowledge; knowledge management, aimed at increasing sustainability and competitiveness, ensures quality improvement.

The theoretical significance of the authors' conclusions is that they rethought the place of knowledge management in the quality assurance system of industry 4.0, which should be inside this system in the interests of sustainability and competitiveness. The practical significance of the developed approach is due to the fact that it will improve the practice of ensuring the product quality of industry 4.0 through the comprehensive achievement of sustainability and competitiveness through the optimization of knowledge management. The authors' recommendations on improvement of knowledge management will reveal the potential for increasing the product quality of industry 4.0 in Russia. The social significance of the article is related to the fact that the authors' developments support the joint and accelerated practical implementation of SDG8 and SDG9.

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Appendix

Country	Cross-Country AI Skills Penetration	Knowledge capital	Higher education outputs	Research, Development and Innovation outputs	Research, Development and Innovation impact	Information and Communications Technology Usage	Economic competitiveness	Goal 8 Score	Goal 9 Score
United States	2.22	86.83	74.94	46.3	52.79	86.96	74.12	81.9	97.8
Canada	1.55	89.21	54.35	24.58	28.62	64.63	70.05	84.6	87.3
United Kingdom	1.53	87.68	62.40	49.94	55.66	79.33	64.16	84.0	91.8
Germany	1.72	87.41	59.83	51.48	31.43	61.13	65.05	87.0	95.8
France	1.13	85.97	50.71	45.17	35.37	66.47	70.02	85.3	92.8
Italy	0.93	82.40	52.03	38.12	42.35	56.31	63.62	79.9	87.5
Spain	0.98	81.56	51.34	28.96	34.73	61.20	61.88	79.4	90.2
Netherlands	0.95	88.66	63.12	47.5	33.89	73.13	65.28	86.3	93.4
China	0.84	86.87	63.09	36.55	45.59	59.10	70.90	78.9	80.3
India	0.84	59.23	37.02	25.39	26.73	48.09	61.59	73.7	51.0
Australia	0.87	85.58	58.50	27.46	43.19	67.54	73.27	86.7	92.2
Korea, Rep.	1.43	86.34	53.16	52.36	24.40	77.36	69.03	85.5	99.1
Israel	1.67	85.49	66.16	33.58	48.60	81.34	65.19	84.3	94.7
Türkiye	1.22	77.37	36.69	34.06	22.44	54.83	54.30	70.0	71.9
Switzerland	0.91	83.20	76.33	65.16	32.53	69.31	63.97	81.6	97.2
Greece	0.91	79.84	42.53	19.49	36.33	45.99	52.20	73.8	81.6
Poland	0.81	87.44	56.43	23.23	23.34	57.42	53.79	86.9	80.3
Ireland	0.69	87.84	59.05	31.8	34.42	62.98	75.47	87.0	86.5
Sweden	0.67	87.78	62.56	49.98	41.77	79.00	66.74	85.0	97.6
Norway	0.65	86.55	61.16	25.13	33.85	68.53	66.52	85.9	92.4
Finland	0.64	87.23	58.23	51.25	37.86	82.67	69.45	86.8	96.0
Belgium	0.60	86.95	60.58	33.4	31.40	56.44	71.66	84.3	97.1
Hungary	0.58	78.83	53.88	17.9	37.69	55.01	59.57	84.6	80.3
Lithuania	0.56	85.02	58.35	19.62	28.35	66.52	60.93	81.1	75.5
Austria	0.55	85.16	58.50	39.91	43.19	77.68	70.51	83.3	97.0
Denmark	0.53	84.75	60.49	49.81	40.27	69.39	75.88	87.6	97.0
Estonia	0.51	87.10	59.24	32.35	48.33	76.88	63.37	82.2	83.3
Mexico	0.49	69.21	42.52	15.17	14.70	48.08	47.31	68.4	57.9
Slovenia	0.43	86.11	69.02	30.74	29.38	66.18	67.42	84.9	80.8
Czechia	0.42	84.02	57.74	22.85	39.58	52.11	60.94	88.0	83.8
Portugal	0.42	86.56	55.19	26.14	27.23	56.00	59.81	81.2	82.2
Luxembourg	0.40	80.68	68.38	42.14	35.06	72.28	65.33	85.7	88.6
Chile	0.39	79.63	45.83	28.84	30.62	58.50	53.38	84.1	75.3
Slovak Republic	0.35	77.62	54.79	16.5	34.28	52.40	45.51	81.5	73.6
Iceland	0.10	80.30	65.67	39.98	32.20	67.65	73.31	77.7	87.4
Latvia	0.90	82.39	55.86	25.24	33.71	71.06	58.89	84.5	77.0
Russian Federation	0.84	86.10	52.81	18.56	19.75	52.94	52.69	81.6	75.9
South Africa	0.84	54.06	38.88	20.48	30.97	48.68	48.23	69.8	70.8
Belarus	0.84	80.1	56.39	13.19	25.76	45.26	53.26	66.6	55.5
Brazil	0.84	70.17	38.71	15.73	19.28	53.46	48.88	76.0	69.0