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Conceptual model for measuring the scientific knowledge diffusion in the context of digitalization

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Abstract. The main idea of digitalization is the transition to a new technological order and, as a result, gaining competitive advantages, therefore, measuring the diffusion of scientific knowledge in the digital economy is especially relevant. The existing articles do not offer general models for the transfer of knowledge, regardless of the digitalization industry. The authors of the article have developed a conceptual model for measuring the diffusion of scientific knowledge, which allows, according to the characteristics of knowledge carriers, to assess the proximity of their paradigms, as well as the likelihood of delays in the transfer of knowledge due to the need to relay knowledge, depending on the paradigms they use. Criteria to assess the reliability of the scientific knowledge transfer in the context of digitalization are proposed.

1. Introduction

Due to the rapid "digitalization" of the economy, the problem of the knowledge transfer speed between industries has sharply exacerbated. This problem is caused by the fact that the paradigms comprising the subject area description languages in which the different fields of scientific knowledge exist are developing independently, becoming increasingly complex and distant from each other. This raises the problem of a cultural barrier between carriers of different paradigms. This problem is traditionally solved either by translation from one language into another, or by educating people who can alternately use different languages, for example, for communication between representatives of science and business. However, interpreter training, like different paradigms mastering, is a time-consuming process that inevitably leads to a lag in life due to the dynamism of both science and economics. The criticality of this gap is increasing with the widespread adoption of digital technology, as the growth of computing power and the development of communication tools in scientific social networks provide new opportunities for the transfer of knowledge between carriers of various paradigms. However, there is so much knowledge and information that it is obviously impossible to do without the automation of the knowledge transfer process. At the same time, the development of



knowledge transfer automation tools is performed by people who can introduce errors into the transfer process, which, in turn, will affect the quality of knowledge transfer.

2. Overview of knowledge diffusion models

The main idea of digitalization is the transition to a new technological paradigm and, as a consequence, obtaining a competitive advantage, the idea of knowledge diffusion in the digital economy is paid increased attention in the world's leading economies

This can be easily observed by examining recent publication activity. A large number of models and high publication activity indicate that the research carried out in this area is extremely relevant and in demand [1-7]. These articles describe various models used in particular fields of knowledge. Different variants of knowledge transfer models are described, as well as the experience of their application in different areas of the economy. It is also characteristic that many models use the approaches and methods of artificial intelligence. This is especially important because it emphasizes the complexity of the task of knowledge transfer, its focus on expert systems and knowledge models adopted in artificial intelligence.

The authors of existing articles are developing various models of knowledge transfer within the framework of one enterprise [8], within the framework of the economic sector [9] and between the sectors of the economy [10]. Conceptual models for the economy in its individual aspects are also considered [11-13]. However, the articles do not present general models of knowledge transfer regardless of the digitalization industry. And this is important, because the majority of modern research is clearly interdisciplinary in nature.

The knowledge diffusion models presented in this review are also not analyzed for the possible influence of various factors on the transmission quality. Apparently fully trusting algorithms and tools, including artificial intelligence, the authors do not dwell on the quality control of knowledge transfer, as well as on the impact on the transfer of the human factor, which may consist in an incorrect description of paradigms or interpretation. This lack of "feedback" leads to the risk of knowledge devaluation and, as a consequence, high financial costs and competitiveness loss of the economy as a whole. Consideration of these issues makes the research carried out within the framework of this article relevant.

3. Diffusion model of scientific knowledge in the context of digitalization

Traditionally, in the publications [14-16], an assessment of the information transmission quality is considered, which can be reduced either to an assessment of the signal-to-noise ratio, or to the reliability of signal conversion during transmission.

However, when it comes to the knowledge transfer between carriers of different paradigms, it is necessary to take into account that the following factors will influence the knowledge transfer quality: the accuracy of the subject areas description; the accuracy of the knowledge transfer model description; the reliability of the knowledge transfer from one paradigm to another one.

The quality assessment here can be carried out only after the fact of the transfer, and its purpose will be to improve its model. Thus, the knowledge transfer quality can be defined as the adequacy of the scientific knowledge mapping presented in the original scientific worldview into scientific knowledge for the target paradigm. And the process of diffusion of scientific knowledge Sk_1 itself, as a reflection of a certain set of knowledge that exists in terms of the original scientific worldview Sv_1 into a set of scientific knowledge Sk_2 , reformulated in terms of the paradigm Sv_2 : $X(Sk_1, Sv_1) \rightarrow Y(Sk_2, Sv_2)$.

In order to quantify the quality of such a display, it is necessary to introduce evaluation criteria. These criteria should assess the extent to which knowledge is transmitted fully, in a timely manner and without distortions (including semantic ones) in the context of digitalization. Then the following can be selected as the evaluation criteria:

- completeness of a set of knowledge transfer Sk_1 that exists in terms Sv_1 of a set of knowledge Sk_2 reformulated in terms Sv_2 , i.e. how complete the transferred knowledge Sk_2 is for solving problems within the paradigm Sv_2 ;
- timeliness of knowledge transfer, i.e. to what extent knowledge Sk_1 is timely transformed and transferred to solve problems within the framework of the paradigm Sv_2 ;
- reliability of knowledge transfer, Sv_2 -, i.e. the extent to which the transferred knowledge Sk_2 is correctly transformed (error-free) to solve problems within the paradigm Sv_2 ;

In addition, a sufficiently universal, paradigm-independent knowledge diffusion model must be introduced as part of this problem solution to formalize the transfer process as much as possible in the digitalization context.

Then the task of the transfer quality assessing or knowledge transformation between carriers of different paradigms is reduced to the task of assessing **against** the three criteria **above**. Such an assessment is relatively easy to obtain, it is quite universal. It can also be argued that a more detailed quality assessment can be carried out after the assessment according to the above criteria has yielded a positive result. For this purpose, particular criteria describing specific areas of knowledge should be developed.

In order to solve the problem of the knowledge transfer quality assessing, it is necessary to introduce a diffusion model. Neural network models, semantic network models, multi-agent models (in particular ant colony models, artificial swarm models), and graph models have been studied for model compilation. As the result of the analysis, a choice was made in favor of probabilistic graph models, as the most flexible and suitable for describing the diffusion of scientific knowledge. By probability, in this case, we mean the frequency of interaction between subjects over a certain period of time. This is due to the fact that the semantic network models allow describing the structure well, but it is very difficult to describe the transfer of information. Neural network models are good at describing data transmission, but describing structure with them is extremely difficult. Ant colony models can in principle be applied, but the modeling performed shows their discrepancy with experimental data.

Let's describe the proposed model for the diffusion of scientific knowledge. The vertices of a directed graph are carriers of knowledge that exist within a certain paradigm, arcs are the directions of knowledge transfer. Thus, the model is a network that allows you to describe the interaction between members of scientific and technical communities who are carriers of different paradigms. The model estimates the proximity of the knowledge carriers' paradigms and the probability of delays in knowledge transfer due to the need to retransmit knowledge, depending on the paradigms they use. In this case, paradigms can be divided into: phenomenological, socio-psychological, sociocultural, rhetorical, cybernetic, semiotic and critical. For each type of paradigm, the following groups of characteristics can be distinguished: social aspects, characteristics associated with areas of education, characteristics and traditions (for example, regional), age factors (in particular, complicating the transfer of knowledge between representatives of different generations), social functions of carriers of paradigms and etc. Then the analysis of similarities and contradictions for each of the paradigms should be carried out based on the proximity function (distances) of the characteristic values. It is necessary to define a strategy for analyzing specific interactions between different carriers of paradigms.

The result of the analysis should be an oriented, connected graph that reflects the knowledge existing among carriers of different paradigms (graph vertices) and the direction of knowledge transfer (graph arcs) between carriers. In fact, such a model represents both interactions between members of the scientific and technical communities, and during refinement between any subjects of the digital economy. Refinement in this case implies the introduction of characteristics of economic entities of the digital economy into the model.

For each of the arcs, a transmission quality assessment should be made. The modern classification of methods of transferring scientific knowledge [12-14] suggests that they can be transferred in four ways: from implicit to explicit (for example, based on observations and copying actions), from

explicit to explicit (formalization of scientific knowledge is implied before transfer) and from implicit to explicit and from explicit to implicit. This requires a formalization of the scientific knowledge diffusion quality measurement.

4. Formalization of the scientific knowledge diffusion quality measurement

It is proposed to assess the scientific knowledge diffusion quality according to such criteria as completeness, timeliness and reliability.

Completeness refers to the success rate of knowledge transfer, i.e. the extent to which the knowledge Sk_1 (paradigm Sv_1) reformulated and transferred into knowledge Sk_2 , is complete for problem solving within the paradigm Sv_2 .

Formally, the problem of completeness estimation can be formulated as follows.

As initial data there is:

- C_1 - the number of facts of critical knowledge transfer from the multitude Sk_1 to knowledge Sk_2 for solving critical problems Sv_2 . Critical tasks are understood as many tasks, without which the normal functioning of the digital economy within the paradigm Sv_2 is impossible;
- C_2 - the number of successfully solved critical problems within the paradigm Sv_2 ;
- C_3 - the number of the knowledge transfer facts Sk_1 into knowledge Sk_2 for solving problems Sv_2 ;
- C_4 - the number of successfully solved problems within the paradigm Sv_2 .

It is necessary to find completeness, i.e. the degree of success in the knowledge transfer for solving specific problems of digitalization.

The mathematical model of completeness is the ratio C_4 of the number of successfully solved problems within the paradigm Sv_2 to C_3 the total number of knowledge transfer facts Sk_1 into knowledge Sk_2 . At the same time, you need to consider critical tasks. Thus, we obtain the following relations:

$$Cm = \sigma \frac{C_4}{C_3}, \quad (1)$$

where $\sigma = 1$, if $C_1 = C_2$, $\sigma = 0$, if $C_1 > C_2$.

Timeliness is understood as the degree of fulfillment of time constraints at which the solution of tasks is not devalued, i.e. to what extent knowledge Sk_1 is timely transformed and transferred to solve problems within the paradigm Sv_2 .

Since different knowledge can be transformed and transmitted at different rates, the time constraints characterize the average expected time for the transformation and knowledge transfer. Then it is advisable to talk about assessing the probability of exceeding a certain threshold time of knowledge transformation and transfer, for which the results will not devalue the solution of problems within the framework of another paradigm.

Formally, the task of assessing timeliness can be formulated as follows.

As initial data there is:

- criteria C_1 , C_2 , C_3 и C_4 ;
- $R = \{r_i\}$ is a set of constraints;
- $T = \{t_i\}$ is a set of specific scientific knowledge transfer periods.

It is necessary to find the probability of the knowledge transformation and transfer in a time not exceeding R .

The mathematical model of timeliness is defined as the probability $P_1(t \leq r)$ of transferring knowledge when performing critical tasks in a time t not more than a given (acceptable) r . And as the probability of performing knowledge transfer for the total number of tasks completed $P_2(t \leq r)$.

An estimate of the transferring knowledge probability for critical tasks in a time not exceeding the allowable time is calculated using the formula.

$$P_1(t \leq r) = \begin{cases} 1, & \text{if } n = C_2 \\ 0, & \text{if } n < C_2 \end{cases}, \quad (2)$$

where n is the number of completed transfers of critical knowledge from the total number C_1 that satisfy the inequality $t \leq r$.

$$P_2(t \leq r) = \frac{nd}{C_4}, \quad (3)$$

where nd is the number of completed transfers of knowledge from the total number C_3 that satisfy the inequality $t \leq r$.

Then, taking into account (2) and (3), the overall assessment of the timeliness of knowledge transfer can be presented as follows:

$$P_3(t \leq r) = P_1(t \leq r)P_2(t \leq r), \quad (4)$$

For an accurate calculation, it is necessary to obtain statistical data and define a set of constraints R , which allows obtaining an estimate of the likelihood of knowledge timely transfer.

The reliability of knowledge transfer can be defined as a property that determines the infallibility of the knowledge transformations from one paradigm to another when transferring knowledge between carriers of different paradigms. In this sense, reliability makes it possible to assess how the transmitted knowledge Sk_2 is correctly transformed (does not contain errors) for solving problems within the framework of the paradigm Sv_2 .

However, the assessment of the knowledge transfer reliability is very difficult, because the quality of the conversion must be taken into account, and this cannot be done without a clear description of what is considered a transmission error. Errors can be introduced both at the level of transfer from one paradigm to another, and at the level of an erroneous description of the transfer in the model. It is also very difficult to assess which task outcome in a different paradigm clearly indicates the presence of errors. A whole system of indicators needs to be introduced to assess the validity of knowledge transfer:

- the number of errors in the transmitted knowledge Sk_1 ;
- the number of errors in translating a set of knowledge Sk_1 from paradigm terms Sv_1 into a set of knowledge Sk_2 reformulated into paradigm terms Sv_2 ;
- probability of error correction in transmitted knowledge Sk_1 at a given time, i.e. the likelihood that the time spent on identifying and correcting an error in the data does not lead to a violation of the task within the paradigm Sv_2 ;
- confidence probability of the required accuracy of translation of the knowledge set Sk_1 from the paradigm terms Sv_1 into the knowledge set Sk_2 reformulated into paradigm terms Sv_2 , i.e. the probability that within a given body of knowledge Sk_2 there are no gross errors leading to a violation of the required accuracy of the task within the paradigm Sv_2 ;
- the average error rate is the ratio of the knowledge amount transferred to the mathematical expectation of the errors number in the transferred knowledge;
- the average information correction time is the mathematical expectation of the time taken to identify and correct the knowledge transfer error.

However, building mathematical models and collecting statistical data to calculate these indicators becomes very difficult and time consuming. It is proposed for the initial assessment to be limited to a

single indicator of reliability: an estimate of the probability that within a given body of knowledge there are no gross errors leading to a violation of the task within the framework of the paradigm Sv_2 .

The problem of assessing the reliability can be formulated as follows. As initial data there is:

- criterion C_3 ;
- the amount of knowledge transferred $V = \{v_i\}$, where v_i is the amount of knowledge gained Sk_2 , $i = [1, C_3]$;
- set of errors $E = \{e_i\}$, where e_i is the amount of erroneous knowledge in the set Sk_2 , $i = [1, C_3]$. In this case, an error means knowledge that does not agree with the terms of the paradigm Sv_2 or other knowledge of this paradigm that is considered reliable;
- set of restrictions $D = \{d_i\}$, where d_i is the maximum permissible share of errors per the amount of knowledge v_i that does not lead to a violation of the task within the framework of the paradigm Sv_2 .

It is necessary to find the probability of the absence of a critical number of gross errors within a given array of transferred knowledge, leading to a violation of the required accuracy of information processing in a digital environment.

The mathematical model of reliability is the probability of finding errors:

$$P_4(E \leq D) = \frac{\sum_{i=1}^{C_3} (v_i - e_i)}{C_3^2}. \quad (5)$$

The overall assessment of the quality of knowledge transfer, given, can be represented by a multiplicative convolution of the criteria (1), (4) and (5) introduced above:

$$Q = Cm^{\alpha_1} P_3(t \leq r)^{\alpha_2} P_4(E \leq D)^{\alpha_3}. \quad (6)$$

where α_i is a weighting factor that determines the importance of indicators, such that $\sum_{i=1}^3 \alpha_i = 1$, $\alpha_i > 0$.

For quality assessment, a threshold value can be specified, below which the transmission quality should be considered unsatisfactory. As a criterion (6), you can also use other principles of optimality or a combination of them.

5. Conclusion

This article presents a conceptual approach to solving the problem of assessing the quality of knowledge diffusion during network interaction between members of scientific and technical communities who are carriers of different paradigms in the context of digitalization. The proposed approach allows for quick assessments of the quality of knowledge transfer using the minimum amount of required data. The calculations based on the developed mathematical models are not highly accurate, but they allow saving time on assessing the quality of transmission of large scientific data in the context of digitalization.

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