SURVIVAL OF ENGINEERS` KNOWLEDGE WITHIN PRODUCTION PROCESSES DIGITALIZATION

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Abstract: The relevance of the study is justified by referring the problem of engineers' knowledge survival within the digital transformations of leading industries at the stage of the world community transition to the knowledge economy. The paper reveals the multidimensional essence of the category "knowledge" within the digitalization; the relationship between the life cycle of knowledge and the life cycle of professional competency of an engineer is shown; the results of the development of tools providing future engineers' knowledge survival are presented; the experimental test of the developed tools efficiency in the educational process of engineering faculties of a transport university is described. This paper may be of practical interest for technical university professors and instructors.

Keywords: knowledge, professional competency, engineer, knowledge survival, knowledge life cycle, digitalization.

1 Introduction

The knowledge economy as a modern view of the economy (Toffler, 1980) states that knowledge (intellectual capital, intangible assets) is the main source of wealth and the main factor in the acquisition of competitive advantages which requires system management. Knowledge management is becoming an important activity in corporations that use modern methods of Artificial Intelligence to extract knowledge from "Big Data", methods of knowledge engineering for the formalization of expert knowledge, its representation in the forms convenient for distribution, accumulation and use in the educational process as well. Digitalization of knowledge affects industry higher educational institutions involved in the life cycle of knowledge formation of industry corporations (Volegzhanina et al., 2017). The life cycle of sectoral knowledge has an impact on the life cycle of professional competency of engineers aimed at doing their job within the digital transformation of production processes.

In this regard, the research objective is to identify the factors affecting the survival of engineers' knowledge within the context of digital transformation of industries and professional education. In order to do this, the following tasks are being solved: to identify the place of the category "knowledge" within the emerging paradigm of digital economy; to reveal the relationship between the life cycle of knowledge and the life cycle of professional competency of an engineer; to develop pedagogical tools providing the survival of future engineers' knowledge; to test their efficiency in transport universities.

2 Literature Review

Knowledge is considered to be a fundamental interdisciplinary category that determines the quality of sources for educational content and the mechanism of social inheritance in the context of the survival of mankind in the XXI century that should affect the traditional attitudes of pedagogical science to knowledge (Subetto, 2010). In different sciences knowledge is defined in different ways. We attempted to reveal a relation between them. In order to do this, we conducted a semantic analysis of over 40 definitions of the term "knowledge" given in the studies on economics, education science, information technologies and cognitive linguistics. To perform the analysis, the machine text analyzer SEO Advego was used. The semantic core of this concept was formed by the following words and phrases: cognitive activity; conscious experience; information represented in a certain form; to store in a memory; an ability to develop; use in activities. On their basis, a working definition of knowledge was formulated taking into account two interrelated aspects of its nature (humanitarian and formal-logical):

Knowledge is an information object having a structured form and existing in some environment, which is called intelligence. Intelligence can have both a natural agent (a person) and an artificial one. Since an agent is an acting entity with a purpose, knowledge is the main resource for the agent to achieve it.

If the agent is a student, he or she is able to generate new knowledge on the basis of the existing knowledge both independently and under controlling actions including the use of digital technologies which involves the representation of knowledge in the form of logical judgments that allow implementing the mechanism of their processing and reuse (Mitsuk et al., 2016).

The highlighted aspects of knowledge are shown within the digital transformations of production processes and social life which is closely related to information technology development from computerization to internetization and intellectualization. This scale explains the main technological trend of the XXI century such as "Industry 4.0". It signifies the move to the production processes managed by artificial intelligence systems which brings together the abilities of people and computers in a "hybrid" corporate environment (Budanov et al., 2017).

In this context, the role of knowledge in the life cycle of professional competency of engineers of the new formation is better understood. In this regard, it seems necessary to highlight another aspect of the knowledge nature related to the belonging to a particular industry which is still insufficiently studied.

There are few foreign publications where the words "industry related knowledge" and "industry sector knowledge" appear (Edler, 2003; Jara-Figueroa et al., 2018; Pathirage et al., 2008). The analysis of these publications has shown that this category of knowledge contains all knowledge existing in the intellectual field of the industry which is formed by not only commercial organizations' knowledge but also all related institutions' knowledge (National Research Council of Canada, 2015), including universities (Bellucci & Pinocchio, 2006; Eraut, 2004). Depending on what they are used for, knowledge can be divided into corporate, fundamental, general professional and narrow professional knowledge related to the competences of an engineer.

The revealed multi-aspect nature of knowledge allows empowering a competence-based approach prevailing in modern professional pedagogy.

The transition of the world community from the industrial economy to the information economy (knowledge economy) leads to the speedup of a scientific and technical knowledge life cycle. This process shows the limitations of the traditional system of professional training in universities that provide training of engineering staff for the leading production industries (for example, a transport complex). A few decades ago, the life cycle of knowledge in these sectors was quite long allowing synchronization with the academic knowledge life cycle. Today, their disagreement has become so obvious that it begins to affect the level of engineers' professional competency negatively. One of the effects is the obsolescence of knowledge that students of engineering faculties of industry universities should acquire before they start their careers. This leads to a rapid loss of professional competency of young employees. This problem requires a differentiated approach to the formation of different components of industry-related knowledge depending on the duration of their life cycle and can be solved within the framework of knowledge survival. *Knowledge survival* can be defined as the proportion of knowledge survived in the intellectual environment of a system (industry, organization, worker) from the moment of its emergence (appearance) to the moment of its elimination (disappearance) or reproduction in a new knowledge life cycle.

Thus, A.D. Nemtsev and I.N. Makhmudova (2012) calculated half-life periods of relevant knowledge for some industries. This indicator means the time after the completion of training while a loss of half of the professional competency of a person occurs due to the obsolescence of the acquired knowledge. The half-life period of a particular type of knowledge is defined on a scale where the extreme points are knowledge with a long half-life period and knowledge with a short half-life period. Based on the assumption that different types of knowledge have different half-life periods, we may get an idea about the "lifetime" of the industry-related knowledge components relating to the minimum period of formation and use of the corresponding competencies. Using data presented in this research and the results of surveys conducted at the enterprises of Russia's large production industries (transport, nuclear industry) as well, we tried to show the following distribution (table 1).

Table 1 Lifetime of the industry-related knowledge components and the related competencies of an engineer

Knowledge type / Competences	Knowledge half-life period, years	Knowledge decay period, years	Min. period of competence formation (education), years	Min. period of competence use (labour activity), years
Fundamental knowledge / General competences	30	60	9-11	10
Including: Knowledge of a foreign language for professional purposes/ Communicative competences	2	4	2-5	3
General professional knowledge / General professional competences	8	15	3-4	3.5
Narrow professional knowledge / Special professional competences	4	7.5	3-4	3.5
Including: Knowledge of innovative technologies / Innovative competences	2	3.8	2-3	2.5
Corporate knowledge / Managerial competencies	1	1.9	2-3	2.5

Source: authors based on Nemtsev & Makhmudova, 2012

Table 1 shows that fundamental knowledge remains relevant for quite a long period (up to 30 years), except the knowledge of foreign languages which need to be updated periodically (it depends on the implementation of foreign technologies and equipment, the development of international cooperation, etc.), while narrow professional knowledge and corporate knowledge exist for a much shorter time (from 1.5 to 4 years). Accordingly, the competencies based on general professional knowledge remain relevant longer (within 3.5-10 years), and the competencies based on narrow professional knowledge lose their relevance rather quickly (within 2.5-3.5 years). The rate of knowledge obsolescence also depends on a specific sector of economy. For example, in high-tech sectors the average half-life period of practically all knowledge categories is rapidly declining. In production sectors characterized by high regulation of business processes (for example, railway transport) the decay of corporate knowledge is associated with the relevance of the rules and regulations. Their life cycle can be of 1-2 weeks and technical training classes are held with the same periodicity.

It is obvious that the assessment of engineers' knowledge survival by using this methodology is of certain complexity. This requires a significant period of time which ideally is equal to the entire career of a person in the industry. There is another way: to assess the level of retention of learning material in the long-term memory of students (a retained knowledge assessment). The results of check tests on knowledge survival by different disciplines presented in research works allow determining the limits of knowledge survival from 30 to 50 % (Koroleva, 2013; Myasnikova, 2017; Umbetalina et al., 2016; Tsybulkin, 2010). However, the time after completion of training is from two months to one and a half years. The authors also pay attention to the fact that the check tests' results depend on the current educational achievements. At the same time, it should be understood that the result of knowledge survival assessment depends on the individual characteristics of human memory, the depth of knowledge absorption, the frequency of knowledge access, the possibility of their practical application, etc.

3 Materials and Methods

In order to solve the defined problem and taking into account the requirements for innovative educational tools for the e-learning 3.0 paradigm (Edwards, 2015; Hussain, 2013; Volegzhanina et al., 2018), through the request of the Training and Methodology Centre for Railway Transport, the multidisciplinary team of Siberian Transport University (STU, Novosibirsk, Russia) has developed the tools that enhance knowledge survival of future engineers before the moment of its update or elimination due to technology update or corporate competencies revision or industry jobs disappearance (Annunziata & Bourgeois, 2018). The developed solutions include:

1. The multilingual e-learning environment Onto.plus (prototype) with ontology content organized via modules; providing the possibility to work with parallel forms of knowledge representation (linear text, hypertext, ontology, graphs); implementing the multilingualism and multimedia functions, automatic generation of frames and tests from ontologies given (Khabarov & Volegzhanina, 2018a).
2. A methodology for creating ontological content by authors who are unfamiliar with programming languages.
3. An interaction diagram for authors and developers of ontological content.
4. The technique of using Onto.plus in the education process (e-learning, blended learning) (Khabarov & Volegzhanina, 2018b).

In education, the students' knowledge survival is one of the ways to control quality of the content assimilation. Assessment is usually based on the results of testing (Belyaeva et al., 2018).

The experiment was conducted among the students of engineering faculties in STU from 2013 to 2017. First, the participants (147 students) were divided into two experimental and two control groups. In the experimental groups, the training was conducted using the developed tools. An experiment condition was a delayed check testing to assess knowledge survival in the first experimental (EG1) and the first control (CG1) groups 30 days after the trial training completion.

For these groups, the null hypothesis of equality of survival functions H0 was tested: $S_1(t) = S_0(t)$ against the alternative H_1 : $S_1(t) \neq S_0(t)$. Since the description of knowledge survival process dynamics requires a period of observation extending beyond 30 days after training completion, these assumptions were tested on a sample of students from EG1 and CG1 who had the value of an individual indicator for quality knowledge assimilation of $Q_{\text{assim.}} \geq 0.7$ according to the results of their final tests (total 52 students). The individual indicator for quality knowledge assimilation was calculated by the formula (1):

$$Q_{assim.} = \frac{B2}{B1} \times 100\% \quad (1),$$

where $Q_{assim.}$ is the quality of knowledge assimilation; B_1 is the total number of tasks; B_2 is the number of correct answers. Each correct answer was equal to one, the wrong answer was equal to zero. The total result was calculated in points and percentages (the ratio of the number of correct answers to the total number of tasks). The result was a value expressed as a percentage for each student.

From May 2017 to September 2018, the progress test on one of the topics of the discipline ("Freight Wagons") was given to students at EG1 and CG1 with intervals of 30, 90, 180, 270 and 360 days. The final test upon the trial training completion was taken as a zero mark. The data obtained were interpreted using the Kaplan-Meier method of multiplier assessment (Goel et al., 2010). The use of this method is justified by its wide application in manufacturing to assess the equipment reliability function. It may allow assessing the survival of industry-related knowledge components by means of different disciplines similarly to the survival of real objects in production cycles.

For us, the advantage of the Kaplan-Meier method is also that it is used for censored (lost) observations and the assessments do not depend on dividing the life time into intervals (loss of knowledge occurs at different times for different people). Therefore, the function of life can be estimated taking into account the decrease in the number of observed students due to the loss of knowledge. At the same time reducing the number of observations does not affect the accuracy of a survival forecast. A survival function was calculated by the formula (2):

$$\hat{S}(t) = \prod_{i=0}^{T} \frac{R_i - d_i}{R_i} \quad (2),$$

where $\hat{S}(t)$ is the evaluation of survival, R_i is the number of students who have Q $_{\text{assim.}}$ $\geq 0{,}7$ up to the time moment t_i, excluding the dropouts (Q $_{\text{assim.}}$ $< 0{,}7$), d_i is the number of students whose Q $_{\text{assim.}}$ was $\leq 0{,}7$ at the time moment t_i, $\frac{d_i}{R_i}$ is the probability of the outcome.
If the observation is censored (there was an outcome of the observed object), its value is equal to 0. If the observation is uncensored (complete), its value is equal to 1. For this case, the assessment of the accuracy of the approximation of the survival curve gives the standard error of the survival rate, which is calculated according to the Greenwood's formula (3):

$$\sigma_{\hat{S}} = \hat{S}(t) \sqrt{\sum_{i=0}^{t} \frac{d_i}{R_i\,(R_i - d_i)}} \quad (3),$$

The confidence interval of survival at the time moment t with confidence probability of $1 - \alpha$ is determined by the formula (4):

$$\hat{S}(t) - \sigma_{\hat{S}}\,\Phi_\alpha < \hat{S}(t) < \hat{S}(t) + \sigma_{\hat{S}}\,\Phi_\alpha \quad (13),$$

where Φ_α is the normal distribution quantile ($\alpha = 0{,}05$).

4 Results and Discussion

Tables 2 and 3 give the obtained results. They indicate smaller losses of knowledge in EG1, compared with CG1 during the period observed. Despite the partial knowledge losses by students in EG1 and CG1 (the value of Q $_{\text{assim.}}$ for all participants would be $< 0{,}7$), EG1 demonstrates a higher number of "survivors" (the value of Q $_{\text{assim.}}$ $\geq 0{,}7$) than CG1 has (7 students and 1 student respectively).

Table 2 Knowledge survival rate of EG1 participants (26 students, 2017-2018)

Assessment period, days	Number of assessments	Number of "dropouts"	Number of "survivors"	Survival probability	Confidence interval 95%; $\alpha = 0{,}05$
0	26	0	26	1.00	1.00-1.00
30	26	4	22	0.85	0.99-0.69
90	22	4	18	0.69	0.90-0.47
180	18	5	13	0.5	0.77-0.23
270	13	4	9	0.35	0.66-0.35
360	9	2	7	0.27	0.59-0.00

Source: authors

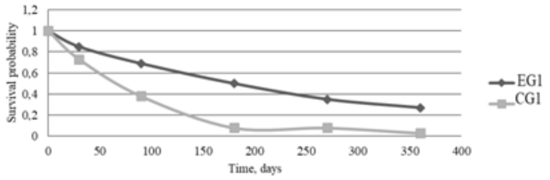
Table 3 Knowledge survival rate of EG1 participants (26 students, 2017-2018)

Assessment period, days	Number of assessments	Number of "dropouts"	Number of "survivors"	Survival probability	Confidence interval 95%; $\alpha = 0{,}05$
0	26	0	26	1.00	1.00-1.00
30	26	7	19	0.73	0.93-0.53
90	19	9	10	0.38	0.68-0.08
180	10	8	2	0.08	0.44-0.33
270	2	0	2	0.08	0,44-0,00
360	2	1	1	0.03	0.41-0.00

Source: authors

If we visualize the data obtained on the graph (Figure 1), the steeper curve of CG1 at the point up to 180 days indicates that the CG1 students lost their knowledge faster than the EG1 students. Unlike CG1 curve, EG1 curve is flatter, thus the survival of knowledge was higher and it took a longer period for the expected event to come (knowledge losses).

Figure 1 Knowledge survival rate in EG1 and CG1 (52 students, 2017-2018)



Source: authors

It is necessary to understand whether the difference between the actual number of outcomes and their theoretical number that can be expected in EG1 and CG1 is statistically significant under the null hypothesis validity. Since the lifetimes are not normally distributed, non-parametric criteria are used to assess the statistical significance of the differences. In our case, it is necessary to analyze the contingency table. It contains information on the frequency of the outcomes according to innovations, while the compared groups are independent. Under these conditions, it is appropriate to use the criterion χ^2.

The calculation of the criterion χ^2 was carried out using the following formula (4):

$$\chi 2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})}{E_{ij}} \quad (4),$$

where *i* is the line number (from 1 to r), *j* is the column number (from 1 to c), O_{ij} is the actual number of cases in cell ij, E_{ij} is the expected number of cases in cell ij.

As a result, we found a value of the criterion χ^2 for EG1 and CG1; it is 5.32 at a significance level of α = 0.05 and the number of degrees of freedom of 1 (f = (r – 1) × (c – 1)). The obtained value is higher than the critical value (4.0). Thus, it proves the statistical significance of the established difference.

5 Conclusion

The factors influencing the knowledge survival of engineers within the digital transformations are identified: the multidimensional nature of the category "knowledge"; the interrelation of the industry-related knowledge life cycle and the professional competency knowledge life cycle of an engineer; the use of didactic tools which can ensure the knowledge survival of engineers within the digitalization.

Knowledge is considered to be a fundamental interdisciplinary category which multi-aspect nature appears in a synthesis of several aspects: humanitarian (focused on the personality of a worker), formal-logical (focused on a hybrid corporate environment where a worker interacts with artificial intelligence systems) and industry-related (related to the industry intellectual field).

Industry-related knowledge is an independent category of knowledge containing all the knowledge existing in the industry intellectual field. It is formed by the knowledge of all related organizations (administration, businesses, science, industry universities). Industry-related knowledge includes fundamental, general professional, narrow professional and corporate knowledge. These industry-related knowledge components have different life cycles defining the need for their elimination or updating.

The high production processes dynamics in the Industry 4.0 has a significant impact on the industry-related knowledge life cycle. This justifies the conversion to the technique for knowledge survival of engineers at the stage of training in an industry university.

The tools providing future engineers' knowledge survival and their professional competency development via the multilingual e-learning environment Onto.plus as the core were developed. Tests automatically generated from the Onto.plus ontologies are able to assess students' knowledge survival. As ontology is a modern international standard approved by ISO/IEC (2014), Onto.plus provides synchronization with industry knowledgebases and the global knowledge resource via the English version of its ontologies.

The results of the pedagogical experiment justify the prospects of the technique for assessing knowledge survival to determine the quality of training of an engineer. Based on the testing data, survival trajectories for different industry-related knowledge components can be developed to predict the life period of competencies within the professional competency of an engineer and compensate its life cycle.

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