Development of a university's intellectual capital within "ontologisation"

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Abstract. This article introduces the concept of Networked Self-Developing Education System (NSDES). Such a system could be considered a modern university with a triple network structure where network team interactions between representatives of science, education and production are developed. A new model to explain NSDES intellectual capital development management is described. The model includes four interrelated parts (intellectual property, human, organisation and consumer types of capital). An important NSDES function is to provide conditions for lifelong self-development of scholars and students' mastery of the scientific method. This is especially important for interdisciplinary natural sciences (biophysics, etc.). The NSDES has its integrative resource potential to meet this challenge. Such potential is accumulated in the open knowledge base and can be transferred to the education process provided knowledge is standardised in an ontology format. To build a course ontology to study the bioluminescent enzyme technology, the experience of developing ontology-based education solutions for railway universities which are evolving into "knowledge factories" is useful. Thus, "ontologisation" is proved to be a trend in the digital transformation of NSDES. The model's implementation through ontology-based education solutions will create a foundation for the development of students' research competences to solve urgent problems in sciences and industries.

1 Introduction

Scientific research dedicated to the development of organisations' intellectual capital in the context of knowledge management has intensified due to the dramatic changes in socio-economic reality brought about by the implementation of 'end-to-end' digital economy technologies (Big Data, Artificial Intelligence, wireless communications, etc.). For example, Ramadan et al. (2017) investigated the mediating effect of social capital on knowledge management and intellectual capital in IT companies [1]. Later, Cabrilo and Dahms (2018) considered the modelling effect of strategic knowledge management in the relation of intellectual capital components, organisation innovations and its operating rates [2]. In their turn, Kianto et al. (2020) highlighted the two main groups of organisation factors influencing

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the development of intellectual capital (strategic and structural) [3]. The researchers also developed a theoretical model that determines the influence of these factors on the most important aspects of intellectual capital.

The ideas of these and other researchers have been transferred to education, where the self-development of a university is discussed as an interdisciplinary issue. Such an organisation appears to be a complex system providing a process of lifelong education for students and scholars. A particularly significant matter is the conditions for self-education, self-learning and self-development not only of an individual in the organisation, but also an organisation itself as a collective actor of lifelong professional education. Great attention is paid to self-education and self-development of scholars in network interactions [4]. In this case, motivation of an individual to lifelong education, contributing to mastering the scientific method and technologies of problem-solving thinking for successful managerial solutions and innovative activity, plays the leading role.

Researchers and practitioners are actively involved in implementing concepts aimed at the evolution of universities into education and research innovative complexes as integrated self-developing systems. In this respect, the well-known models "University 3.0" [5], "University 4.0" [6], and "University as a learning factory" [7; 8] are being discussed. These types of education organisations have a significant integrative resource potential for the development of intellectual capital, as Schneidewind (2001) justified more than two decades ago [9]. The latest publications (e.g., [10]) consider a university as the key element of innovative ecosystems, including those related to specific industries through formalised knowledge management [11]. A distinct body of researches is works on the development of implementation tools such as knowledge management systems [12]. They establish an environment for self-development of a university's intellectual capital.

Recent scientific and technological advances provide technologies for extracting knowledge from massive data sets, which is a valuable intangible asset for any organisation whether in industry or education. The main trend nowadays is turning to neural network technologies as universal interpolators based on Big Data. However, there are also alternative machine learning technologies that provide a way to extract patterns hidden in data and transform them into valuable knowledge. The extracted knowledge is represented in formats of rules, frames, and semantic networks as elements of knowledge bases, which unlike neural networks may be interpreted by both a human and a computer. This circumstance against the background of researchers' and practitioners' passion for the statistical approach (neural networks) has been neglected. However, it is the symbolic approach in Artificial Intelligence that refers to machine and human-shared formats of knowledge representation has a great potential to develop an adaptive formalized-knowledge management system of a university.

According to the experience, the limitations of most information systems for the implementation of knowledge management functions in universities relates to utilisation of textual and hypertext formats. To overcome these limitations, knowledge needs to be brought to some standard, which ontologies are seen as. The existence of ISO/IEC standards for individual industries and e-learning (ISO/IEC 20016-1:2014) is an advantage in selecting this format. Ontologies are also a key element in Semantic Web (Web 3.0) technologies with globally supported standards. Taken together, existing standards, methods and software solutions provide the foundation for an open knowledge base of a modern university. Such a knowledge base is described as shared environment where partner organisations from academia, education and industry collaborate.

For the implementation of a rather universal idea of intellectual capital (IC) development of a Networked Self-Developing Education System (NSDES), it will be beneficial to draw on the experience of industry-specific ontology development. The earlier studies on the training of future railway engineers (e.g. [13]) present the results of a comprehensive analysis of the world's existing ontological solutions in an industry-specific context. It is obvious that

studying the development of IC within an ontologisation context as the trend of digitalisation in education will require new concepts, models and implementation tools.

Development of ontologies in the fields of natural sciences, especially multi- and interdisciplinary ones, holds a research perspective. For example, advances in biophysics, physical and chemical biology and genetics have discovered the molecular mechanisms of bioluminescence as well as the possibility of extracting enzymes from luminous organisms that control the biochemical reactions that emit light [14]. Bioluminescence is one of the unique tools for teaching students biochemistry, microbiology, molecular biology and biotechnology, as it opens up the possibility of visualising a multitude of biological and physical processes and patterns. This is particularly relevant with regard to the formation and development of research competences among younger generations. At the school level, the aim is to provide career guidance and further selection for gifted students to study science and technology at universities. Further, the university establishes a foundation for the successful professional and scientific careers of future graduates, as well as the "nurturing" of excellent scientists.

The pursuit of these ambitious goals is practically evidenced by a situation where research and project activities become compulsory for pupils not only at upper secondary level but also at primary level. The results obtained are far from being always satisfactory to the scientific community. There is a low level of research competence not only among pupils and students, but also among their supervisors. Unfortunately, there are few instruments for teaching the scientific method. This is usually provided in scientific schools headed by well-known scholars. However, scientific schools do not always work even with novice researchers, much less with schoolchildren or students. Moreover, well-known scholars are convinced that a diligent learner should cope with the challenges of scientific investigation on his or her own.

The authors of this article consider the reason for such a situation as the lack of integration between natural sciences and humanities. The achievements of natural sciences remain without reflection and, therefore, the processes of IC development in these fields do not match. Hence, an important task is to develop students' research competences related to the scientific method, scientific design, research skills, academic writing and presentation of findings to the academic community in their native and other languages.

A potential solution could be the elaboration of ontologies adapted for education purposes. It should be noted that there are many off-the-shelf ontology solutions around the world. Examples of large ontologies include DBPedia [15]. This ontology contains the concepts on algebra, geometry, mathematical logic, mathematical analysis, probability theory, and mathematical statistics. Smaller examples are OntoMathPRO [16], ontology of physical units and quantities UnitDim [17], etc.

Bio-ontologies also have their own examples. As Soldatova and King (2005) argue, ontologies are not only intended to harmonise concepts in the professional language of biologists. Their potential relates to the interoperability of biological knowledge with knowledge from neighbouring fields. In addition, bio-ontologies will enable the development of intelligent software solutions for the effective sharing and reuse of interdisciplinary knowledge [18]. The importance of ontology-based knowledge management in the natural sciences, including biology, is also emphasised by Beisswanger et al (2008). They described BioTop that was a top-level ontology for molecular biology [19]. Later, Bernasconi and Masseroli (2019) developed a systems biology ontology (SBO) incorporating terms used in numerical modelling [20]. Other study described ontologies in the field of biomedicine [21].

As one can see, although individual aspects of university IC development have been sufficiently studied, it is hardly possible to discuss the existence of a coherent methodology and technology for the development of IC at the university as a NSDES. Moreover, the representation of NSDES as a collective entity of lifelong professional education requires

establishment of interdisciplinary relations between a school, a university and an industry within knowledge management.

Thus, the analysis of the world theory and practice in the development of IC, self-developing universities and networking revealed the following contradictions between:

1) the existing demand of society and business to find new ways for integrating science, education and industry during the IC development in a modern university as NSDES and the lack of interdisciplinary studies of NSDES IC development in the context of digital economy and knowledge-based society;
2) the value of developing a methodology and technologies for the development of NSDES IC and the lack of a new concept, model and implementing tools for the development of NSDES IC;
3) the need in providing conditions for the development of research competencies among young people, scholars and educators, and the insufficient development of IC in the modern university as a NSDES;
4) the demand for tools to support the on-going development of IC in NSDES, and shortage of relevant methods, technologies and education aids.

These contradictions specify the research problem related to the demand for a theoretical and methodological justification and elaboration of a new model for the development of IC in NSDES, as well as its implementation tools. These tools, inter alia, include an adaptive knowledge management system based on ontologies.

2 Materials and methods

The research method is pedagogical modelling, described in, for example, [22]. This method is employed to develop a model for explaining how to manage the process of IC development in NSDES. The methodological basis of this study is provided by the synergetic and network methodological approach offered by one of the authors and described in an earlier publication [23]. The materials for this study were theoretical works of scholars on the development of IC in business and education organizations, the results of researches on building domain ontologies. In particular, we used the experience of developing ontology-based solutions for educating future railway engineers [11; 13].

3 Results

A networked, self-developing education system (NSDES) is defined as an education organisation with a triple network structure. The employees of this organisation continuously develop their readiness and ability to improve their professional performance in the process of ongoing self-education and self-development in R&D activities. The structure of the triple NSDES network includes a central, managerial core; an internal, modular concentric and dynamic network that facilitates networking among its participants and brings together internal and external partners on a mutually beneficial basis to improve the performance of NSDES.

Among the main features of NSDES, the following were identified:

- having an open, flexible, triple-network structure involving different partners (scientific, education, business organisations);
- ongoing development of the key managerial competencies of NSDES employees, so that they are ready and able to improve their professional performance and successfully develop and implement managerial solutions to current professional challenges;
- lifelong professional education involving distance learning technologies (formal, non-formal, informal education), providing the double-learning loop effect;

- effective team networking among triple-network participants to achieve the best results through a combination of integration and cooperation strategies, team-building, division of duties and responsibilities;
- a value-based corporate culture that motivates scholars and educators to the ongoing professional and personal development;
- involving scholars and educators in knowledge and experience sharing in their self-education, mutual learning and self-development;
- a sustainable positive synergy effect exhibited by increased employee performance indicators and the development of NSDES IC.

The following Figure illustrates the model for managing the development of IC in NSDES. This model recognises the fact that interactions between employees in an education organisation are constantly changing. Educators act as mentors, consultants and mediators, guiding students and colleagues towards effective networking and ongoing performance improvement. This article consider team networking as a process of communication between employees in the education organisation to facilitate their joint work and pedagogical cooperation as well as mutual learning while sharing knowledge and experience.

The Figure illustrates that the structure of NSDES IC includes four interrelated parts: human, organisation and consumer capital, as well as intellectual property. Based on these parts, the major systems of IC development are specified in relation to: management of human and intellectual resources, a business model of the university system, the quality of education demands among students and marketing, the system of knowledge generation and R&D.

This vision of the main systems for NSDES IC development provides a framework to specify the mechanisms in this process. The first mechanism is considered to be a system of ongoing development of the managerial competence among university managers and research supervisors through their training, self-study and engagement in R&D. This mechanism also involves a comprehensive system of motivation, sharing of knowledge and experience, self-education, mutual learning and self-development.

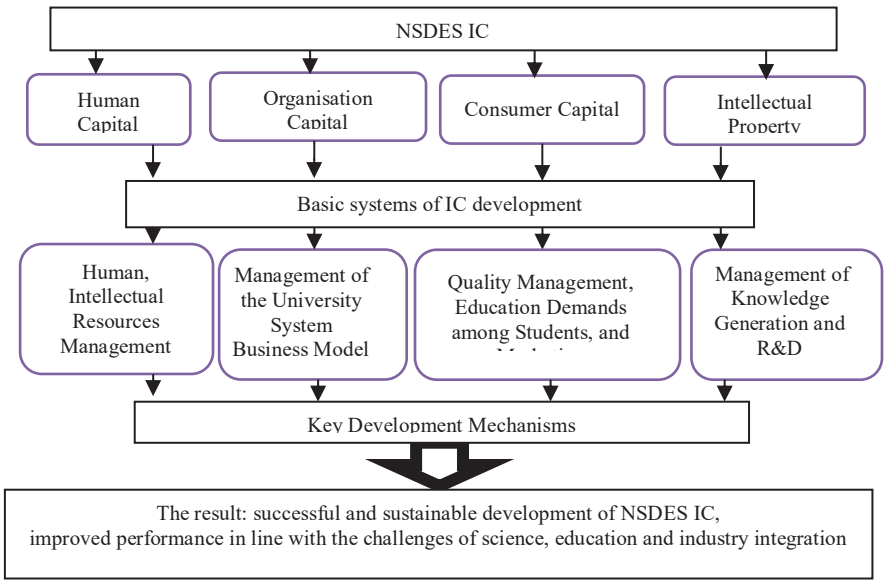

Fig. 1. A model for managing the development of IC in NSDES

The second mechanism establishes: the incorporation of partners into the triple network structure; description, regulation, formalisation of partner network interactions; implementation of management innovations; effective management solutions; development of networking, information and communication technologies, distance learning technologies; development of corporate culture and team-building.

The third mechanism is the formalisation of external and internal relations; marketing surveys and advertising; the elaboration and implementation of methods for the development and diagnosis of the NSDES components (ex., research competences of young people); the utilisation of education solutions based on Artificial Intelligence and pedagogic technologies (problem solving and teaching the scientific method).

The fourth mechanism relates to the elaboration and implementation of further professional education programmes, training courses, teaching and learning support; the formalisation and capitalisation of knowledge; a system of intellectual property protection measures (publication of scientific papers, etc.); fundamental and applied researches; holding of scientific conferences, publishing of scientific journals; development and implementation of innovations.

Finally, the fifth mechanism is the deep integration of science, education and industry through an adaptive knowledge management system based on ontologies; a formalised knowledge base containing education course ontologies; and integrative education solutions based on education course ontologies.

As a result, NSDES IC is expected to rise to a higher level, thus determining the successful and sustainable development of the university to meet the challenges of science, education and industry integration.

4 Discussion

Scientific value and relevance of the model offered for managing NSDES IC development is explained by a trend in digital transformations of science, education and industry, named ontologisation. The study of experience in the development and application of ontology-based solutions for the "railway industry – industry-related university" system reveals fundamental changes in existing business models in terms of IC management in industrial and education organisations. This experience is versatile and considered in the model for managing the development of IC in NSDES.

The representation of NSDES IC structure as interrelated parts, determining the core systems of intangible assets development in a modern university, provided alternative mechanisms for IC development in the context of digital economy and knowledge-based society. The elaborated model relies on a new didactic concept which implementation focuses NSDES on the evolution into a university as a "knowledge factory". The conceptualisation of an intellectual object in a certain standard form (ontology) aims at deep integration of science, education and industry through an open knowledge base. Owing to ontologisation, the process of accumulating the integrative resource potential of NSDES and its use for IC development is specified.

In this article, the authors would like to draw attention to the investigation of NSDES IC development from an interdisciplinary perspective. This means applying a variety of approaches and methods from different sciences, escaping chaos but generating fundamentally new knowledge. This is the challenge that the synergetic and network methodological approach is intended to overcome. From the viewpoint of this approach, the resource potential of NSDES for IC development under deep integration of science, education and industry is accumulated in an open base of knowledge represented in a format of ontologies. Its content requires the elaboration of education course ontologies in engineering and natural sciences, especially multi- and interdisciplinary ones. The latter

would include a course ontology to study the bioluminescent enzyme technology. An important purpose of this education course is the involvement of young people in the high-tech fields of science such as biophysics and physics and chemical biology. However, scientific sophistication of its content requires the development of students' research competencies. This problem can be solved with the help of NSDES integrative resource potential.

The vision of NSDES integrative resource potential, being transformed into a valuable resource (this is new knowledge) during the collaborative activities of scholars and educators, students and industry representatives, is harmonised with the idea of resource saturation of the education environment as its key attribute. In the context of lifelong professional education, the use of this potential will occur when a student gradually masters his/her research skills. This process involves increasing the complexity of research work focused on solving urgent problems in industries and sciences. In general, the IC development in NSDES aims to nurture a new generation of scientists who would be able to consider their research not only from the perspective of fundamental science, but also through commercialisation.

5 Conclusion

The scientific novelty of this article lies in the consideration of a modern university as NSDES with a triple network structure, where network team interactions between the representatives of science, education and industry as well as students are developed. For the first time, a model representing the structure of NSDES IC as four interrelated parts (human, organisation and consumer capital, and intellectual property) was elaborated. Such a representation provided an opportunity to specify the relevant systems and mechanisms for IC development in NSDES.

Studying this model from the perspective of interdisciplinarity and the synergetic and network methodological approach reveals that NSDES provides the conditions to form a value-based corporate culture. This type of culture encourages the university authorities and academic staff to further self-education and self-development, as well as students to master the scientific method. To achieve these goals, the integrative resource potential of NSDES is used. It is accumulated in an open base of knowledge, which is standardised in a format of ontologies.

This vision supports the recognition of ontologisation as a trend of digitalisation in education, which has provided practical solutions for bridging the natural sciences with the humanities (ex., pedagogy). Through ontology-based solutions, the achievements of natural sciences could receive a reflection to facilitate the successful development of research competences among young people.

References

1. B.M. Ramadan, et.al, Journal of Intellectual Capital **18(2),** 437-462 (2017) https://doi.org/10.1108/JIC-06- 2016-0067
2. S. Cabrilo, S. Dahms, Journal of knowledge management **22(4),** 621-648 (2018) https://doi.org/10.1108/JKM-07-2017-0309
3. A. Kianto, et.al, Intellectual Capital in the Digital Economy, Routledge **4** (2020) https://doi.org/10.4324/9780429285882-6
4. N. Kopylova, ELEKTRO, pp. 1-5 (2020) https://doi.org/10.1109/ELEKTRO49696.2020.9130313

5. C. Boehm,Emerald Publishing Limited, Bingley, pp. 61-86 (2022) https://doi.org/10.1108/978-1-83867-727-520221004
6. M. Zbigniew, Innovative university 4.0. In Sustainability, Technology and Innovation 4.0. Routledge, 21 p. (2021) https://doi.org/10.4324/9781003184065-2
7. N.I. Saputro, Sofyan H. Soenarto, *Integrated Learning Factory Design on Future Learning*, in 1st Virtual Workshop on Writing Scientific Article for International (2022) https://doi.org/10.2478/9788366675827-024
8. M.R. Darun, D. Palm, R. Athinarayanan, et al, *The Learning Factory - A New Stimulus to Enhance International Collaboration*, in Procedia Manufacturing : 9th Conference on Learning Factories **31,** 290-295 (2019) https://doi.org/10.1016/j.promfg.2019.03.046.
9. U. Schneidewind, Mobilizing the Intellectual Capital of Universities. In: Klein, J.T., Häberli, R., Scholz, R.W., Grossenbacher-Mansuy, W., Bill, A., Welti, M. (eds) Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society. Schwerpunktprogramm Umwelt / Programme Prioritaire Environnement / Priority Programme Environment. Birkhäuser, Basel (2001) https://doi.org/10.1007/978-3-0348-8419-8_9
10. S.S. Zmiyak, E.A. Ugnich, P.M. Taranov, Lecture Notes in Networks and Systems **73** (2020) https://doi.org/10.1007/978-3-030-15160-7_57
11. V. Khabarov, I. Volegzhanina, Transportation Research Procedia **63,** 1899-1908 (2022) https://doi.org/10.1016/j.trpro.2022.06.210
12. B.F. Oladejo, G.A. Apantaku, The International Journal of Technology, Knowledge, and Society **15(2),** 31-41 (2019) https://doi.org/10.18848/1832-3669/CGP/v15i02/31-41
13. V. Khabarov, I. Volegzhanina, Lecture Notes in Networks and Systems **403** (2022) https://doi.org/10.1007/978-3-030-96383-5_50
14. V.A. Kratasyuk, L.V. Stepanova, R. Ranjan, O.S. Sutormin, et al, Luminescence 36(2), 384-390 (2021) https://doi.org/10.1002/bio.3954
15. S. Auer, C. Bizer, G. Kobilarov, J. Lehmann, et al, *DBpedia: A nucleus for a web of open data*, in The Semantic Web, 6th International Semantic Web Conference, 2nd Asian Semantic Web Conference, ISWC 2007 + ASWC 2007, Busan, Korea, November 11-15 (2007) https://doi.org/10.1007/978-3-540-76298-0_52
16. O. Nevzorova, N. Zhiltsov, A. Kirillovich, E. Lipachev, Knowledge Engineering and the Semantic Web. KESW 2014. Communications in Computer and Information Science **468** (2014) https://doi.org/10.1007/978-3-319-11716-49
17. Ha. Rijgersberg, J. Top, UnitDim: an ontology of physical units and quantities (2021)
18. L.N. Soldatova, R.D. King, Nature Biotechnology **23(9),** 1095-1098 (2005) https://doi.org/10.1038/nbt0905-1095
19. E. Beisswanger, et.al, Applied Ontology **3(4),** 205-212 (2008) https://doi.org/10.3233/AO-2008-0057
20. A. Bernasconi, M. Masseroli, Encyclopedia of Bioinformatics and Computational Biology. Academic Press, pp. 858-866 (2019) https://doi.org/10.1016/B978-0-12-809633-8.20399-3
21. J. Kelso, R. Hoehndorf, K. Prüfer, Theory and Applications of Ontology: Computer Applications. Springer, Dordrecht (2010) https://doi.org/10.1007/978-90-481-8847-5_15

22. S.V. Konovalov, O.A. Kozyreva, Tomsk State Pedagogical University Bulletin **1(178),** 58-63 (2017) https://doi.org/10.23951/1609-624X-2017-1-58-63
23. E. Belova, I. Volegzhanina, A. Tayurskiy, Atlantis Press SARL, pp. 37-43 (2022) https://doi.org/10.2991/assehr.k.220208.007