Principles for constructing the architecture of information ecosystems in education

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***Abstract*—Information ecosystems are the basis of the development of modern economy and business. The peculiarities of their use are the use of contemporary information technologies and management rules according to the concept of Management 4.0. The results of research, development and implementation of information ecosystems and their development in education allowed the authors to highlight the main principles of architecture construction and to determine the indicators of ensuring the quality of functioning of the information ecosystem in education. A detailed analysis of each principle makes it possible to form general architectural models. These models can be used to create and introduce an information ecosystem for other educational institutions. The main principles of the information ecosystem in education are determined. Among them - are systematicity, modularity, scalability, multiple use of information, minimization of duplication of data and information in different forms, adequate storage of information and knowledge, and role focus on user and human-machine interaction. The considered scenarios of the implementation of the specified principles and the formation of mathematical models for assessing the completeness of their implementation allow us to evaluate the level of development of the information ecosystem. The visual model of the complex information ecosystem "Electronic University" will enable you to determine the level of system coverage of various activities in the educational institution and the implementation of the principles of the information ecosystem. The system's integration and communications levels are determined - from connections with external services to communications between the main actors - student-teacher, student-dean's office, supervisor-employee. The evolution of versions of information systems at the university, from the automation of information processes to the implementation of complex technical and management solutions, made it possible to more accurately form service modules and assess the level of coverage of information processes by the ecosystem. The electronic university information systems introduced by the authors in various educational institutions confirm the adequacy of the proposed models.**

***Index Terms*—information ecosystem, microservice architecture, electronic university, electronic information educational environment.**

I. INTRODUCTION

The concept of an ecosystem is successfully used in the economy, business, and communications, as well as in the field of information technologies. The first principles of information ecosystems were already laid down in management information systems. Modern management considers digital business ecosystems as networks of production connections based on contemporary, primarily cloud-based digital technologies. The information ecosystem involves the introduction of an ecology of relationships and obtaining the results of information processing and use by the set goals by optimizing information processes. Information ecosystems are complex adaptive systems that include information infrastructure, management tools, and communication with mass media, producers, consumers, and other communication participants. They represent complex organizations of dynamic social relations, thanks to which information is transmitted and transformed inflows, transformed into knowledge, stored and used. The information ecosystem involves introducing an ecology of relationships and optimizing information processes to obtain the results of processing and using information in accordance with the set goals. Information ecosystems are complex adaptive systems that include information infrastructure, management tools, and communication with mass media, producers, consumers, and other communication participants [1]–[5]. Features of modern information ecosystems are the use of contemporary information technologies and management rules according to the concept of Management 4.0. Information ecosystems in education should also take into account the principles of the Education 4.0 concept. The defined principles of building the architecture of information systems in education should be built according to the criteria of optimal use of data (avoidance of duplication, multiple use), determination of those responsible for technological and management processes (reliability of input, processing, storage and transmission of information, role focus on the user and man-machine interaction), scaling and use of modern microservice architecture with built-in Microsoft and Google services, which have become familiar to teachers and students. The active development of information ecosystems in education is due not only to the introduction of a student-centred personalized approach but also to the need to change the forms and methods of teaching to rationally use the tools of blended and distance learning [2]. In addition, the force majeure circumstances of the pandemic and wartime actualized the development of digital ecosystems in education as integral platforms for distance and blended learning.

Based on our experience as developers of three essential platforms for the "Electronic University" system [6]–[8], we can confidently state that defining the principles of information ecosystem architecture in education, and subsequently developing models for the learning and management environment, as well as assessing the level of automation and digitalization processes, will enable the more systematic and qualitative creation and implementation of electronic university systems in educational institutions.

II. Analysis of known definitions of information ecosystems and the purpose of the study

A. The evolution of the development of information ecosystems

The analysis of the evolution of the development of information ecosystems (IES) allows us to determine the following main stages: the formation of the system by the principles of building communication transactions, the creation of modules and profiles of the IES by management decisions [1]–[5]. The information ecosystem has a digital platform as a technical basis and is defined differently by different consulting companies and researchers. So, for example, in the definition of Gartner Research, it is a group of enterprises, mutually interested and dependent in their activities, united by a digital platform. Alphabet sees the digital ecosystem as a network of industrial connections. Researchers M. Koch, D. Cromer, and others present a digital ecosystem as an association of suppliers and consumers to achieve a common goal and benefit through network effects [9]. Academician V.M. Hlushkov defined the general principles of building information systems to remain relevant and acceptable for information ecosystems. These are the principles of systematicity, development, informativeness, compatibility, standardization, decomposition and efficiency [10].

The presented principles need to be detailed and supplemented to create and implement an information ecosystem in education. According to the standards of the international community [5] and the results of the author's experience of many years of development and implementation of the "Electronic University" information ecosystem [6]. The authors started the development of the "Electronic University" information ecosystem as the development of a system for automating educational and management processes. The transition from a monolithic to a modular architecture, analysis of the level of process automation, and analytical work with user feedback allows us to assert that for the introduction of the digital ecosystem "Electronic educational institution", it is necessary to determine the main features of educational and management processes in an educational institution, to analyze each principle of the architecture of information systems in education and determine ways to implement such an ecosystem in your institution. The analysis of the defined principles and the choice of implementation with further monitoring of the level of development of the information ecosystem will allow educational institutions to introduce a practical electronic system of management of training and educational institutions.

B. The aim of the study

The analysis of known approaches to building an information ecosystem in education showed that universities can build a sustainable socio-technical information ecosystem if a common goal and objectives are closely related to ensuring education quality [5]. The purpose of the study is to determine the basic principles of building the architecture of information ecosystems in education and to assess the level of development of the introduced "Electronic University" system (using the example of real working digital information systems of educational institutions in Vinnytsia).

C. Main results

The analysis of known approaches to constructing self-learning and developing systems information ecosystems highlighted the following principles of building the architecture of information ecosystems in education: 1) Systemicity; 2) Multiple use of information in a complete system with a single entry. Minimization of duplication of information; 3) Scalability; 4) Compliance with user needs; 5) Modularity; 6) Effective processing storage of information and knowledge.

The "Electronic University" systems were implemented using the defined principles in three educational institutions in the city of Vinnytsia. Data from the implementation of two systems—JetIQ VNTU and SEL—will be used to calculate the level of coverage of educational and management processes. Let's consider each of the identified principles in more detail.

1. The principle of systematicity consists of observing the system's integrity, compliance with the primary goal and the goals of the development of the information system dependent on it, the introduction of modules for single registration, login and, as a result, monitoring of user actions. Thus, for the "Electronic University" information ecosystem, the goal of the system development is the automation of the learning processes and management of the educational institution's support of systematic and scientific activities. The specified modules of the system, linked into a single ecosystem, should maximally automate or//and digitize educational and management processes. In addition, the information ecosystem should have unified communication processes with unified state educational databases and universal cloud digital platforms.

2. Agent communications between system modules support multiple uses of information, the ability to provide access to colleagues, and information exchange between repositories. A single login to the system is also essential. Systematicity and multiple uses of information are also supported by the "Electronic University" information system integrated with Google Work Space and Microsoft Office 365 services. Fig. 1 presents the general architecture of the "Electronic University" system, integrated with Google Work Space, Microsoft Office 365 and USEDE (Ukrainian State Electronic Database on Education) services. We can note that the practical implementation of the presented visual model of the integrated architecture of the digital ecosystem "Electronic University" involves the automatic registration of students according to the data of USEDE through a particular LoD interconnection system. Registration of teachers and employees is carried out by the subsystem "Electronic personnel department". According to the level of access, users of the digital ecosystem can use

the services of the local system and external services, mobile applications, and manage messages and publications in social networks.

The general scheme of integration of the main modules of the system is presented in Fig. 1, which indicates the possibility of implementing full-fledged distance and blended learning and supporting various types of activities. Video conferencing tools, technologies for interactive student-teacher communication, and data and information processing capabilities with subsequent knowledge production provide such opportunities. Also, this principle ensures the minimization of duplication of information together with the principles of systematicity, scalability and effective data processing, generation, transfer and storage of knowledge

3. The principle of scalability is a fundamental aspect of our system, designed to cater to the diverse needs of the university. It considers management and educational processes from the general management of the university to the electronic deans of each faculty and within each individual discipline. The system's adaptability is further demonstrated by the introduction of mobile application modules, compatibility with different browsers and gadgets, and modules for managing news and publications in social networks. This adaptability reassures the audience that our system can evolve and grow with the university's changing needs, providing a sense of security.

To determine the level of system development, mathematical models of the coverage of educational and management processes and the introduction of user solutions are advisable.

The following mathematical model can be used to assess the level of system development by the degree of process coverage and implementation of a technical solution for users.

$$X_j = \sum_{i=1}^{n} (Y_i * W_i)$$

Where X_j - coverage level by process group; Y_i – assessment of the presence of an automated process (0 - no; 1 - present); W_i – assessment of the level of the technical solution according to the capabilities and requests of users according to a 10-point system; N – the number of processes in the group.

The general level Z of development is calculated as follows:

$$Z = \sum_{i=1}^{M} X_i * K$$

Where the factor K of unevenness by groups of processes is taken into account, which can be represented as

$$K = 1 - \frac{\sqrt{\frac{\sum_{j=1}^{M}(X_j - \overline{X})}{M-1}}}{\sum_{j=1}^{M} X_j}$$

Where M – is the number of process groups. The proposed model can be used to evaluate a complex system and individual modular solutions [11].

The assessment of the teacher's office's level of development in the two systems, SEL (Vinnytsia Trade and Economic Institute) and JetIQ (Vinnytsia National Technical University), showed that JetIQ covers 86% of the defined processes in the system and SEL covers 74%.

Thus, Table 1 presents calculations for the main groups of processes in the JetIQ and SEL systems. The SEL' Electronic University' system, featuring the Moodle subsystem for online education, distance course creation, and its own repository system, is a testament to modern educational technology. It also includes an electronic journal, teacher communication tools, workload accounting, and a document management system. Similarly, the JetIQ VNTU' Electronic University' system, with its unique development, is a modern solution. Both systems are at the forefront of technology, utilizing cloud technologies and seamlessly integrating with Google Workspace and Microsoft Office 365.

The coefficient of unevenness, according to calculations, is close to unity, the coverage value for the "ideal model" of processes (16 process groups, 10 - the maximum coverage score) is 160, and for the JetIQ system, the coverage level is 125 points, and the SEL system is 93 points.

5. We implemented the principle of modularity during the development and development of the "Electronic University" system by moving from a monolithic architecture to a microservice architecture. Fig. 2 presents a fragment of such an architecture on the example of a student's activity in the system. The system's modularity is confirmed by the presence of separate microservices that work separately and are connected to the necessary services by modern integration technologies. Historically, the presented system was created and developed as a monolithic architecture. However, with the development of microservice architecture and the growth of the number of necessary modules, the information ecosystem "Electronic University" was reshaped as a system of microservice architecture. The presented microservice architecture, together with the integrated services of the well-known digital platforms Microsoft and Google, allows us to take into account the needs of the user (principle 4) and form modules as digital decision tools. For example, the communications and file exchange module allows not only the transfer and receipt of information but also the recording of the date of receipt, evaluation of work, the formation of a short answer, the change or "freeze" of files, etc.

6. The principle of obtaining relevant information, generating, transferring, and storing information and knowledge is complex and intricate, necessitating dedicated research and publications on the outcomes. While the details of this principle are beyond the scope of this report, it's worth noting that various mechanisms in the implemented systems support it. These include registration and confirmation, the formation of multi-agent interaction, and the development of knowledge in the form of 'smart' electronic books, analytics modules, and more.

Fig. 3 presents a diagram of the "Electronic University" information ecosystem based on the JetIQ VNTU platform. The scheme shows the level of coverage of processes according to the activity type and the system's integrity permeated by communications. The system's implementation began in

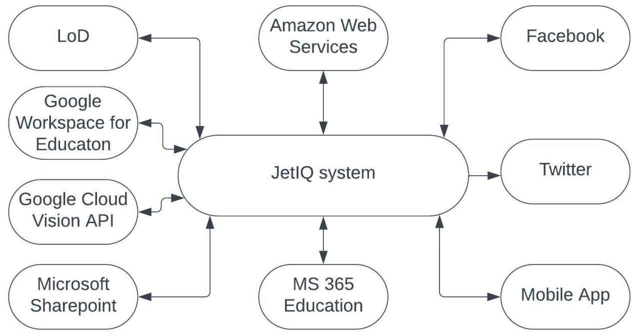

Fig. 1. Complex ecosystem with external services

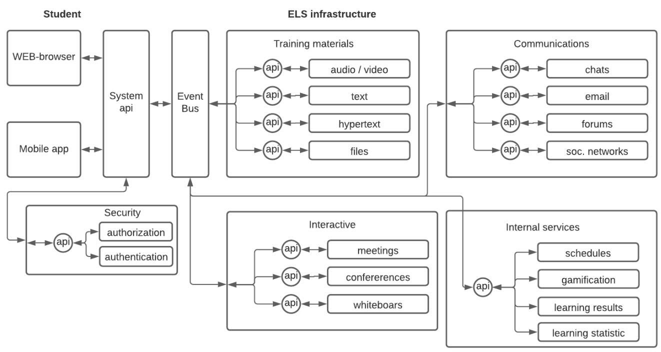

Fig. 2. Microservice architecture connection model (user ”Student”)

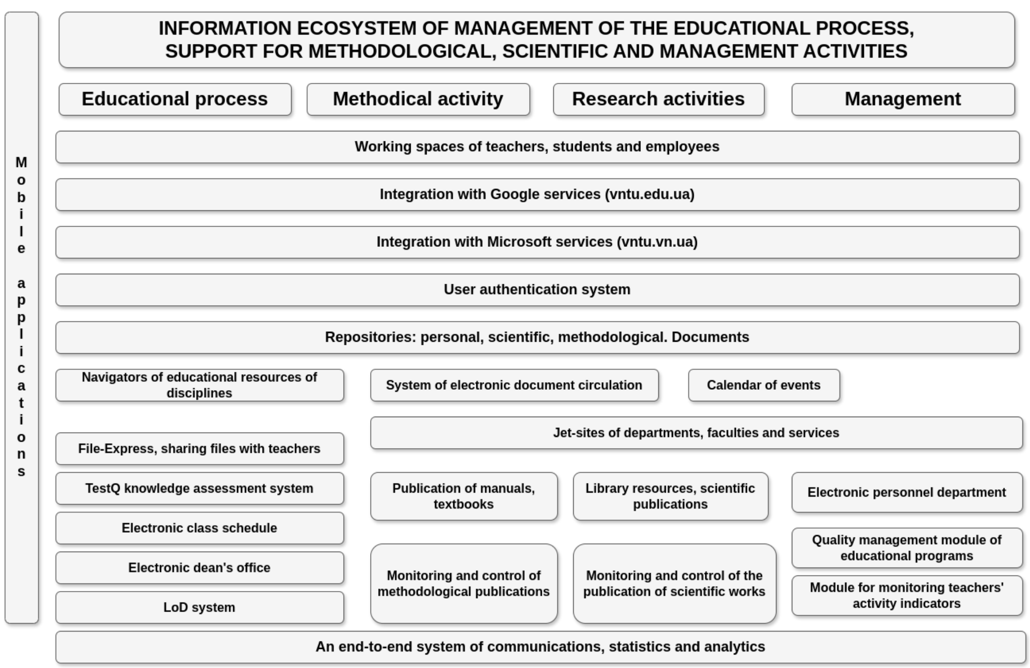

Fig. 3. The ”Electronic University” system based on the JetIQ platform

2015 and intensified during the pandemic and martial law. The presented scheme demonstrates a real system used by the entire VNTU university. The implementation results indicate the adequacy of the proposed models and the possibility of

TABLE I
THE MAIN GROUPS OF PROCESSES IN THE JETIQ AND SEL PLATFORMS

Groups of processes	Technical implementation, Y_i – assessment of the presence of an automated process (0 - no; 1 - yes) coverage level according to a 10-point system	
	SEL	JetIQ
Storage and use of personal electronic resources in the repository of working with an electronic journal	1/7	1/8
Work with load information	1/10	0/0
Student files and messages	1/8	1/8
Activity log	0/0	1/8
Teacher's activity evaluating systems	0/0	1/10
Systems for monitoring the results of professional development	0/0	1/10
Document management systems	1/10	1/10
Video conferencing systems	1/10	1/10
Systems of corporate mail	1/10	1/10
Management of the corporate website, personal pages, news publications	1/2	1/8
For curator work	1/9	1/9
To present electronic resources of the discipline (navigator, distance course).	1/9	1/9
Creating and using tests to test students' knowledge	1/7	1/7
For the work of the guarantor	0/0	1/6
A group of processes for reports on scientific and academic work	1/4	1/4
Average coverage level	5.81	7.81

TABLE II
ECOSYSTEM PRINCIPLES AND THEIR IMPLEMENTATION ON THE JETIQ AND SEL PLATFORMS

	Basic Principles						
Platform	Systematicity	Modularity	Scalability	Multiple use of information	Minimize duplication	Information and knowledge	Compliance with user needs
JetIQ	+	+	+	+	+	±	±
Sel	+	+	±	+	+	±	±

recommending the use of the specified principles of information system architecture in education for other educational institutions.

CONCLUSIONS

The conducted research made it possible to determine the principles of building the architecture of the digital ecosystem "Electronic University" and to form architecture models to assess the levels of development of the information ecosystem in education based on the data of coverage of educational and management processes. We propose to use the defined principles of information system architecture in education to build the architecture of information ecosystems in other academic institutions. The presented models have a practical implementation in the author's information circular ecosystems, "Electronic University," in educational institutions of the city of Vinnytsia. In the plans of further research - assessment of the level of development of knowledge management for an academic institution.

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