THE DIGITAL ECOSYSTEM OF TEACHER EDUCATION

INTRODUCTION

Society is changing rapidly. It offers us new social, economic, and environmental challenges. This is due to the accelerating rate of development of engineering and technologies and the variety of options for their use in various spheres of human activity. The art of living, ability to work, create new and innovation in a rapidly changing world will require from today’s schoolchildren the ability to quickly mobilize the totality of their knowledge, competencies, and skills, ability to self-organization, adaptation, and independent thinking, to solve problems under conditions of uncertainty and digitalization. Training the younger generation to create new values in a technologically saturated, continuously and dynamically developing digital environment requires new solutions from the education system as a whole and teacher education in particular. Teacher education plays a special role in the successful development of the state, intellectualization of society, reproduction of skilled personnel, and meeting the challenges (RADIF & MOHAMMED, 2019).

One of these challenges is digitalization. Its impact makes teacher education more technological, flexible, open, and mobile. It adapts to the changing digital environment, which, in turn, is part of TE’s digital ecological system. Due to digitalization, tremendous changes are taking place in the TE system. Its structure, technologies, objects, forms, and tools of interaction are changing (TIEN et al, 2020). Traditional educational systems no longer keep pace with the growth of innovative change (SERGEEVA et al, 2019). The diversity of educational opportunities can provide emerging educational ecosystems. Speaking at the All-Russian Scientific and Practical Conference "Digital Didactics of Professional Education and Training", A. M. Kondakov defined the educational ecosystem as "an integrative interaction environment based on data exchange between all participants of educational relations, with a variety of adaptive and variable educational content, innovative products, technologies and other elements of the ecosystem, ensuring personal safety, implementation of FSES requirements, formation of 21st-century skills, values of Russian civil society, personal, social and professional self-realization of a person in the network society of the multinational state (KONDAKOV, 2019).

It was also noted that the unified digital information educational environment of the Russian Federation - this is the educational ecosystem. Developing the idea of digitalization of the economy of the Russian Federation, representatives of the scientific and pedagogical community developed the concept of the Unified Digital Educational Ecosystem (UDEE). It includes four activities that are seen as trends in the educational ecosystem. These are “management, control and normative regulation on the implementation of UDEE program; the ecosystem of the personal electronic educational portfolio; digital educational currency; transformation of educational organizations into a network-centric ecosystem of educational providers” (KONDAKOV, 2019; KOROLEVA & NAUSHIRVANOV, 2020). Russia is actively moving towards changing its educational system towards the ecosystem approach. It takes into account the experience of foreign colleagues and makes its significant methodological and practical contribution to the general world system of research, colored by the specificity of national conditions (LUKSHA, 2018).
Over the years, experimental work on creating the DESTE was carried out in the Herzen State Pedagogical University (HSPU). It is based on the adaptive approach and understanding that the main condition for successful adaptive training is a mutual adaptive activity of the teacher and adapting activity of students in an adaptively developing digital educational environment.

The feasibility of using elements of artificial intelligence (AI) is also taken into account. Various educational organizations participated in the experiment: pedagogical universities, schools, organizations of the extended education system. The study was conducted from 2011 to 2021 by a team of authors who worked and work in educational institutions of different regions of the Russian Federation (St. Petersburg, Sakha (Yakutia), Republic of North Ossetia – Alania, Vladivostok, Tula, Yekaterinburg). The diversity of partners, professional dialogue with colleagues make it possible: 1) to better understand why and how the classical software system is being transformed; 2) to comprehend the problems, challenges, and dynamics of effective TE development towards an ecosystem approach in conditions of comprehensive digitalization, adaptation and orientation towards AI application in the educational sphere; 3) to design and implement a comprehensive project that brings together multiple stakeholders, digital tools and services for interaction and implementation of innovative collaborative educational solutions, including digital; 4) to develop relevant for professional training adaptive learning technologies based on the idea of adaptive interaction of participants of the educational process, including the use of digital technologies and tools.

LITERATURE REVIEW

The ecosystem approach to education is attracting more and more attention of academicians and practitioners of both Russian and foreign pedagogical communities. The diversity and versatility inherent in educational ecosystems make the research conducted in this field equally diverse. In (LUKSHA, 2018; EFIMOV, 2020), it is substantiated those traditional educational systems are not oriented to the rapidly changing world. They do not meet the demands of the times, the rapid development of a wide range of technologies, and especially digital. As a consequence, they prevent education from being flexible and rapidly changing. Traditional education systems do not correspond to the growth dynamics of digital technologies, which are one of the main drivers of the formation and development of the educational ecosystem, as well as its technological basis (KURBATOVA & AISNER, 2020; VAN DE HEYDE & SIEBRITS, 2019).

The works (AREEPATTAMANNIL & SANTOS, 2019; LI, F., & WANG, 2021; RIEBER, 2017; TRETYAKOVA et al, 2020; ZHAROV et al, 2020) proved that it is the ecosystem approach that will make it possible to develop the most productive educational models that people can use for lifelong learning. Therefore, the works in which the authors present their vision of the structure, components, and functionality of educational ecosystems of different types of educational institutions as the system-forming elements of regional educational ecosystems are highly relevant (MARTYNOV, B.V. & PROKOPENKO, 2021; BLINOV et al, 2021; KARANATOVA & KULEV, 2020). It is emphasized that university educational ecosystems are considered as an ecological vector of higher education and as a tool for creating conditions that increase the competitiveness of universities due to numerous and diverse relationships and interactions of their elements, as well as opportunities to implement the full cycle of development and innovation (LAANPERE, 2014; LEGAN et al, 2020; LUO et al, 2017; DYORINA et al, 2020).

At the same time, Koroleva and Naushirvanov (2020) identified some problems that prevent ecosystem innovations in Russian education. These are insufficient funding and a high level of bureaucracy. But this does not stop research and creation of best practices by teachers of specific subjects (ALLY, 2019; RIZAL et al, 2019; HERNÁNDEZ et al, 2018; KASIMOĞLU & ÇELİK, 2021; VORONIN, 2021; MARTYNOV & PROKOPENKO, 2021). All of them agree that the educational ecosystem completes the existing educational system through new, largely digital tools, technologies, and formats. This provides multidimensionality to the educational ecosystem, the possibility of personal and collaborative education, combinative and various educational practices.
The analyzed works do not adequately reflect the problem of designing, developing, and actively using digital ecosystems of teacher education based on the ideas of adaptation and intellectualization of the digital education sphere. The theoretical foundations of the research performed were the works of Russian authors in these areas (BARAKHSANOVA et al, 2017; KOSTIKOVA et al, 2020; VLASOVA et al, 2018; VLASOVA et al, 2020; VLASOVA et al, 2019a; VLASOVA et al, 2019b).

MATERIALS AND METHODS

The study was conducted for more than 10 years. Teachers and students, as test subjects, participated and participate in the study. They actively used the developed local digital ecosystem (LDES) in their teaching and learning activities. The work continues to the present day. The results of the study reflect the dynamics of changing formats of training of future teachers, ideas about how to organize and implement the educational process based on partnerships, options for using digital tools and solutions, the emergence of new types of activities of participants of the educational process, the development of e-learning technologies towards the AI use. Throughout the study period, experimental data are collected on the problem of formation of local digital educational ecosystems in teachers colleges, their development, restructuring, and transmission of the results obtained to partners in the pedagogical community. The degree to which this transmission is a promoter for the DESTE development as a whole is studied.

Based on the results of analysis of the content of educational programs, observation of the educational process in several pedagogical universities in Russia, which increasingly uses the didactic potential of digital technology, as well as conversations with colleagues-teachers of pedagogical universities, a generalizing conclusion was made that the digital transformation and the DESTE increase the effectiveness of the educational process and educational relationships. It also makes the educational process flexible, adaptive, full of innovation and increases the educational activity of all actors of the educational process. At the same time, it should be noted that the DESTE is a practice being created here and now for the future of TE. This general practice is made up of individual local practices of educational organizations involved in TE development. It requires both theoretical and practical research and development.

The initial period of the conducted research was focused on creating conditions for increasing the competitiveness of two pedagogical universities: the HSPU and M.K. Ammosov North-Eastern Federal University (NEFU). A flexible mechanism of interaction between the teaching teams of the universities was developed, allowing them to respond timely and adequately to external and internal changes caused by digitalization. The joint works (VLASOVA & BARAKHSANOVA, 2019; BARAKHSANOVA, 2019; AKSYUTIN et al, 2016; VLASOVA et al, 2019) of this paper authors reflect the results. The works show that professional cooperation at the scientific and methodological level; at the level of mutual and relevant professional development; at the level of joint work on the organization and implementation of the educational process on the network master's educational program "Corporate e-learning", which evolved through the collaboration of two teaching teams, provided the creation of an efficient digital environment for learning.

In the process, the participants of the experiment concluded that the efficiency of the environment will increase through the use of a wide range of information technologies (IT), e-learning technologies, alternative sources of knowledge, cooperation with various educational organizations and partners that help understand the relevance of sustainable development tasks for a particular region or educational sector (GONCHAROVA, 2017; POPOVA & BARAKHSANOVA, 2020). Particular attention was paid (GONCHAROVA & AKSYUTIN, 2020; ILYINA, 2019; AKSYUTIN et al, 2019) to the selection of digital tools and solutions, which, on the one hand, were used by our team to organize and implement the educational process in an e-learning format, and, on the other hand, were proposed to students for study and subsequent use to create their educational ecosystem, focused on the development and further application in future professional activities. The cumulative use of the above components and the synergy of their joint action leads to better learning outcomes. The digital learning environment for teachers is transformed into a digital ecosystem of teacher education,
which is first formed at the local level (at the level of a particular educational organization, department, subject taught). Then they merge.

The study subjects were students of pedagogical universities of the Russian Federation (St. Petersburg, Vladivostok, Vladikavkaz, Yekaterinburg, Tula, Yakutsk) who study the direction of “Teacher Education” and the “Information and Communication Technologies” (ICT) subject using a specially developed local digital ecosystem. The system was developed by a team of teachers of the Department of IT and e-learning of the HSPU (AKSYUTIN et al, 2020). The total number of participants in the experiment is more than 6,000 bachelors. The system was also used when HSPU and NEFU teachers worked with master’s students (115 master’s students) who studied under the Corporate E-Learning program (2017-2021), as well as during the implementation of supplementary vocational education programs (2016-2020) by HSPU teachers (318 trainees). The participants of the experiment were asked to identify the most essential characteristics (out of several suggested ones) that, from their point of view, make the digital ecosystem comfortable for learning and contribute to a higher resultant grade point. These characteristics included: adaptability, flexibility, use of AI elements, availability of a wide range of digital tools and technologies used for interaction and communication. However, it should be noted that the intensive dynamics of the development of the digital environment and digital tools can amend this list towards its expansion. It will require the development of this study and, as the authors believe, the use of the method of principal components to identify the most significant factors (characteristics). This circumstance can be seen as some limitation of the conducted research at this stage of its implementation.

Also, the task was to find out if and how the LDES comfort in the study of the ICT subject affects its results by students. The results of learning this subject were assessed on a 100-point scale, and the LDES comfort - on a 50-point scale. The average values for each group of students were recorded. In the course of the study, students were asked to answer the question: “Does comfortable working in the LDES contribute to obtaining a higher grade point while studying the ICT subject?”, as well as to predict the change in the final grade for the subject with increased working comfort in the LDES while studying this subject. Regression analysis was used to process the data obtained, specifically – the simple regression.

RESULTS

The experiment resulted in sample data (Table 1) in the form of a set of average grades of assessment of LDES comfort on the ICT subject learning (y) and the average grades of students (x) that they received as a result of learning this subject.

| y  | 14.8 | 16  | 19  | 22.5 | 24  | 34  | 32  | 20.9 | 22  | 23.5 | 32  | 35  | 24  | 47.9 | 27.5 |
|----|------|-----|-----|------|-----|-----|-----|------|-----|------|-----|-----|-----|------|-----|
| x  | 38   | 40  | 41  | 60   | 55  | 95  | 70  | 48   | 53  | 95   | 75  | 63  | 100 | 70   |

Source: Search data.

The algorithm for processing experimental data included three stages. The first stage is model selection. The construction of the correlation field (Figure 1) made it possible to assume that the functional relationship between x and y is linear, i.e., has the form $y = a + bx$. 

Table 1. Sampling data on the ICT subject learning
At the second stage, the calculation of the unknown parameters by formulas (1) and (2) was carried out.

\[ b = \frac{\bar{xy} - \bar{x} \bar{y}}{\bar{x}^2 (\bar{x})^2}, \quad (1) \]

\[ a = \bar{y} - b \cdot \bar{x}, \quad (2) \]

A fitted regression function is defined, the regression equation of which has the form (3).

\[ y = 2.124 + 0.37x, \quad (3) \]

At the third stage, an analysis of the model adequacy was carried out on how well the chosen model describes the available data. To this end, the following was determined:

1. Correlation coefficient \( r \) was determined by the formula (4):

\[ r = \frac{\bar{xy} - \bar{x} \bar{y}}{\sigma_x \sigma_y} \quad (4). \]

In this formula, the standard deviations of \( x \) and \( y \) are denoted as \( \sigma_x \) and \( \sigma_y \).

According to the calculation results, the value of the correlation coefficient \( r \) was equal to 0.879. This value is quite close to 1. The strength of a relationship is considered to be strong if \( r \) is in the range from 0.8 to 0.85. In our case, \( r \) takes on an even larger value. Based on this, it is concluded that the relationship between the features is strong enough. Evidence shows that the relationship between \( x \) and \( y \) is direct, close to a linear functional one.

2. The determination coefficient is calculated as the squared correlation coefficient. It turned out to be equal to \( k = r^2 = 0.773 \). From this, it can be concluded that approximately 77% of variations are due to variability of \( x \), and 23% are explained by other reasons, which are not taken into account in the model. Variability of the function \( y \) is explained by the variability of factor \( x \), i.e., 77% of differences in the grades obtained by students is explained precisely by the difference in the quality of the learning conditions in the developed LDES for the ICT subject. The remaining 23% comes from other unaccounted factors (absences, initial IT...
training, and others). In addition to the calculated coefficients, it was determined how significant the correlation coefficient is. To this end, two hypotheses were previously formulated:

1) The main statistical hypothesis (null) $H_0$: the correlation between the comfort level of the LDES and the average grade of the students that they get as a result of studying this subject is zero, i.e. the factor under study has no significant impact on the effective feature;

2) The alternative hypothesis $H_1$: the correlation between the comfort level of the LDES and the average grade of the students that they get as a result of studying this subject is not equal to zero, i.e. the factor under study has a significant impact on the effective feature.

The null hypothesis was tested using a t-test. The target value was calculated by formula (5):

$$t_{tag} = \frac{|r|}{\sqrt{\frac{1-r^2}{n-2}}} \quad (5)$$

Then the target value was compared with the critical value $t_{cr}$ at significance level $\alpha = 0.05$ and for the number of degrees of freedom $df = n - 2 = 15 - 2 = 13$. It is equal to 2.16. Given that $t_{tag} > t_{cr}$, the leading statistical hypothesis $H_0$ is rejected, and an alternative one $H_1$ is accepted. Therefore, the comfort of LDES of the ICT subject has a statistically significant effect on students' grades.

Next, the significance of the effect of LDES comfort on the student's grades was confirmed. The calculations were performed according to the following algorithm: 1) statistical significance of the regression coefficient using the t-test was determined. Its target value $t_r$ was found by formula (6):

$$t_r \frac{b_1}{m_{b_1}}; \quad m_{b_1} = \frac{\sum(y-y1)^2}{(n-2)\sigma^2 n} \quad (6)$$

It is equal to 5.797; 2) according to the table of critical points of the t-distribution, the value $t_{cr} = 2.16$ was determined; 3) based on the fact that $t_{tag} > t_{cr}$, the conclusion about the statistical significance of the regression coefficient was made.

**DISCUSSION**

The high dynamics of TE digitalization creates conditions and new opportunities for qualitative changes in the educational process, creates prerequisites for changing the entire "architecture" of relationships and interactions between its subjects. Digital technologies create fundamentally new opportunities for productive educational activities based on network cooperation. Full implementation of new digital learning opportunities guides the teaching community to develop models of the DESTE. They will make it possible to organize fundamentally different communications and options for cooperation between participants in the educational process, not only in the universities themselves but also in the regions; to activate education professionals to jointly solve innovative problems and involve them in professional pedagogical collaborations. The basic tool that ensures the formation and support of the digital ecosystem of the department, university, and region are digital platforms, which are formed considering the interests and needs of all potential ecosystem participants.

The LDES, developed by the teachers of the Department of IT and e-Learning of the HSPU, is designed for teaching and learning the ICT subject. It has gone through all stages of its development: birth, content and functional expansion, modernization, transition to other educational ecosystems. The LDES provides a flexible mechanism for interaction not only between teachers and students of one university but also other participants in the educational...
process (students of other pedagogical universities and teachers; school teachers as representatives of employers; other relevant partners and external digital resources). It enables them to timely and adequately react to the dynamics of external and internal changes through the use of convergent technologies. The system has such characteristics as multidimensionality, fast adaptability, presence of AI elements, multi-leveledness, ability to serve a wide range of learners’ needs, provide them with a variety of activities, communications, resources, digital solutions, and the ability to move along individual learning paths. A new level of opportunities is provided by the diverse and flexible use of digital technologies, tools, and learning formats, as well as the continuous development of the system in the context of adaptive interaction and management from a synergetic viewpoint. Synergic principles of learning allow for a non-standard approach to the organization of interaction of subjects of the educational process at different levels and the choice of related interaction content, forms, and learning technologies.

The developed LDES is dynamic and includes players from different educational sectors (and also geographically). They jointly develop and transform their professional competencies, working in a cooperative and competitive logic. There is mutual professional enrichment in the ecosystem, that is, not only students develop their competencies and new professional functions but also teachers working with an audience of professionals. They apply new types of teaching activities based on the transition from the strategy “to teach” to “to teach to learn” one, the use of cognitive and digital technologies, the idea of building the educational activities of students on the educational content basis.

CONCLUSION
The study shows that in order to successfully train education professionals in activities that constantly change and evolve under the impact of digitalization, it is advisable to train them in a Deste environment. It is shown that its large-scale development is advisable to start with the creation of LDESs within the university, for example, with ones designed to study specific subjects. Based on the method of mathematical modeling, which was performed using regression analysis, the following was revealed: the degree of comfort of students in the digital ecosystem for the study of the ICT subject positively affects the achievement of positive final results by students. The degree of comfort is determined by the extent to which the digital ecosystem characteristics are developed, which, as was found in the course of the study, are constantly developing, supplemented, and increase its didactic productivity due to the constant adaptation of the ecosystem associated with the variability of digital technologies, solutions, devices, and interfaces. The scientific novelty of the study lies in the fact that the adaptive approach of Deste development was proposed and implemented, which improved the quality of student learning both in full-time and distance forms of education.

The scientific novelty of the study lies in the fact that the adaptive approach of Deste development was proposed and implemented, which improved the quality of student learning both in full-time and distance forms of education. These might be regarded as a set of principles that should be followed when creating the LDESs for educational purposes. The practical significance of the work lies in the possibility of applying the study results by education professionals in the development of the LDES, as part of the Deste, adapting to the changing digital environment.

The trend toward new digital formats continues to intensify, and consequently, LDESs focused on the training of educational professionals will also improve. These ecosystems will merge and integrate into the digital ecosystems of pedagogical universities. Thus, the prerequisites for the emergence of the Deste – a complex self-organizing, self-regulating, and self-developing – are created.

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El ecosistema digital de la formación del profesorado

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Resumen
Este trabajo tiene como objetivo mejorar la efectividad del desarrollo adaptativo de DESTE, considerando las necesidades educativas intramuros y regionales y las tendencias del mundo digital que cambia rápidamente. Se utilizaron métodos de investigación empíricos y analíticos. Se realizaron análisis y síntesis de investigaciones nacionales y extranjeras en el campo de la creación de ecossistemas educativos en las condiciones de digitalización en la educación. Los resultados forman la base de un enfoque adaptativo para crear el DESTE e investigar su efectividad en la mejora de la calidad del aprendizaje, que se realizó mediante análisis de regresión. El documento corrobora la necesidad y la oportunidad de acelerar los desarrollos educativos innovadores intramuros y cooperativos (junto con los socios) para su posterior transferencia. Se identificaron las características clave de DESTE y su importancia para la formación de especialistas en educación digital. Un ecossistema digital local para estudiar la asignatura "Tecnologías de la Información y la Comunicación" fue desarrollado como parte de la universidad DESTE.

Keywords: Digitalization. Digital ecosystem. Teacher education. Adaptation. Professional activities.

Palabras-clave: Digitalización. Ecosistema digital. Formación de profesores. Adaptação. Actividades profesionales.