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Mathematical Modeling of Information Technology Integration in Digital Education: A Regional Perspective

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ABSTRACT

This study was motivated by the necessity to graphically delineate the optimal use of information technologies (IT) within the educational process. The primary objective was to investigate the characteristics of applying mathematical modelling to the incorporation of IT in the digital transformation of education. A mathematical methodology was employed to tackle tasks related to the integration of contemporary digital technologies in the educational domain. The versatility of this methodology allowed the authors to determine the scope and depth of the examination of IT usage for digital education in a specific region. The research identified a key limitation: the selected mathematical model could not be implemented more than once in a region without first adapting to the specific characteristics of that region. This constraint applies not only to education but also to other regional activities. While this study focused exclusively on the educational process, mathematical modelling can be applied successfully in the digitalization and development of various other sectors. Future research should therefore explore the application of modern mathematical modelling methods to diverse regional education systems.

1. INTRODUCTION

The evolution of education systems necessitates digital transformation, a process that maximizes the utilization of digital technology's potential. The digitalization encompasses the technological modernization of educational institutions' infrastructure, the establishment of a secure digital learning environment, and the development of digital competency among educators, scientific-pedagogical, and administrative staff for efficient application in education.

Mathematical modelling, defined as the construction and analysis of mathematical models, serves as an indirect, practical, or theoretical exploration of a subject. This process involves studying an auxiliary system (the model) that stands in objective correspondence to the subject of interest, replacing it in certain respects, and providing information about the subject through the model's analysis.

As we move into the third vital phase of mathematical modelling development, it integrates into the structures of the information society. The increasing complexity and intersection of human activity spheres align with the advancements in information processing, transmission, and storage. Today, addressing many of the world's complex and diverse challenges necessitates harnessing information 'resources.' However, raw information is often insufficient for analysis, forecasting, decision-making, and monitoring their implementation. What is needed are reliable methods to process this information into precise knowledge. The history of mathematical modelling methodology suggests that it should serve as the intellectual core of information technology, thus informing the entire process of digitalizing education. The use of mathematical modelling methods in digitalizing education is particularly relevant today, as modern science's study of educational systems exceeds the completeness and accuracy that conventional theoretical methods can provide.

Mathematical modelling can be employed to study several management tasks in education, including the optimal organization of the educational process, systemic representation and analysis of institution activities, the development of intelligent IT for mathematical problem-solving, planning control measures, organizing a balanced system of independent student work, considering student and teacher typologies, and developing new methods for assessing education quality.

Today, the digitalization of the education process is a crucial component of regional sustainable development, given that optimal regional development is unattainable without competitive and comprehensive information and communication technologies.

Educational institutions face several tasks, including finding a digitalization model within their autonomy, developing the institution's IT infrastructure, training and retraining staff in digital technologies, creating new forms of educational content, organizing an open distance education system, and establishing effective network communication among all education process participants.

In the digital transformation context, there's a need to enhance the digital competence level of education process participants. This competence includes technical security, technical literacy, information literacy, critical thinking, communication in a digital educational environment, digital content creation, cooperation, learning, and self-learning.

The primary digitalization areas of the educational process include augmented, virtual, and mixed reality, cloud technologies, mobile and Internet technologies, distance education, massive open online courses, gamification of the

educational process, and the development of digital libraries and university campuses. The primary pedagogical technologies offering digital learning include adaptive learning, distance, mobile, and blended learning technologies, and flipped classroom technology.

Therefore, digitalization is a key transformation direction in the education system, ensuring the quality and accessibility of education, strengthening individualization and differentiation of education, and developing and deepening individuals' digital competence. It shifts the communication paradigm with the outside world and serves as an internal tool for optimizing the educational and scientific environment.

This article aims to explore the features of applying mathematical modelling to the use of information technologies in the digitalization process of education. Thus, the scientific task will be to model the stages of correct information technology usage in education. The value of the mathematical modelling methods used lies in their convenience in representing the main tasks and their implementation sequence.

The article structure will include sections on literature review, methodology, research results, discussion, and conclusions.

2. LITERATURE REVIEW

The pursuit of education strives to shape a worldview grounded in sustainable development principles, endorsing systematization and assimilation of pertinent information. The digitalization of education, although intricate, has acquired substantial importance, with a multitude of scholars proposing solutions through the application of mathematical approaches [1, 2]. A vast array of scientific literature emphasizes the formulation of mathematical models for employing information technologies within the educational process. The consensus among the majority is that the contemporary application of information technology for educational digitalization is a novel approach to organizing the educational procedure. The utilization of mathematical methods, enhancing and systematizing this process, is deemed paramount to efficiency and effectiveness [3].

A faction of researchers [4, 5] purports that independent work organization facilitated by information technology provides optimal sequencing for each student, tailored to their speed of material perception and ability to organize work independently. It fosters skills in analytical and research activities, enabling self-assessment of the quality of acquired knowledge and skills, thereby promoting time efficiency for students.

Nonetheless, effective digitalization management of the educational process necessitates transitioning from subjective descriptions of pedagogical phenomena and processes to rigorous and objective assessments. This transition is feasible only through the employment of mathematical modelling methods. The construction of mathematical models of educational process quality has received considerable attention in modern literature [6, 7].

According to Häkkinen et al. [8], mathematical modelling, among various mathematical methods, is of salient importance in formalizing the learning process. It enables the accurate documentation of structural changes within any system and their quantitative reflection.

Conversely, an alternate set of authors [9, 10] advocates that mathematical models are essential for evaluating the efficacy of educational systems, forecasting, and designing their development. Utilizing models that encapsulate learning process patterns facilitates control over students' cognitive activities, considering the varying degrees of influence from different factors determining its performance.

In the course of developing approaches to applying mathematical modelling methods in pedagogy, Cai et al. [11] delineate the following stages in the evolution of mathematical modelling methods, corresponding to the automation requirements of the pedagogical process:

1) Emergence in pedagogy;
2) Development of individual methods and directions;
3) Recognition and generalization of mathematical modelling possibilities in pedagogical science.

May and Elder [12] establish an indissoluble link between the system of amplifying information technology use and the digitalization of the educational process. In their perspective, societal informatization is a promising trajectory for economic, social, and educational advancement. Education informatization aims at the formation and development of a region's intellectual potential, refining the forms and content of the educational process, and introducing computer teaching and testing methods. This approach enables high-level education problem-solving, in alignment with global requirements.

Given current trends in the field of education, an integral component of this training involves the use of mathematical modelling methods in implementing information technologies and deepening knowledge about their positive impact on regional development.

While acknowledging the perspectives of various scientists and partially concurring with the majority, it is crucial to underline that employing information technologies for the digitalization of the educational process is a complex task. The resolution lies in selecting an appropriate mathematical modelling method capable of visually representing this entire process.

3. METHODOLOGY

For various systems (technical, economic, environmental, educational) studied by modern science, today there are not enough tools for a full-fledged study by classical methods. A direct full-scale experiment on them is either too expensive or time-consuming, dangerous, and in some cases impossible. The price of miscalculations and mistakes is unacceptably high. Therefore, mathematical modeling, along with other classical methods of research and forecasting, is involved in the processes of scientific and technological progress.

The effective use of modern digital technologies makes it possible to simplify the process of compiling mathematical models, as well as to make more accurate calculations. The use of computers in mathematical modeling has changed the very concept of “solving a problem”. Previously, the researcher managed to create a mathematical model, while initially it was assumed that this model adequately describes the phenomenon under study, and it was enough to prove with its help that the solution to the problem in principle exists. In conditions where there are no simple formulas that describe the behavior of the model, the only way to solve the problem is to reduce it to calculations, to the application of numerical methods for solving problems. In this case, a specific algorithm is needed that indicates the sequence of computational and logical

operations that must be performed to obtain a result.

For a better perception of information about the system of mathematical modelling presented by us, its substantial essence should be considered in stages:

1) Firstly, we should decide on the region, which will be an example, and the object of our study. It also requires the application of certain methods. As an example, we can use the analysis and synthesis method to evaluate regions in order to select the best option for our study. Thus, omitting the intermediate analysis, we opted for the Central Bohemian Region. One of the criteria in the analysis and synthesis was the fact that the co-authors work in the educational field of the region. That is, we can talk about the factor of practical experience that influenced the application of this method of analysis.

2) The central place in our mathematical methodology will be occupied by the methodology for solving problems of mathematical modelling of complex socio-economic systems. This may include systems that meet certain criteria. We explore the features of the use of information technologies for the digitalization of the educational process. Embedded mathematical modelling methods are best suited for this. One of them is the functional modelling of complex systems using a graphical language with a certain set of interrelated functions.

It should be noted that it is the mathematical modeling methods that are the basis of the research methodology. Thus, the methodology includes: a mathematical modeling method using a graphic language to solve the tasks.

In general, the process of solving problems of mathematical modelling of complex systems can be described as shown in Figure 1.

It should be noted that the application of this mathematical methodology has a wide range, and therefore the authors independently determined the breadth and depth of the study of the use of information technologies for the digitalization of the educational process. The authors achieved a balance in modelling and did not allow models to be overloaded with unnecessary data.

Mathematical modeling is not related to digital technologies, it has a different purpose. Mathematical modeling in the article acts as a method of graphical display of the processes of applying information technologies for the development of education.

All modelling steps will be presented through the results of the study later in the text.

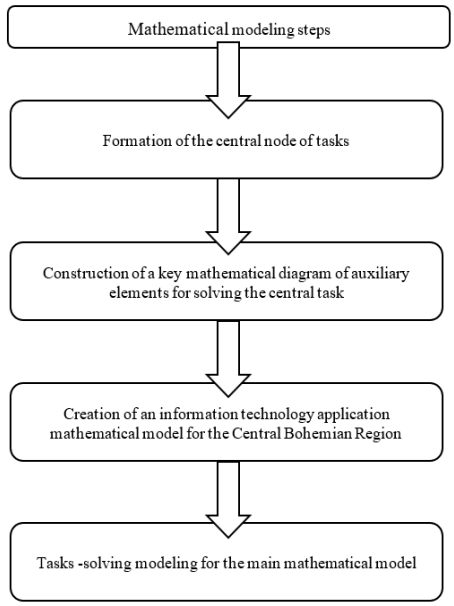

Figure 1. The process of solving tasks of mathematical modelling complex systems (developed by the authors)

4. RESULTS

To begin with, you should familiarize yourself with the tasks and how they should be solved. The main task is to model the use of information technologies for the digitalization of the educational process in the Central Bohemian Region. To solve it, it is necessary to solve at least tasks that together give a certain process with certain results. So, all this can be represented by a hierarchy of task nodes. The central one is shown in Figure 2.

The task node of the first level is shown in Figure 3.

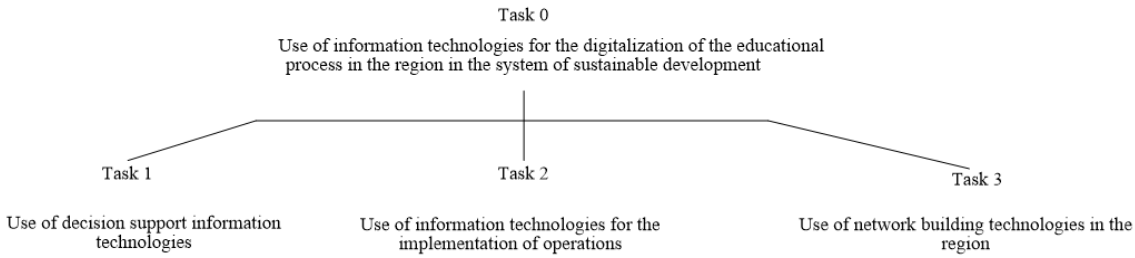

Figure 2. The central node of tasks (developed by the authors)

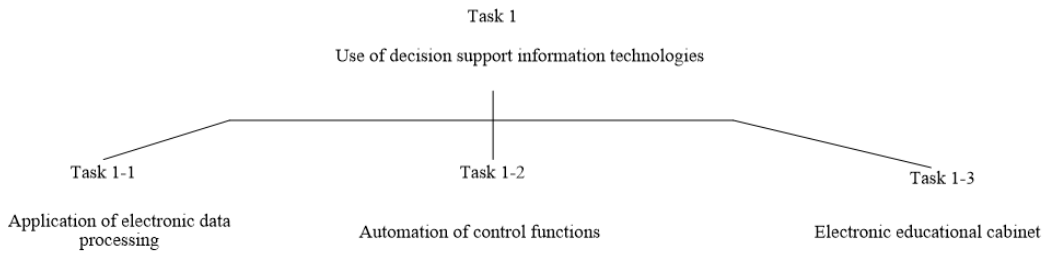

Figure 3. The task node of the first level (developed by the authors)

Similarly, it should be presented for subsequent levels. The task node of the second level is shown in Figure 4.

The final level will be the third, which, in turn, also involves solving certain tasks to reach the central level. The node of tasks of the third level is presented in Figure 5.

The next result will be the formation of a diagram of auxiliary elements for solving the central task according to the modelling technique (Figure 6).

Next, we will present the results of mathematical modelling the features of the use of information technologies for the digitalization of the educational process of the Central Bohemian Region. The central model for solving tasks on the use of information technologies for the digitalization of the educational process in the Central Bohemian Region (Figure 7).

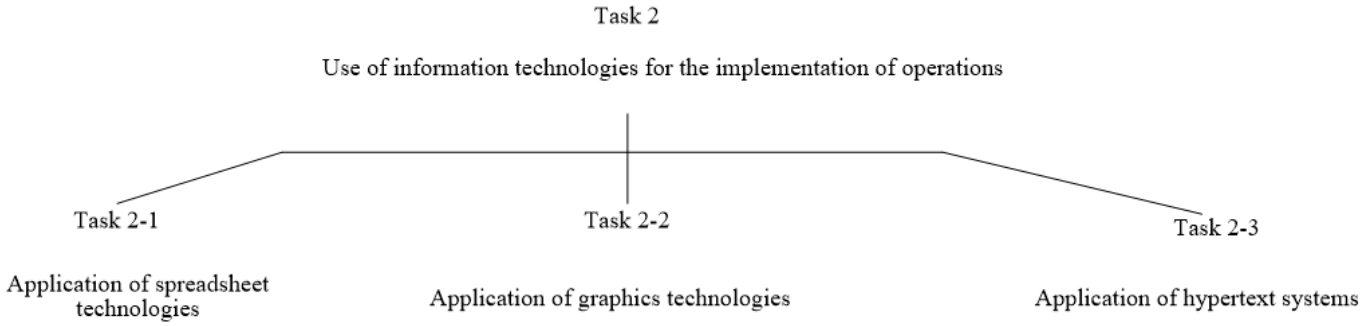

Figure 4. The task node of the second level (developed by the authors)

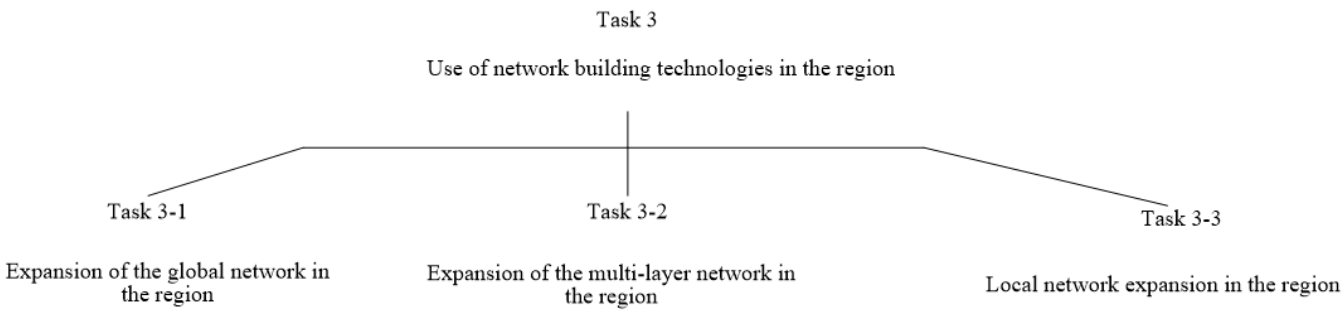

Figure 5. The task node of the third level (developed by the authors)

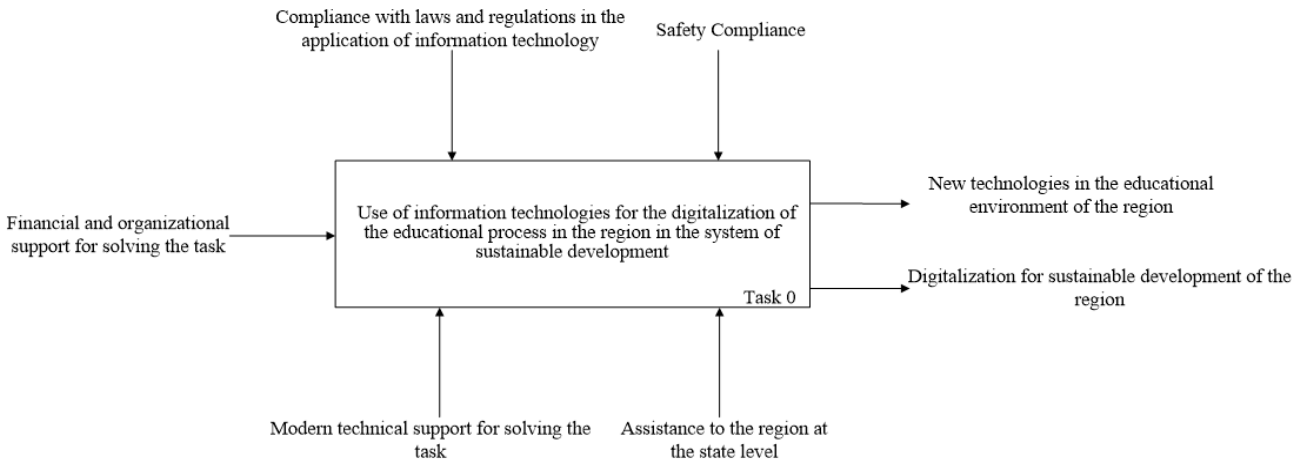

Figure 6. The diagram of auxiliary elements for solving the central task (developed by the authors)

The theoretical basis is to use a methodical approach with the best features of the model mapping. The technical basis lies in the use of vector modelling programs, which, through a graphical language, represents the step-by-step execution of the tasks. The key function of the presented model is to inform the process of achieving the task.

Let's consider each of the presented tasks on the use of information technologies for the digitalization of the educational process, in more detail:

Task 1. Use of decision support information technologies. The transition of the education system to a qualitatively new level without its informatization is simply impossible. The implementation of the informatization of education requires understanding the essence of this process and determining the

main directions for its implementation. Different approaches to the definition of the concept of informatization of education reflect various aspects and components of the process of introducing information technologies into the education system. In general, we can say that the informatization of education is the creation and use of information technologies to improve the efficiency of activities carried out in the education system. Yes, the process of supporting and making decisions on the development of education in the region is characterized by a hierarchy of management levels and multi-functionality. Therefore, decision-making automation provides a higher level-information about the analysis of the market, conjuncture, competition, alternative options for finding a strategy and scenarios for the development of education; middle level-solving tasks on the calculation of planned indicators, control over their implementation; operational level-processing the actual results of activities in real-time as they occur.

Task 2. Use of information technologies for the implementation of operations. The educational process involves a number of calculations and technological operations in the workplace. Information technologies should be introduced at all stages of the educational process: preliminary operations, main operations, intermediate operations, final operations, and auxiliary operations.

Task 3. Use of network building technologies in the region. The educational process in the region should have well-functioning information and communication network at all levels. This includes a single educational institution and ends with a network throughout the country. Institutions are very complex social systems in any region and therefore have to communicate and share information at all levels. Computers are central to the network. They provide their users with great advantages in the organization of joint data processing in solving professional tasks within a certain region. That is, they, first of all, provide a link between the communities of specialists. Another purpose is for global and regional computer networks.

Next, it is necessary to present in detail the mathematical modeling of the solution of all three tasks on this research problem (Figure 8).

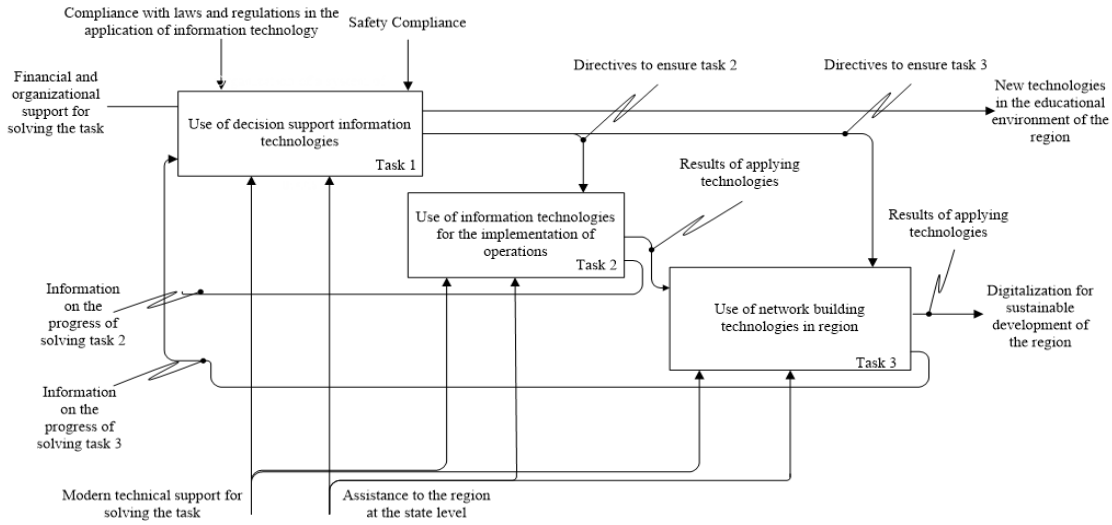

Figure 7. The central mathematical model for solving tasks on the use of information technologies for the digitalization of the educational process (developed by the authors)

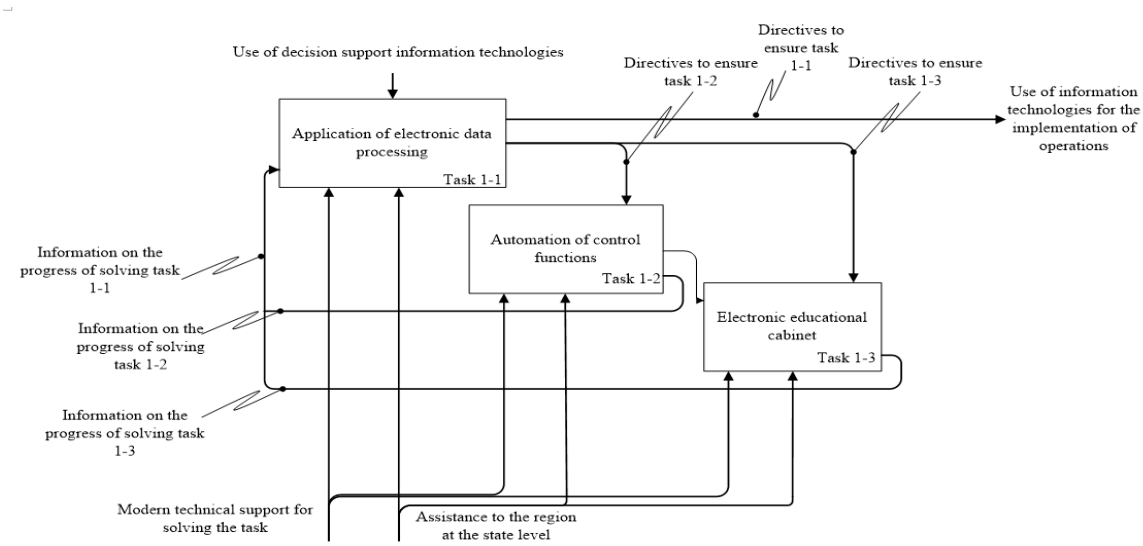

Figure 8. Mathematical model for solving task 1 on the use of information technologies for the digitalization of the educational process (developed by the authors)

When we talk about the use of information technology for decision-making support, the most important thing to solve this task is to automate the control system itself and digitalize the implementation of decisions as much as possible. To do this, you need to have an electronic cabinet.

Further, the solution of the second task according to our mathematical methodology (Figure 9).

To solve the task of technical operations in the educational process, the key place should be occupied by the development of graphic technologies and technologies of the hypertext system. Further, the solution of the third task according to our mathematical methodology (Figure 10).

It is impossible to talk about the use of information technology without building an appropriate network. A suitable network for information technology should be at all levels, from multi-layer to local. Unfortunately, the volume of research materials for building a network for the application of new information technologies in the region should be considered separately.

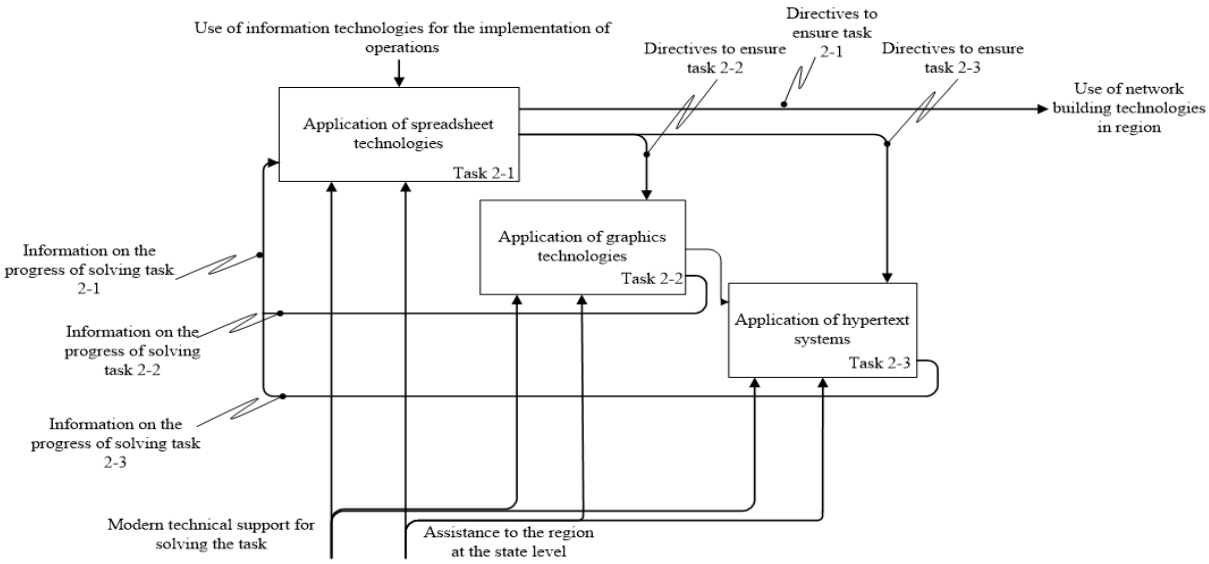

Figure 9. Mathematical model for solving task 2 on the use of information technologies for the digitalization of the educational process (developed by the authors)

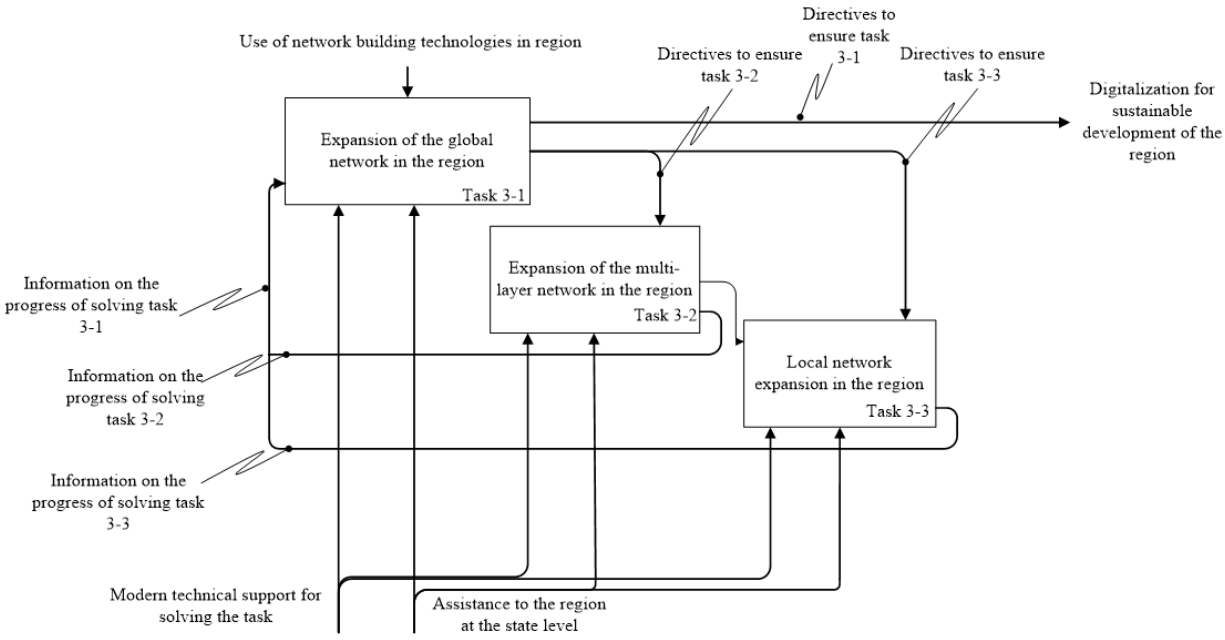

Figure 10. Mathematical model for solving task 3 on the use of information technologies for the digitalization of the educational process (developed by the authors)

5. DISCUSSIONS

Discussing the results of our study, it should be noted that our study, unlike others, is aimed at solving complex problems through mathematical modelling of complex systems. When other authors choose other approaches that do not include elements of mathematical calculations and mathematical modelling, which only partially allow structuring and

systematizing this process.

Given the above, the next logical and important step is to compare and highlight the key differences between our study and the existing ones.

The use of information technology and the process of digitalization of the educational process are new phenomena in a world in which a significant part of human life is in the digital space. At the same time, according to the studies of a significant group of scientists [13, 14], the issues of digitalization and the active use of digital technologies today are a reliable guarantee not only of the formation of a competitive specialist, but also a condition for the survival of the education system both at the level of a single region and at the level of the whole country .We agree with this statement, but it should be noted that the proposals presented in these studies are of an abstract recommendatory nature and do not contain a clear methodological basis. Their study contains only a list of recommendations that are not organized into a clear structure. At the same time, our study is based on a well-defined mathematical methodology that greatly simplifies the understanding of the problem and how to solve it. Effective management of the process of digitalization of the educational process is impossible without replacing subjective descriptions with strict objective assessments of the learning process, which makes it possible to make a method for constructing a mathematical model.

The issue of streamlining or systematizing the main activities for the use of information technologies for the digitalization of the educational process is also quite a topical issue. So, for example, scientists Czocher et al. [15] and Greer and Verschaffel [16] also made attempts to use certain methods and algorithms for this process in their works. But it should be noted that all the methods used were limited to ordering according to the principle of sequence or hierarchy, while such important elements as intermediate results were not taken into account at all, and all the necessary theoretical and practical elements were not taken into account. account. At the same time, our mathematical model shows all the elements of the process of achieving the final goal and differs in its own plasticity, which is especially important in the conditions of the rapid change in the environment of the education system in the region.

Kaiser and Brand [17] and Schukajlow et al. [18] in their works also used mathematical modelling models to model the educational process, but in their works, they focused on the general elements of improving the educational process, which is ineffective in the context of the transience of today's educational environment. In our study, we focused exclusively on the process of digitalization, since they are key in ensuring the effectiveness of the educational process.

Despite the fact that we fully agree with the above statements, in all works and studies related to the development of the educational process, the use of innovative and modern information technologies in the implementation of the educational process, their impact on the system is not unambiguous and generalizes. Given this, a distinctive feature of our study is the presence of clear recommendations on the process of using information technology for the digitalization of the educational system using mathematical modelling.

6. CONCLUSIONS

The analysis of mathematical modeling of the processes of digitalization of the educational process revealed that today on the Internet there is a large amount of software for building mathematical models. They allow you to freely simulate any processes and objects of the surrounding world. This undoubtedly simplifies the acquisition and processing of data and opens up new horizons for development.

As a result of the study, the features of the using mathematical method of modelling the process of using information technologies for the digitalization of the educational process were studied, we were able to conclude that digital technologies make the educational process mobile, differentiated, and individual and mathematical modelling here will be a key element of its implementation. At the same time, they do not replace the teacher but harmoniously complement him. Lessons based on the use of digital technologies are characterized by adaptability, manageability, and interactivity, a combination of individual and group work, as well as unlimited learning time.

In addition, digital technologies provide a number of new opportunities for both teachers and students, in particular: getting pleasure from the exciting process of communication and learning; automation of most of the teaching work, freeing up time for searching, communication, self-improvement, individual work with students; providing feedback; the perception of students with weak training in the role of leader, which generally contributes to the success of the entire academic group; correction of individual development of future specialists; increasing the efficiency of management of the educational process and education in general.

The innovative nature of the article is characterized by the use of a methodical approach to modelling the use of information technology in the educational process. The presented models include a well-defined sequence of tasks to achieve the goals.

We can assume that the contribution made by the article is in the very approach to solving the problem raised through modelling.

The study has a limitation, which consists in the impossibility of introducing the selected mathematical modelling more than one for a region without first adapting this modelling to the realities of a particular region. This also applies to areas of activity in a particular region. We have chosen only the educational process, but this is not the only area in which mathematical modelling can be successfully introduced into the processes of its digitalization and development. Further research should be devoted to the implementation of modern mathematical methods for modelling other regional education systems.

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