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The use of Petri Nets for inclusive education IT-support

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Abstract. The work is devoted to inclusive education process modeling by means of Petri nets with the aim to formalize the requirements to information technology support of such learning. The analysis of mathematical model of the inclusive education process allowed identifying factors of influence on this process. The study of specific interaction of external and internal factors and their influence on the output parameters was carried out, using the analysis of the procedure of educational aim achievement and additional conditions. Petri net of the education process of a person with special needs was developed. The decomposition process of inclusive education in the form of serial and parallel implementation of relevant educational tasks allowed developing functional requirements to a complex information technology of inclusive education support. For the design of information technology for information storage and structuring in the process of inclusive education, a mathematical model of subject domain description formation process was used.

Key words: inclusive education, persons with special needs, Petri nets, parallel processes, information technology.

INTRODUCTION

One of the dominant trends of modern education is the desire to ensure the full development of the personality of persons with special needs and promote their widest socialization through systematic development of inclusive education. The integration of children with special needs in mass educational institutions is a world tendency, inherent in all highly developed countries. The current scientific and practical task is to improve the accessability of educational services for persons with special needs through the development of software for complex modeling of information and technological support of inclusive education.

THE ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The research of education of persons with special needs in the world has been going on for more than thirty years. Scientists from Europe, USA and other countries [1-5] laid foundations for the development and establishment of education for this category of persons. There are information technologies abroad that facilitate the work of teachers and methodologists in the formation of individual learning aims and assessing pupils with special educational needs. Also there are open Internet resources for the development of personal communication passports and information resources for persons with special needs containing news of inclusive education and relevant legal information; centers of computer support for persons with special needs are working etc. The theoretical and practical experience as well as the information technology and software developed abroad cannot be automatically applied to the process of education of persons with special needs in Ukraine.

Fifteen-years international cooperation and national projects in the field of inclusive education have allowed Ukrainian specialists to form a theoretical base for the development and implementation of inclusive education. Ukrainian scientists have proposed conceptual components of inclusive education implementation in our country (P. Talanchuk, K. Kolchenko), organizational and methodical approaches to inclusive education implementation were developed (B. Dikova-Favorska, A. Kolupaeva, S. Litovchenko, Yu. Naida) as well as fundamentals of training and methodological support of inclusive education in Ukraine [6 – 8]. The development of information technologies contributes to the dynamic expansion of a range of information and technological tools for the support of the education process of persons with special needs in Ukraine, at the expense of specific tools and technologies that can be customized to perform specific learning tasks [9-11]: specialized application software packages for various data accumulation have been developed; teachers of educational institutions create problem-based software to teach selected topics; there are educational portals of regional and city departments of education; an independent electronic gradebook online service has been created with a focus on educational institutions of CIS countries, whose main function is to organize and keep gradebooks on the Internet; information is available at the websites of psychological, medical and pedagogical commissions, foundations and public organizations.

To ensure adequate working conditions for persons with special educational needs on the basis of works of Lviv Polytechnic National University scientists (V. Pasichnyk, M. Davydov, N. Kunanets [12 – 14]), computer technologies of access to educational information resources have been developed; the system of information and library services is working to provide educational services to users with special needs; basing on modern information technologies a system of remote education of persons with special needs is being actively developed. However, educational process support with modern information technologies is uneven, algorithmic

and software tools are usually not systematically related, there is no comprehensive approach to managing the educational environment focused on individuals with special needs.

Modern prospects of the development of inclusive education system in Ukraine are the application of information technologies to support persons with special educational needs. The application of methods of mathematical modeling for the analysis of such complex systems will improve their efficiency and the effectiveness of such education. In the works of foreign researchers S. V. Astanin, G. V. Mayer, V. V. Lomakin, as well as Ukrainian scientists L. Slipchyshyn, O. Cherednichenko and others, mathematical models of management of the education process are presented, but such works do not take into account the specificity of education of persons with special needs [15-19]. Ukrainian scientists have a number of works that are in a way connected with the development of software for certain stages of education of person with special needs. In his works Yu. Nikolsky proposed a model of large amounts of data process analysis. T. O. Dmytrenko adapted the application of the graph theory to solve optimization problems of the curriculum, V. I. Kut has developed a model of distance learning, M. V. Davydov suggested a mathematical software system to identify the elements of Ukrainian sign language [14, 20]. The need for a comprehensive reflection of functional and structural characteristics of the education process of persons with special needs with the consideration of national specificities of this process determines the relevance of this study.

OBJECTIVES

The basis of a comprehensive study of problems related to information and technological support of inclusive education is the development and verification of appropriate mathematical models. The purpose of this article is to determine the paradigm of information technology support of the process of inclusive education on the basis of analysis of the functional model of such a process. The development of information technology mathematical models typical for the process of inclusive education will promote holistic engineering of education information technologies aimed at integrated support of such learning.

THE MAIN RESULTS OF THE RESEARCH

To create a mathematical model of the process of inclusive education we use the principle of "black box"; this approach allows considering the process of inclusive education as a system, whose basic elements are variables at the input and the output of the system and the operators of their transformation.

The factors influencing the process of inclusive education are the following:

- controlled input and unmanageable impact factors that take into account the peculiarities of psycho-physical and intellectual development of the person, basic knowledge, the professional level of inclusive education specialists; the range of factor variation is set by the conditions of educational and extra-educational institutions,
- controlled input and managed impact factors establishing the rules of inclusive education; the range of factor variation is set in regulatory documents, the training content, material and technical, scientific and methodological support, the set of corrective actions etc.,
- output parameters characterize knowledge, skills, competencies and the level of social integration of persons; the range of variation of these parameters is set by the standards of educational and social skills of the inclusive learner.

Internal parameters of the system are, in particular, scientific and methodical, material and technical support of inclusive education process, learning aims and its corrective component, technologies and evaluation methods of educational and social progress of a person with special needs etc.

The mathematical description of inclusive education process in general will be the following:

$$InclEduSupportSystem(OSID, IER)=PS,$$

where: *OSID* – an impact factor, considers objective and subjective characteristics of participants in inclusive education; *IER* – an impact factor, establishes the rules for inclusive education; *PS* – the outcome factor reflecting the level of socialization.

Formally, the impact factor *OSID* will be presented as follows:

$$OSID=(IntegrEval, HRSupport, \{ParentsHelp\}),$$

where: *HRSupport* – human resources of inclusive education, *HRSupport=(MedS, PedagS)*, here *MedS=({Psycol(PPFeat)}, {CorMed(PPFeat)})* – medical professionals (psychologists *Psycol* and correctional medicine specialists *CorMed*), *PedagS=({CorPedag(PPFeat)}, {PedHelp(PPFeat)})* – educators (correctional teachers *CorPedag* and teacher assistants *PedHelp*), accompanying inclusive education depending on the nosology *PPFeat* of the person; *{ParentsHelp}* – available parental assistance; *IntegrEval* – integrated evaluation of the person obtained by intellectual data mining, using function *DataAn*: *IntegrEval=DataAn(<RegData>, <DiagnPMPC>, <ParentsInfo>, <PersonInfo>*), parameters of which are: *<RegData>* – registration data of the person, *<DiagnPMPC>* – the diagnostic results in PMPC, *<ParentsInfo>* – information from parents, *<PersonInfo>* – information from the person.

Formally, the impact factor *IER* will be presented as follows:

$$IER=(OrgLegActs, EdMetSupport, MatTechSupport, \{EdInst(PPFeat)\}, \{ExtraEdInst(PPFeat)\}, \{AssessmentRules\}),$$

where: *OrgLegActs* – organizational and legal support of inclusive education, *OrgLegActs=({LegActs(PPFeat)}, {Consult(PPFeat)}, {PublAssoc(PPFeat)}, {SocServ(PPFeat)}, {Sport(PPFeat)}),* here *LegActs* – legislative acts, *Consult* – information of consulting centers, *PublAssoc* – information from public organizations, *SocServ* – help from social services; *EdMetSupport* – educational and methodological support of inclusive education,

EdMetSupport=({IETextbook(PPFeat)}, {IEProgr(PPFeat)}, {IEMet(PPFeat)}), here *IETextbook* – consolidated special and general education textbooks, *IEProgr* – curriculum, *IEMet* – methodical support of inclusive education depending on the determined features of psychophysical development; *{EdInst(PPFeat)}* – available inclusive institution; *{ExtraEdInst(PPFeat)}* – available inclusive extraeducational institutions; *{AssessmentRules}* – methods of assessment of educational development of persons with special needs; *MatTechSupport* – material and technical support of inclusive education, which depends on the provision of appropriate educational and non-educational institutions: *MatTechSup=MTS(TechSup, MatSup, ArchDes),* where *TechSup=TS(EdInst*, *ExtraEdInst*) – technical support of the education, depending on educational and non-educational institutions, *ArchDes=AD(EdInst*, *ExtraEdInst*) – features of the architectural design of educational institutions.

Formally, the output factor of *PS* is presented:

PS=(EduRes, SocRes),

where: *EduRes* – assessed learning outcomes of the individual education plan *IndEdPlan*: *EduRes=Evl(<IEPlanRes>, {AssessmentRules}, IndEdPlan)*, where *<IEPlanRes>* – the results of the implementation of the individual educational plan *IndEdPlan, {AssessmentRules}* – methods of assessment of learning outcomes, *IndEdPlan=IEPDesign(HRSupport, OrgLegActs, MatTechSupport, {ParentsHelp}); SocRes* – evaluated level of social development of the person, the level depends on the results of the corrective component of inclusive education *CorEduRes*: *SocRes=SR(CorEduRes*).

The analysis of the specificity of interaction between external and internal factors of the system and their impact on output factors lies in studying the functional stages of the education process, and inclusive education is a part of it. According to [21], the implementation of the first phase of education of a person with special needs is the accumulation of data for a comprehensive study of personality by various specialists (psychologists, doctors, teachers) and information from parents. Also on the basis of comprehensive assessment the peculiarities of psychophysical development of a personality are determined. The second phase of education of persons with special needs involves the determination of learning aims of the entity, depending on peculiarities of their mental and physical development. This aim unites form and content of learning with the correctional rehabilitation component. The third stage of education is the selection of appropriate methods and means to achieve learning aims, a fixed set of methods and tools with regard to personal orientation is the individual educational plan (IEP) of the person. The fourth stage of education is the implementation of the IEP, the accumulation of learning outcomes and their assessment.

A phased study of the education process of a person with special needs has allowed identifying its characteristic features: a strict sequence of stages of the investigated process [21, 22] and the need for parallel implementation of some educational tasks within the designated stages of the education process for person with special needs. For formal representation of such requirements Petri nets were applied [23]. The advantages of this mathematical abstraction is the possibility of reflection of causal relationships in complex systems and a visual representation of parallel phenomena and processes in complex systems.

Let us set the Petri net of education process of a person with special needs as a set of positions P and transitions T, an input function I and an output function O. The Petri net transitions are events, and positions are conditions in which events occurre. The sequence of educational task realization is reflected by Petri net transition triggering.

Let us define Petri net positions and their content in terms of education of a person with special needs. Position p_0 is interpreted as a requirement of the person concerning the acquisition of education, p_1 is the accumulated registration data, p_2 – diagnostic results at PMPC, p_3 – results of the interview of parents, p_4 – results of the interview of the person, p_5 – comprehensive evaluation of the person, p_6 – established psychophysical development features of the person (PDF), $p7$ – forms of learning of the person with PDF, p_8 – the content of inclusive education, p_9 – adapted Curriculum, p_{10} – training and methodological support of inclusive education, p_{11} – logistical support of inclusive education, p_{12} – human resources of inclusive education, p_{13} – a list of inclusive education institutions at the place of residence of the person, p_{14} – a list of extraeducational institutions at the place of residence of the person, p_{15} – organizational and legal support of inclusive education, p_{16} – parents, p_{17} – individual education plan (IEP), p_{18} – the results of implementation of IEP, p_{19} – evaluation of educational achievements, p_{20} – social development evaluation, p_{21} – evaluation of IEP implementation results.

Let us define an appropriate formal notation of Petri net transitions and define their content. t_1 transition is interpreted as the process of identity formation, t_2 is the process of comprehensive assessment of the person, t_3 – the process of comprehensive assessment analysis, t_4 – the process of learning form determination, t_5 – the process of learning content determination, t_6 – the process of agreement of learning aims, $t7$ – the process of IEP components formation, t_8 – the process of IEP components agreement, t_9 – the process of IEP implementation, t_{10} – the process of evaluation of the results of IEP implementation, t_{11} – the interpretation process of the results of IEP implementation, t_{12} – the decision-making process of IEP implementation.

Let us set the Petri net analytically – as a set of positions, transitions input and output functions. The set of positions: $P=\{p_0, p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}, p_{17}, p_{18}, p_{19}, p_{20}, p_{21}\}$. The set of transitions: $T=\{t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9, t_{10}, t_{11}, t_{12}\}$. The input functions set: $I=\{I(t_1)=\{p_0\}, I(t_2)=\{p_1, p_2, p_3, p_4\}, (t_3)=\{p_5\}, I(t_4)=\{p_6\}, I(t_5)=\{p_7\}, I(t_6)=\{p_7, p_8\}, I(t_7)=\{p_9\}, I(t_8)=\{p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}\}, I(t_9)=\{p_{17}\}, I(t_{10})=\{p_{18}\}, I(t_{11})=\{p_{19}, p_{20}\}, I(t_{12})=\{p_{21}\}\}$. The output functions set: $O=\{O(t_1)=\{p_1, p_2, p_3, p_4\}, O(t_2)=\{p_5\}, O(t_3)=\{p_6\}, O(t_4)=\{p_7\}, O(t_5)=\{p_8\}, O(t_6)=\{p_9\},$

$O(t_7)=\{p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}\}$, $O(t_8)=\{p_{17}\}$, $O(t_9)=\{p_{18}\}$, $O(t_{10})=\{p_{19}, p_{20}\}$, $O(t_{11})=\{p_{21}\}$, $O(t_{12})=\{p_0\}$.

Graphically a Petri net that gives you the opportunity to simulate parallel processes in the education of a person with special needs, is given in Fig. 1.

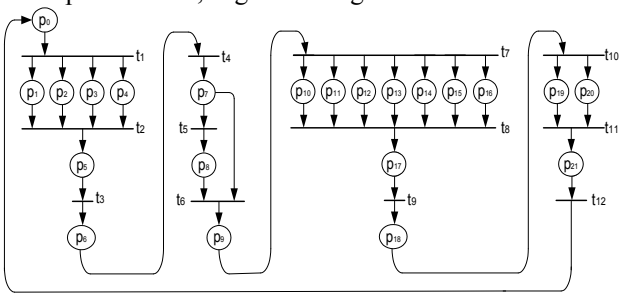

Fig. 1. The Petri net of education process of a person with special needs

Graphic setting of a Petri net is a convenient tool of showing parallel phenomena in the system. For example, the triggering of transition t_1 initiates the execution of parallel educational tasks. Such educational tasks are to obtain a person's identity, results of their diagnosis in PMPC, receiving information from the person and parents in Fig. 1. These tasks are corresponded to positions p_1, p_2, p_3, p_4. The performance of all educational tasks is the triggering condition for transition t_2. The parallel execution of educational tasks of determining the form and the content of education of persons with special needs (position p_7, p_8) allows you to initiate the approval procedure of learning aims (transition t_6). To initiate the agreement procedure for the components of individual educational plan (transition t_8), it is necessary to form appropriate components. The selection of components for IEP formation must occur through simultaneous interaction of all the components of individual educational plan (position p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}). To interpret the results of IEP implementation (transition t_{11}), we must simultaneously take into account academic achievement and the development of social skills of the person (positions p_{19}, p_{20}).

Transition t_4 triggering determines the form of learning based on the characteristics of the person's physiological development. In the case of education in a mass school, we are talking about the process of inclusive education, where access to quality education for children with special educational needs is implemented through the organization of their learning in schools through the use of learner-focused teaching methods, taking into account individual characteristics of the educational-cognitive activity of these children. On the basis of the developed Petri net it is convenient to model the process of inclusive education with the help of activity diagrams – an UML diagram, which shows the decomposition process of inclusive education into its component parts according to stages in the form of coordinated, sequential and parallel execution of nested educational tasks (Fig. 2).

The analysis of inclusive education based on the activity diagram allows designing functional requirements to a complex information technology that will be used for inclusive education IT-support. The analysis of functional requirements to a complex information technology have made it possible to design it and thus ensure IT-support of inclusive education.

Table 1 contains the paradigm of information technologies and indicates the status of participants in the process of inclusive education in relation to this information technology (S – the process participant is the source of data for information technology, C – the process participant is the consumer of the results of information technology).

According to Table 1, in the complex information technology of inclusive education support we shall emphasize the following main types of information technology, according to the tasks they perform:

- information storage and structuring – accumulation of identity, pedagogical, psychological, medical data and learning outcomes,

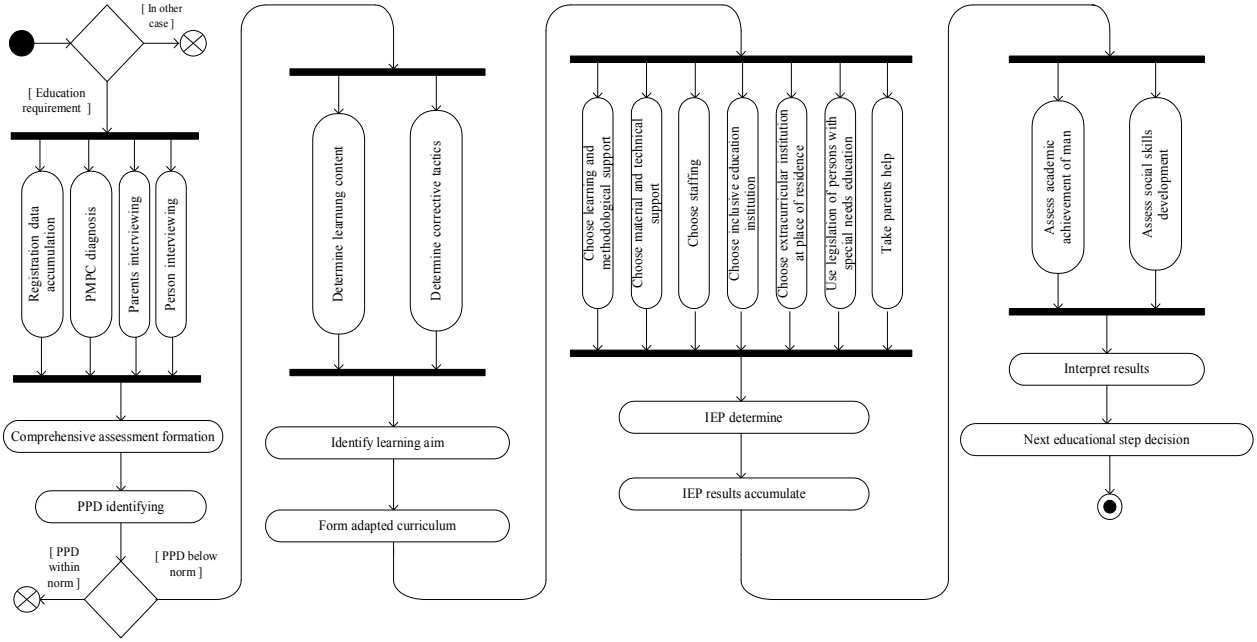

Fig. 2. Activity diagram of the inclusive education process

Table 1. Information technology support of inclusive education and the status of participants

Process participants	Information technology												
	Stage I					Stage II			Stage III		Stage IV		
	The accumulation of ID data	The accumulation of teachers' diagnostics	The accumulation of psychol. diagnostics	The accumulation of med. diagnostics	Person's PDF determination	Knowledge level assessment	Social skills assessment	Adapted curriculum	Educational network design	IEP components design	Accumulation of learning results	Knowledge level assessment	Social skills assessment
Person with PDF	S	S	S	S	C	C	C		C	C	S	C	C
PMPC doctors				S	C								
Doctors				S									
Ed. institution doctors					C			C		C	S		C
PMPC psychologist			S		C		C						
Psychologist			S										
Ed. institution psychologist			S		C		C	C		C	S		C
PMPC teachers		S			C	C	C						
Ed. institution teachers		S			C	C	C	C	C	C	S	C	
Extra-ed. institution teachers					C		C	C	C	C	S	C	
Parents	S		S	S	C	C	C		C	C	S	C	C

- data analysis – determination of special needs: personal development and social skills,
- automated knowledge control – assessment of knowledge level of the person,
- learning strategies personification – curriculum adaptation, designing individual education plan with educational needs and opportunities for a particular person taking into account the network of inclusive education institutions.

Information technology that implements information storage and structuring is used at the first and fourth stages of inclusive education. For the design of information technologies for information storage and structuring in the process of inclusive education a mathematical model of the process of subject domain formation is used [24].

The set of subject domain objects is denoted $X=\{x_1, x_2, \ldots, x_n\}$. Each object x_i, $x_i \in X$, is specified by a tuple of its properties $a_i=a(x_i)=(a_1(x_i), a_2(x_i), \ldots, a_{mi}(x_i))$ with the values $v_{ij} \in V_{ai}$, where V_{ai} are determined by the specifics of subject domain objects description. The rules for determining the properties of the set A of objects X rises to uncertainty or redundancy in the formation of subject subject domain. Each object x_i, $x_i \in X$ has the property d, $d_i \in V_d \subset D$, which is a note of its classification [25].

It is appropriate to present the informational description of the subject domain as a decision-making table:

$$T = (X, A \cup \{d\}). \quad (1)$$

The subject domain formation process model is the following:

$$M=(X, A, d, \mu(x,a), \eta(x,d), \Phi(x), \Gamma(a)), \quad (2)$$

where: $\mu(x,a)$: $X \times A \rightarrow V_a$ is a function that computes the set of attribute values in the T with the corresponding properties of the object x; V_a – set of values of the function $\mu(x,a)$; $\eta(x,d)$: $X \times d \rightarrow V_d$ – is a function that computes the attribute value of the decision d of the object x; V_d – is the set of values of the function $\mu(x,a)$ [24]. The model of the form (2) matches the set of objects X of subject area Π to its description (1).

Uncertainty in the description of the subject domain (1) can be of two types: explicit (when there is no particular attribute value) and hidden (in case of full or partial objects discernment). Redundancy can also be of two types: explicit (in the case of existence of identical objects or attributes) and hidden. Functions $\Phi(x)$ and $\Gamma(a)$ eliminate the obvious redundancy and are defined as follows: $\Phi(x):X \rightarrow X'$, where X' is a subset of objects obtained by T object removal; $\Gamma(a):A \rightarrow A'$, where A' is a subset of attributes obtained by elimination of redundant attributes from set A.

For the design of information technology for the formation of integrated assessment of a person (accumulation of identification, pedagogical, psychological, medical data) model (2) would be:

$$M_1=(X, A, d, \mu(x,a), \eta(x,d)).$$

The formation of subject domain description lies in defining a set of objects: X – persons with educational needs that were examined, A – properties of objects that are test indicators, d – results of the diagnosis. The functions $\mu(x,a)$, $\eta(x,d)$ are used to compute the values of table attributes. The process model M_1 generates the decision-making table:

$$T=(X, \{A_1, A_2, A_3, A_4\} \cup \{d_1, d_2\}),$$

where: d_1 is a set of nosology, d_2 is a set of social skills, $d_i \in V_d$.

The specificity of the inclusive education process requires splitting of a set of properties $A=\{A_1, A_2, A_3, A_4\}$ into subsets: A_1 – registration information of the person, A_2 – results of pedagogical diagnostics of the person, A_3 – results of psychological diagnostics of the person, A_4 – results of medical diagnostics of the person.

The emergence of explicite and hidden uncertainty and redundancy associated with the possible lack of certain diagnostic data [25, 26].

A comprehensive analysis of the accumulated data will be used in the next phases of inclusive education to determine psychophysical peculiarities of personality development as well as the level of their social development and progress. Identification of redundant attributes in the analysis of the decision-making table will optimize the process of conducting medical, psychological and educational testing to determine psychophysical development features.

CONCLUSIONS

The study described in this article proposes a model of inclusive education process, which, unlike the existing ones, fully embraces all its components and reflects the current national approach to this type of learning. The use of Petri nets allows formalizing the functional stages of this process and consider its specificity. The authors also suggest that scientific and methodological basis of the creation and use of software for complex information modeling and inclusive education technological support has made it possible to substantiate structural requirements to such software systems. Also the mathematical model of the subject domain formation process is the basis for developing an information technology of information storage and structuring in the process of inclusive education.

Further research will study the possibilities of using a data analysis model in the context of inclusive education, which will improve the data mining technique of integrated evaluation of persons with special needs.

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