DOI: 10.2478/jtes-2021-0018

sciendo

Journal of Teacher Education for Sustainability,
vol. 23, no. 2, pp. 77–90, 2021

Open Innovation Model of Student's Research Activities

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Abstract

The study is aimed to develop the open innovation model of student's research activities based on the adaptation of modern scientific achievements in the context of transition to sustainable development of the education system. It advances a general approach to the design of the structure and implementation of main components of hybrid intelligent system to integrating a production-frame model of knowledge and neural network algorithm for the formation of an individual learning scenario. The software implemented as a hybrid intellectual environment for organizing student's research activities is conventionally represented as a combination of blocks: a graphical user interface; technological core of hybrid learning environment, including a neural network classifier and a training data bank; a system for interaction and activation of third-party software and software and hardware. The technological basis for the individualization of the learning trajectory is the automated construction, forecasting of development and interactive correction of competence-oriented and associated models of a subject area. As a technological core, it uses a hybrid system of interaction between an artificial neural network and an expert system functioning based on a database of research projects. The presented innovation algorithm makes it possible to implement the technology of student's research activities organizing as a process of setting up the generalized constructions of complex knowledge. Further research prospects consist of the program implementation of hybrid intellectual learning environment for the development of student's research activities and its preparation for trial operation.

Key words: sustainable development, digitalization, open innovation, intelligent management, hybrid intelligent environment, research activity, neural network

Introduction

The key determinants of modern science, technology, economy, and education development are an uncertainty and variability of surrounding world generated by the influence of random factors, the dynamically changing preferences of the educational process subjects, and the instability of the competencies in demand in the labor market (Loshkareva, 2017). On the one hand, a superficial understanding of the competence approach may give the impression that the task of education is only to train competent specialists for the labor market. Such a narrow vision can lead to the dominance of anthropocentrism, mercantilism and individualism expressed by the prevalence of individualistic values in society. The consequence will be an unstable economy and a free lifestyle that allows you to meet the internal needs of the present time, and not act in accordance with social obligations. These processes will lead to catastrophic changes in the environment and will not be able to ensure a common safe future. "The Anthropocene era in the 21st century has acquired the status of an era and has already been given several designations: an era of uncertainty, an era of wicked problems, an era of unsustainable development, which is recognized by the enumeration of various crises and problems. All of these names are clearly associated with the quality of unsustainability that has manifested itself in our planetary system around the relationship between human and nature" (Salīte et al., 2020, p. 3).

On the other hand, actively implemented e-learning methods and technologies can also increase social risks, since the learning environment is designed to provide information. If it is only information about the economocentric model, then the epoch of the Anthropocene will continue to exist.

To solve these problems, the world community has begun to build a model of sustainable development of civilization, at once solving the problem of building an information society. Both of these areas of development are closely interrelated, since the model of the information society, including the model of digital transformation of education, logically fits into the model of sustainable development, strengthening its conceptual power, consistency and information technology. The transition to sustainable development implies a high degree of digitalization of both society as a whole and education in particular. Awareness of the role of the education system as one of the main components of the sustainable development strategy implies accelerating changes in the field of digitalization of education based on modern achievements of such sciences as computer science, pedagogy, synergetics and others.

The breadth and depth of the changes introduced by the education strategy for sustainable development do not allow us to limit ourselves to existing educational technologies or subject-based teaching methods. We fully support the conceptual vision of the team of authors (Salīte et al., 2019) that the time has come for a broader and deeper reassessment of the role of pedagogical science from the point of view of the theory of sustainability. The development of a new theory of learning for sustainable development, which may soon be called the digital didactics of sustainable development, is widely presented in the articles of the "Journal of Teacher Education for Sustainability. In particular, a large-scale study by Mirke et al. (2019) determines the readiness of students for e-learning under conditions of sustainable development with an emphasis on differences in socio-demographic or professional characteristics of respondents.

The study by Kapenieks (2016) is devoted to the search and improvement of the most demanded key competencies in the near and medium-term future, namely, digital literacy, literacy in the field of ICT, the formation of critical and creative thinking as an essential component of education for sustainable development. The author notes, "E-learning environment is of high importance in the study and it is designed to favor the development of creative thinking skills and institutions – the most significant aspects of learning at the same time determine efficient learning environment. Such a learning environment aims towards sustainable development, complementing awareness of learning goals, personal meaningfulness and networking to achieve the core process of the direction – action and reflection" (Kapenieks, 2016). The author has established the effective influence of the electronic learning environment on the development of sought-after competencies. The results obtained by the author are consistent with the conclusions of a large-scale study (Rekalde-Rodríguez et al., 2021), which identifies 11 key competencies necessary for sustainable development.

The nature of the educational process, according to Kapenieks and Kapenieks (2020), has changed rapidly as a result of the COVID-19 pandemic. Firstly, the demand for the formation of digital competencies and digital literacy has increased. Secondly, traditional and mixed learning formats have been completely replaced by online education, which is characterized by practicality, flexibility, mobility, accessibility, distance, convenience and efficiency. The unplanned transition to a distance learning format has become a catalyst for the creation and implementation of more effective teaching methods focused on innovative electronic tools. The method of interval e-learning proposed by the author is aimed at achieving a complex goal – "to design the MOOCs type e-learning environment for the development of the learner's personality simultaneously with the improvement of instructional acquisition of the course content, leading to the sustainability goals of learning".

Thus, a brief analysis of publications on the search for new forms of ensuring the sustainable development of education (Kapenieks, 2016, 2020; Mirke et al., 2019; Rekalde-Rodríguez et al., 2021) has established that the intensification of the development of education in the interests of sustainable development, the growth of its social effectiveness in this area should be due to the process of digitalization.

We see the solution to the problem of interaction between two global trends – education for sustainable development and the large-scale process of digitalization of the education system in the development and implementation of automated learning systems (ALS) in school practice (Ishii & Tamaki 2009; Michalski, 1987; Pear & Novak, 1996; Tikhomirov et al., 2015).

"Automated training systems is a computer ergatic system designed to optimize the learning process using information and communication technologies based on the automation of student's activity management processes" (Robert & Lavina, 2012, p. 4). Learning, as a complex dynamic intellectual process that is poorly predictable, requires the presence of fundamental intellectual basis in modern automated training systems, which allows solving unformalized and poorly structured tasks of managing cognitive activity (Agbo et al., 2019; Hwang, 2014). While integrating the functions of expert systems, fuzzy logic, artificial neural networks and genetic algorithms, intelligent learning environments make it possible to implement a hybrid approach in the symbiosis of mathematical and computer modeling of the content and hierarchies of knowledge and

procedures in interactive learning and evaluation activities (Basalin et al., 2018; Vasiljeva et al., 2020).

Today, intelligent learning systems are applied in three directions, implementing the fourth goal actively (Ensuring inclusive and fair quality education for all) of the concept of sustainable development for 2015–2030:

- as learning systems that implement step-by-step learning activities based on a typical neural network architecture that includes the following components: subject area, didactic model, student model, adaptive learning activity model, data collection and data analysis;
- to evaluate learning outcomes based on the implementation of expert systems with fuzzy logic and neural networks. The intelligent math software MATHia should be actively introduced into the educational process, as well as widely available digital intelligent programs to support individual learning: Dreambox Learning ® Math (USA), Toppr (India) and Yixue (China);
- in the role of a research learning environment based on a constructivist approach to learning in accordance with the main trends of sustainable education (Jurgena et al., 2018). Research training using automated systems has been around for a long time (educational research environments – Fraction Lab, Betty's Brain, Crystal Island), but these issues remain controversial. Critics of automated learning argue that due to the lack of clear instructions, and the fact that students must independently discover the principles of the subject area, these systems cause cognitive overload, lead to poor learning outcomes (Holmes et al., 2019).

The choice of the latter direction makes it possible to designate digitalization of the processes of self-actualization and self-realization of the individual, the development of the motivational sphere, the expansion of metacognitive experience, including the development of research activities of students, as one of the key tasks for ensuring sustainable education.

The goal of the present study is to develop the concept and technological basis for the functioning of a hybrid intellectual environment for organizing of student's research activities based on the adaptation of modern scientific achievements to school mathematics in the context of the transition to sustainable development of the education system.

The objectives of the study are as follows:

1. To justify the methodology for supporting the student's research activities, as well as the methodology for evaluating the results by using an intelligent learning system;
2. To define the structure of an intelligent learning system as an interactive triad "teacher ↔computer ↔learner", functioning on the basis of computer modeling and hybrid interface;
3. To develop and implement a software package by using: (a) neural networks; (b) expert systems and fuzzy parameter modeling; (c) rules for structuring the data of the didactic field of educational elements; (d) interaction of the intellectual system and the expert (teacher), which provides the manifestation of synergetic effects of the development of research competencies.

Conceptual Framework and Methods

The choice of pedagogical approaches and methods of using the intellectual environment of organizing research activities of schoolchildren is considered in a broader perspective in order to emphasize the relevance of education for its sustainable development. In particular, value-oriented, interdisciplinary, personal-activity, constructivist and synergetic approaches are applied. The study is based on the concept of the foundation of personal experience and visual modeling under conditions of uncertainty and stochasticity of generalized constructs of complex knowledge, as well as the theory of complex adaptive systems. "Broader perspective of the framework is considered in terms of a complex approach. Complex processes are non-linear, completely unpredictable. They cannot be solved at once; the humanity is solving them continuously through diverse activities. In the case of a complex approach, the understanding of processes is explained as the development of open, adaptive evolutionary dynamic processes that manifest themselves as fluctuations of the qualitative states which may lead to changes in the quality of the system that is related to changes in the direction of development processes" (Fedosejeva et al., 2018).

Therefore, the effect of not just development, but self-development of personality is necessary on the basis of actualization of overcoming processes (experience foundation), motivation (applications and practice-oriented activities) and understanding (visual modeling, symbiosis of mathematical and computer modeling) during the development of generalized constructs of complex knowledge (modern achievements in science).

The leading idea of the developed concept of hybrid intellectual learning environment is as follows: the key aspect of personal development in teaching mathematics is the development of complex knowledge based on the adaptation of modern achievements in science, vividly and significantly presented in applications to real life, the development of other sciences, high technologies and industries (Bershadsky et al., 2016).

The implementation of the concept involves the design of ordered, forming a single motivational and applied integrity complexes of research tasks for the development of complex knowledge and the further inclusion of students in the study of the properties and characteristics of generalized mathematical constructs. Objects of study include fractals, fuzzy sets, cellular automata, information coding and encryption tools, models of the instability of solutions of nonlinear dynamic systems, polyhedral surfaces, stochastic structures, etc. In this intelligent management model, the process of teaching mathematics is the process of organizing research activities being conducted in the use of a functional of hybrid intelligent tutoring system (ITS) that is characterized by openness to external influences and factors, the possibility of learning individualization and updating personalized feedback cognitive and evaluative processes. In the most general form, the algorithm of interaction of the student with the hybrid ITS is presented in the following stages:

- Personalized entry into a hybrid learning environment;
- Definition of personal preferences and support for the status of scientific knowledge of the student on the basis of identifying problem areas, quality development stages and levels of generalized construct scientific knowledge. However, as the classifier of the state of scientific knowledge, a feedforward neural network with the classical sigmoidal activation functions seems to be promising. Training a neural network using the error back-propagation method, in addition to the simplicity of implementation, allows a person to get an artificial intelligence system that is resistant to output data anomalies;

- Self-organization of project and research activities of students with the effect of building an individual educational and research trajectory with information support of expert systems and the use of mathematical and computer modeling methods, as well as pre-installed software tools, saving and displaying the progress achieved on the basis of fuzzy logic;
- Control and evaluation of the results of design and research activities and the state of personal growth;
- Completion of the work in a hybrid learning environment, determination of the state of scientific knowledge of the elements and target competencies, and preservation of the achieved results.

Let us focus, in more detail, on the characteristics of functional modules of hybrid ITS. In the process of designing the training system structure, we relied on the research of Russian (Dobrovolskaya, 2009; Kureichik & Bova, 2014; Ostroukh, 2015) and foreign (Agbo et al., 2019; Bonner et al., 2015; Klašnja-Milićević et al., 2017; Sinatra et al., 2020; Shute, 2012; Van der Linden, 2010; Wilson & Scott, 2017) scientists who made a significant contribution to the theory of intelligent automated learning environments. It should be noted that the advanced developments in the field of artificial intelligence, such as multi-agent dynamic systems, ontologies of evolving knowledge, systems for maintaining an individual learning environment (Bershadsky et al., 2016; Popova & Burakovsky, 2016; Rybina, 2014), etc. make it possible to build the architecture of ITS training based on the task-oriented methodology.

This methodology breaks down the task of managing non-formalized learning into an ordered sequence of subtasks: diagnostics, interpretation, planning, and design. Conceptually linking these subtasks with ontological engineering, we include the intelligent interface, the competence-oriented model of the learner (diagnostics), the domain model (content), the repository of educational objects, the adaptive learning model (planning, interpretation), and the knowledge assessment model (determining the current level of the learner's research competencies) as the basic components of hybrid ITS. The interface combines the linguistic information and software tools of interaction between the user and the expert (teacher) with the corresponding components of the hybrid learning environment and the services available in the system.

The main interface tasks are as follows: (i) user registration, storage of account information and information about activity in the system; (ii) user access to the personal environment and viewing the knowledge base; (iii) access to the content of the repository; (iv) interaction with the module for assessing the level of knowledge and competencies; (v) interaction with the module for creating individual training programs; (vi) storage (attendance statistics, task completion success).

The flexible overlay network model of the student is competence-oriented, based on the results of diagnostics of such qualimetric characteristics as personal qualities (scientific thinking, scientific activity, scientific communication technological readiness, creative independence, self-organization of educational research, self-esteem), initial and target competencies, and individual learning style (the preferred way of presenting, processing and memorizing information). Diagnostics are carried out by means of psychodiagnostic web tests generated based on applying a genetic algorithm to a specific section of mathematics, as a result of which "problem areas" in the knowledge and skills of the student and their current competencies are identified. Note that the model of the student's growth is dynamic: in the process of moving along an individual educational route, it is

updated with new data on the current state of the student's interaction with the learning environment, on the mistakes made by them, and adjusted learning goals, among others. Based on this information, a forecast of academic performance is built, and educational resources are personalized.

The multilevel model of the subject area is formed by the allocation of didactic units (modules), which are structured, semantically complete fragments of mathematical content. Each module is represented by several levels of meaningful interpretation, differing in the degree of detail and the form of presentation of the material. Based on the idea of learning as the space of states, we understand the event of a transition of the system from one state to another, followed by the output terminal indivisible, logically complete fragment of the studied material (definition, theorem, algorithm description). Each event in the domain model corresponds to a certain production rule that determines the conditions for the activation of this event, as well as a fragment (frame) of the studied material presented at various levels of meaningful interpretation. The aggregation of hierarchical structures of training frames is carried out by the sub-system for the formation of individual trajectories for each student, which provides them with the opportunity to work with training objects within the planned sequence.

The repository of educational objects provides the formation, storage and the possibility of using educational objects of various levels of complexity and nature. The adaptive learning model includes a set of learner's models, a set of learning strategies (plans) and learning effects, as well as the function of selecting (generating) learning strategies. Using long-term knowledge of frame-production model and operational data on the current state of learning process, the conceptual analyzer (the "intellectual core" of the system) predicts the achievability of target competencies and generates an individual learning scenario from a variety of training actions that ensures their successful achievement. Such an algorithm for the functioning of an adaptive learning model allows one to build the multiple educational trajectories, each being an optimal sequence of learning elements for the student with the possibility of successfully overcoming the "problem areas".

Results

The results of the study consist in the development of an intellectual environment for the organization of research activities of schoolchildren on the basis of its digitalization in close connection with the strategy of transition to sustainable development of education and the formation of an information society.

A software-implemented hybrid intellectual environment for organizing student's research activities can be conventionally represented as a combination of two large visual blocks: a proprietary graphical user interface that hides the technological core of hybrid learning environment, and a system for interacting and calling third-party pre-installed software and hardware (Figure 1). The technological core is a hybrid system of interaction between an artificial neural network and an expert system that operates based on research projects database, including text comments and explanations, formula and tabular data, static and dynamic graphics, microfilms, presentations, with a database of generalized scientific constructs as the final goal of user training.

Figure 2 shows in more detail the structure and features of neural network components functioning as a hybrid system, creating a permanent, secure and sustainable infrastructure.

Figure 1

The Conceptual Structure of Hybrid Intelligent Research Environment

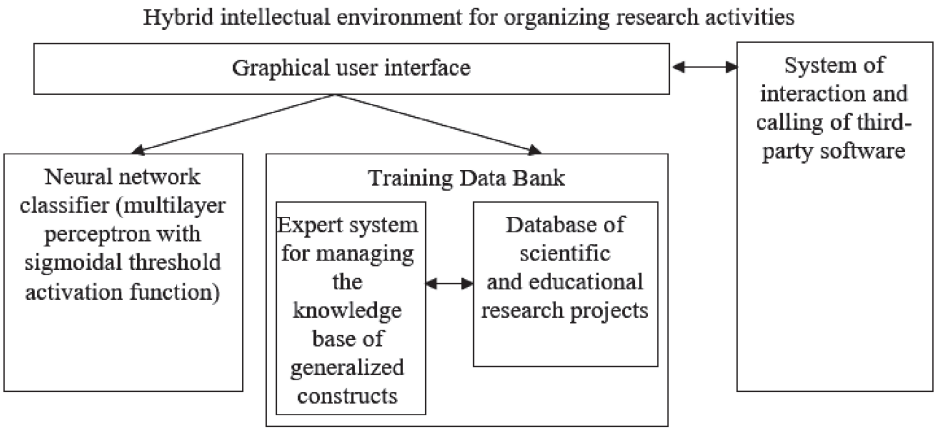
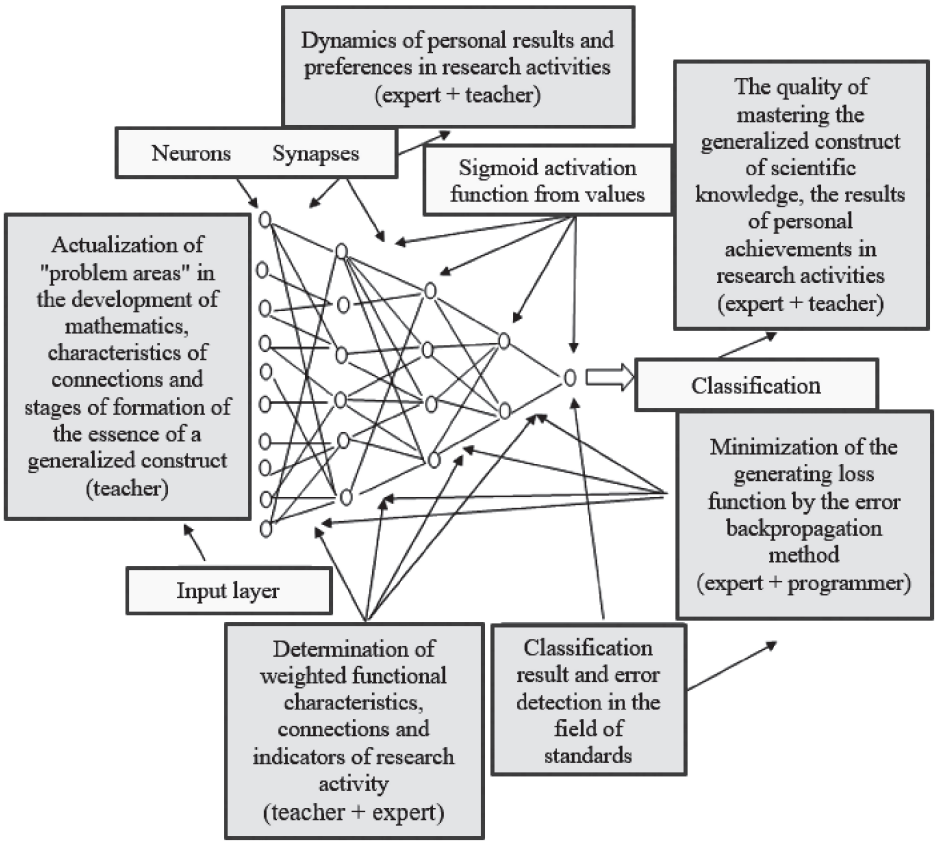


Figure 2

Logical Scheme of Neural Network Components Functioning as a Hybrid Intelligent System for Organizing Student's Research Activities

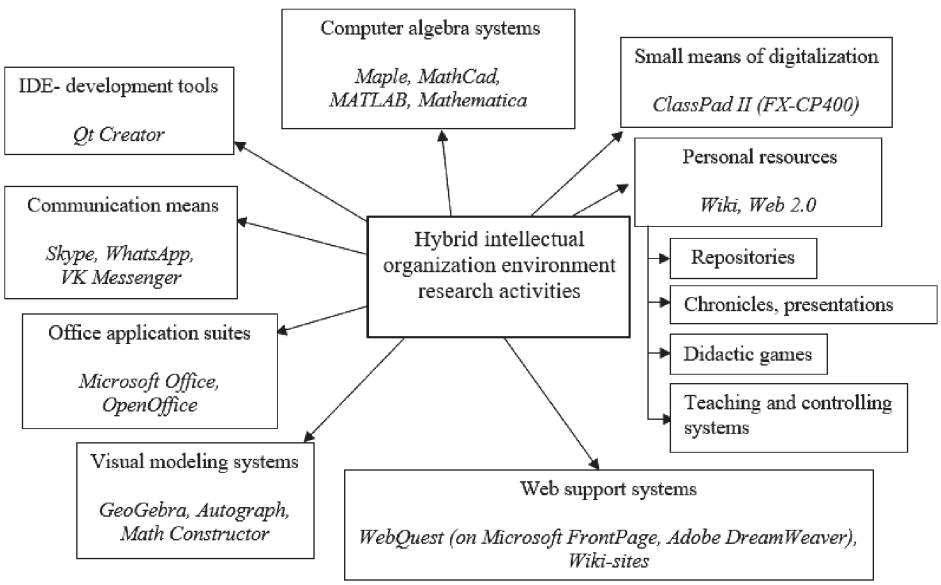


As can be seen, the basis for the construction of ITS is the dynamic random selection of parameters on the layers of an artificial neural network using an expert system. It uses a direct-action neural network with backward error propagation and fuzzy modeling of the rules for fuzzification of input variables, including on hidden layers, in the process of recognizing the results of complex didactic field of educational element mastering (knowledge, skills, mathematical methods, algorithms, and procedures). The value of an activation function by generalized Gaussian function or the sigmoidal function is determined.

The system of interaction and calling of third-party software determines the place of hybrid learning environment in the structure of modern software and software-technical EdTech solutions applicable in student's research activities (Figure 3). The hybrid learning system acts as a link between individual training products, software packages and software-technical complexes, allowing them to be effectively integrated into the student's research activities in order to optimize the computational load on the hardware of the user's computer. The system of interaction and calling of third-party software facilitates flexibility, transparency and universality of the research environment, and acts as a means of communication interaction between students and teachers, including due to the extensibility and updating of the training module.

Figure 3

The System Functionality for Interaction and Calling Third-Party Software

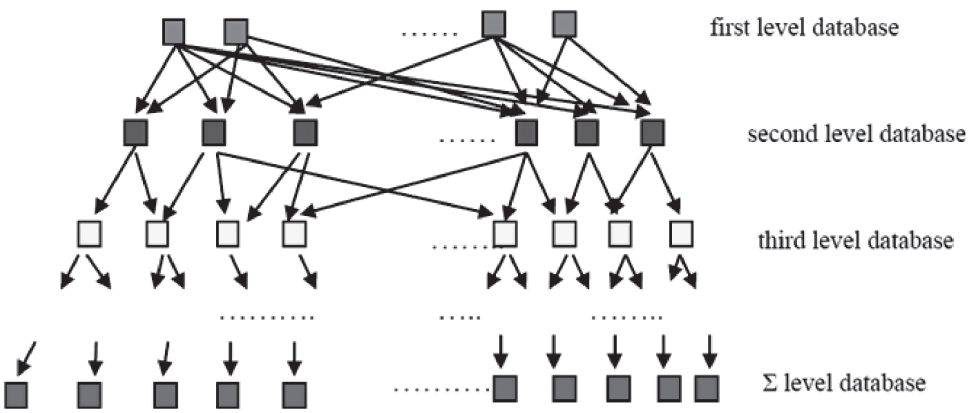


The functioning model of hybrid intelligent learning system with an extensible database is formally represented as a hierarchical tree, which is based on a database of educational and research projects differentiated by three complexity levels of generalized mathematical construct elements (Figure 4). Each variation of generalized construct is the end of subtask tree arranged in logical chains, equipped with instructions, an information block and a bibliographic list.

At each next level of the tree, experts form a database of logical continuation of the study by particular block of knowledge in accordance with such factors as the degree of scientific knowledge, the state of the student's perception and preferences, and the success of mastering research competencies. Thus, an individual educational trajectory is formed for the sustainable personal development of the student. Examples of constructing the foundation chains of student's research activity content in the form of multi-stage mathematical tasks that actualize the essence of complex knowledge as one of generalized constructs (for example, fractal geometry) are considered by the authors in (Smirnov, 2020).

Figure 4

Hierarchical Tree of Research Task Chains



Discussion

The results of the study make a significant contribution to the theory and practice of the use of digital technologies for sustainable education (Fedosejeva et al., 2018; Jurgena et al., 2018) and for the creation of intelligent learning environments in the context of sustainable development (Agbo, 2019; Cheng et al., 2016; Sinatra et al., 2020). The study links the direction of possible use of intelligent systems in education with the improvement of quality of student's research activities and teachers' innovative practices based on artificial intelligence. This direction of the introduction of applications and algorithms of artificial intelligence to the field of education was determined by the search for possible extensions and modernization of existing models of intelligent learning (Klašnja-Milićević et al., 2017; Kureichik & Bova, 2014). Research learning environments are an alternative to step-by-step automated learning. In scientific research, one can find a lot of criticism towards this direction due to the lack of explicit instructions, the fact that students must discover the principles of subject area themselves, which can cause cognitive overload and can lead to poor learning outcomes (Holmes et al., 2019). In our opinion, the use of neural network algorithms for automatic control of research activities, the establishment of feedback and the choice of alternative approaches provides the effective support for students during training. In this case, a hybrid intelligent system is built with dynamic random selection of fuzzy rule sets and their characteristics on the layers of an artificial neural network using expert systems and fuzzy modeling. Feedback

aims to enhance the student's affective states to move them from nominally negative affective states (such as frustration or boredom) to nominally positive affective states (which are generally considered more conducive to learning). Such a conceptual solution has not previously been considered in the practice of digital education with the support of artificial intelligence.

One of the principal findings of the conceptual model presented by the authors is that the structural-logical, hierarchical, functional and fractal schemes of didactic field structuring of educational elements are updated by means of visual modeling, determination of local attractors with incomplete information and attraction of basic information. Equipping the didactic field of educational elements with a system of multi-level hierarchical databases of exercises, motivational-applied research, practice-oriented tasks using the expert systems and the integration of mathematical information, natural science and humanities knowledge and procedures would provide the student with the necessary information and cognitive support.

Conclusion

The priority role of the formation of education for sustainable development will require its more accelerated and large-scale development than is currently happening, and this acceleration is possible due to a closer connection with digitalization. The study focuses on the development of technology for self-organization of student's research activities by means of intellectual management. Students aim at identifying the potential of neural networks for solving problems of modeling the generalized structures of complex knowledge in order to master the modern sections of mathematics. To organize research activities, the technology has been developed based on the hybrid intelligent system, mathematical modeling methods and computer design tools. The projected version of hybrid intelligent learning environment is based on a fuzzy model of knowledge representation; it is flexible, providing the user with wide opportunities in terms of creating an individual learning scenario. Tasks for the future studies are the software implementation of hybrid intellectual learning environment for the development of student's research activities and its preparation for trial operation; detailing the algorithm of interaction between the intellectual system and the expert (teacher); development of an algorithms and characteristics of technical and software support to perform procedures for building hierarchies of knowledge and procedures, assessing the level of subject mastery and meta-subject competencies in a computer simulated environment.

Acknowledgments

The research was founded by RFFI Project No. 19-29-14009.

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