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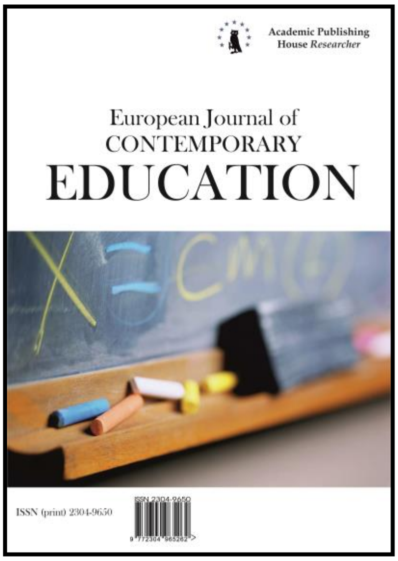

Preparing Engineers of the Future: the Development of Environmental Thinking as a Universal Competency in Teaching Robotics

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Abstract

The problem of the research is urgent due to the need to develop a special style of thinking. This type is based on problem cognitive activity, focused on lean production, resource conservation, and supported by an automated system that provides resources for solving socio-economic problems in the conditions of the fourth industrial revolution and the digital economy formation.

The purpose of the research is to theoretically prove and experimentally verify the need to change methods, tools, organizational forms of teaching robotics for the purposeful development of environmental thinking and lean manufacturing as the demanded competencies of future specialists in the context of digital transformation.

The research methodology is the analysis of psychological and pedagogical work, development strategies, concepts of education; methods of mathematical statistics, methods of psychodiagnostics and survey. The pedagogical experiment is based on the example of assessing the ecological thinking formation and the energy conservation skill in teaching robotics to train engineering, technical and management specialists.

The research results. The study clarifies the concepts "environmental thinking", "lean production", and "environmental competence" in the context of training specialists for the digital economy, in particular, engineering and technology. The study substantiates the didactic potential of a robotics course for the formation of environmental thinking as a demanded skill of future engineers. The authors describe didactic principles, a model for teaching robotics in a personalized environment for the formation of environmental thinking as the basis for the introduction of innovations and the challenges of automation, globalization and competitiveness.

The authors conclude that a robotics course with specially organized interdisciplinary design forms of activity supported by appropriate means and training methods is necessary. It will create

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additional conditions for the formation of environmental thinking and lean production skills as key professional competencies in the training of demanded specialists in the digital economy.

Keywords: environmental thinking, robotics, energy conservation, lean production, training, professions of the future, digital economy.

1. Introduction

1.1. The relevance of the problem

Technological development in the field of information technology, support of using new digital services in various types of activities is an actual direction of modern science and education (Karakozov, Ryzhova, 2019). The aim of the global digital transformation of the didactic system is to efficiently and flexibly apply the latest technologies in order to transit to a personality-oriented, continuous and non-linear educational process. The digital era requires not only new skills from school and university graduates, but we also need a different approach to organizing the training for the professions of the future (Varshavskaya, Kotyrlo, 2019).

Therefore, famous Russian and foreign researchers (Beliovskaya, Beliovsky, 2016; Asmolov, 2015; Margolis, 2018; Saritas, 2013) justify the need to change the content, methods and organizational forms of educational work. The didactic process in the era of automation and globalization must be focused on solving the problems of socio-economic development of the country in the conditions of the fourth industrial revolution.

According to S.D. Karakozov, N.I. Ryzhova (Karakozov, Ryzhova, 2019), the basis of the digital economy is the synthesis of previously existing material production (new materials, computer design/production) and digital technologies, which support the widespread use of artificial intelligence models and the development of the Internet of things. According to E.A. Aslamova, M.V. Krivov, V.S. Aslamova (Aslamova et al., 2018), K.K. Denschikov, A.Yu. Varaksin (Denshchikov, Varaksin, 2019), “smart products” will be usual in a world where intelligent computerized devices (robots) get the opportunity to interact in the preparation and deployment of automated production processes.

The new industrial or technological (digital) revolution (Perelet, 2019) has special demands to the highly qualified specialists of the future. E.Ya. Varshavskaya, E.S. Kotyrlo (Varshavskaya, Kotyrlo, 2019) reasonably conclude that a high level of mathematical literacy, science and humanitarian training will be necessary.

Y. Kuzminov, P. Sorokin, I. Froumin (Kuzminov et al., 2019) focus on the abilities that are called “competences of the 21st century”. They are fundamental theoretical knowledge, technology competencies (creativity, communication, self-organization, initiative, critical thinking, etc.).

E.V. Soboleva, N.L. Karavaev, N.V. Shalaginova, M.S. Perevozchikova (Soboleva et al., 2018) specify that the main task in the digital educational space is to prepare an independent personality through the formation of different types of thinking, including environmental one. Environmental thinking in the new conditions of digital transformation is understood as long-term thinking and here a person always thinks about ecology. There is a practical need to organize activities for the development of environmental thinking among future professionals in order to integrate sustainable development goals into real projects and implement them in science and industry (Tocháček et al., 2016)

Digital transformation of the manufacturing sector is already underway. However, while implementing technological innovations there are problems due to insufficient training of engineering, technical and managerial personnel because of an ecological culture formation, concern for the protection of the natural environment, a responsible attitude to nature, and ecological thinking.

1.2. The objectives and tasks of the research

The objective of the research is due to the need to change the cognitive activity of students in the course of robotics in order to develop environmental thinking and skills of lean production as key competencies of the demanded specialists in the era of global digital transformation.

Tasks of the research are:

–to clarify the terms “environmental thinking” and “lean production” while preparing engineers of the future in teaching robotics to achieve the goals of the country's scientific and strategic development;

–to describe didactic principles of using means and tools of robotics in a personalized environment while forming ecological culture, protecting the natural environment, having responsible attitude to nature, ecological thinking;

–to formulate basic ideas of the approach which reflect the necessary changes in the methods, techniques, organizational forms of teaching robotics for the purposeful formation of environmental thinking as the basis for the introduction of innovations and the implementation of trends in automation, globalization and competitiveness;

–to introduce a personalized model of teaching robotics, focused on the development of a special "green" style of thinking, to support lean production, security, resource conservation and solving problems of a socio-economic nature;

–to experimentally confirm the effectiveness of the proposed changes in order to improve the quality of training, the formation of environmental thinking and lean production skills, taking into account the challenges of the digital economy.

2. Relevance

2.1. Literature review

2.1.1. Russian literature review

The tools of the new industrial, or technological (digital) revolution, influence all aspects of society. However, the most powerful acceleration of scientific and technological progress has pressure on the interaction "man-man", "man-nature", which leads to the ecosystem and the environment changes. The sharpest contradictions between the technological sphere and the natural environment have led to the threat of a global environmental crisis. To form special, ecological, human style of thinking is of great importance in order to find a balance between the challenges of the digital economy and maintaining the integrity of the biosphere, between the needs of the high-tech industry and of the natural environment.

The term "ecological thinking" was actively used as a scientific term in the 80s of the XX century. The reason for its spread in the socio-economic sphere is due to the formation of environmental information space in Soviet society and to the activation of the environmental aspect of social practice. Therefore, a new goal of the education system is the development of environmental thinking (Turdikulov, 1982; Hromov, 1988). The works of E.A. Turdikulov were significant as he was the first to propose the task of "developing ecological thinking" along with the task of forming environmental knowledge. These ideas were developed by S. S. Khromov, who introduced the concept of "ecological type of thinking, justified the need for targeted pedagogical support for the transfer of environmental knowledge and skills. Later, Russian scientists L.Yu. Chuikova (Chuikova, 2012), V.P. Kalenskaya (Kalenskaya, 1999), I.S. Telegin (Telegina, 2000), V.A. Ermolaeva (Ermolaeva, 2002), L.M. Dautmerzaeva (Dautmerzaeva, 2003) dealt with the problem of environmental thinking formation. Let us underline some of their ideas, which we are taking into account in this research.

I.S. Telegina (Telegina, 2000) believes that environmental thinking should not be considered as a new form, it is "a direction of thinking, a level peculiar to it". V.P. Kalenskaya (1999) notes that environmental thinking is thinking, characterized by its "creative character".

L.Yu Chuikova (Chuikova, 2012) presents in details a generalization of Russian studies on the problem of determining the social type of thinking and environmental thinking as its separate branch, distinguishes the concepts "environmental consciousness", "ecological worldview", "ecological culture" and proves the importance of environmental education in modern society. We support the author's position, who considers that the "environmental competence" has some important characteristics. They are: the quality of mental operations aimed to solve situations and problems in the field of ecology and energy; the consistency of getting environmental knowledge; the understanding the integral, systematic and process character of the surrounding world; the ability to predict the final result; the ability to put forward hypotheses and choose the most acceptable option; the ability to establish causal relations.

The last thesis was developed in modern studies by S.I. Gilmanshina, R.N. Sagitova, I.R. Gilmanshin (Gilmanshina et al., 2018), who considered the features of science education. In particular, the authors underline the need for a systematic development of scientific ecological thinking in the structure of environmental competence. They distinguish educational, motivational and behavioral criteria for the formation of ecological thinking and use a system-activity approach, which involves a research focus and the creative interdisciplinary nature of students' project activities. They also underline the importance of taking into account age-related characteristics, individual styles of cognition in the planning of environmental education.

The provisions of the “Development Strategy for the Information Technology Industry in the Russian Federation for 2014–2020 and for the Prospect until 2025” are the basis for the development of the digital economy as a new concept in the national policy that take into account global trends in globalization and automation. Analyzing the environmental aspects of the digital economy, R.A. Perelet states that achieving strategic priorities is impossible without maintaining a balance between the technosphere and the sociosphere (Perelet, 2019). However, during the transformation of the country's economy, special attention should be paid to the strengthening of the environmental component when training specialists using digital technologies in manufacturing.

According to the Atlas of Future Professions (Cross-professional competences), which registers the main cross-professional competencies demanded by society, government and business for the specialists of the future, it becomes obvious that environmental thinking and the lean production skill are included in the training program for most training profiles. The formation of relevant skills is especially important in the training of engineering, technical and managerial specialists of the future.

Modern industrial production is impossible to imagine without automation of processes in the field of ecology and energy, the use of cyberphysical devices and intelligent systems. In this regard, studies on the potential of the robotics course in terms of training engineers of the future are relevant (Ershov, 2011; Filippov, 2016; Filippov, 2013). Moreover, innovative educators propose projects for the formation of environmental thinking in robotics. For example, D.G. Koposov (Koposov, 2017) presents the project “Franz Josef Land” with the task to create a model of a robot utilizing space debris. N.A. Beliovsky and L.G. Beliovskaya (Beliovskaya, Beliovsky, 2016), in the Ecology block, presents the following environmental project as an example: to design a drone robot to monitor the environmental situation and take samples.

So, robotics has the tools and means to effectively change the situation in terms of reducing the environmental and energy load on the environment. Robotics allows to form a careful attitude to the surrounding nature and man, the ability to apply it in cognitive, communicative, social practice and professional orientation through familiarity with the structure of living organisms in order to create robotic devices. However, all the presented scientific and methodological solutions and approaches are implemented according to traditional didactics, where the teacher plays the leading role in teaching. A. Ponomarev, I. Dezhina (Ponomarev, Dezhina, 2016) state the need to change the content, organizational forms, methods and means of training in the context of the priorities of the digital school. They offer a model for determining the scientific and technological priorities of Russia and consider possible tools and directions for their application.

Among the possible approaches and technologies how to take into account the requirements of global digital transformation, including the orientation of the educational space on personalization, many of the innovative teachers underline a mixed form of training (Karakozov et al., 2018; Soboleva, 2019).

2.1.2. Foreign literature review

Many foreign researchers such as P. White (White, 2009), S. Otto, G. Florian (Otto, Kasier, 2014), P.W. Schultz (Schultz et al., 2004), E.V. O’Sullivan, M.M. Taylor (O’Sullivan, Taylor, 2004), M. Morris (Morris, 2002), U. Beck (Beck, 1999) and others have dealt with environmental thinking. In particular, P. White (White, 2009) notes that the term “environmental awareness” appeared as a new scientific term in the 1970s. Other scientists (E.V. O'Sullivan, M.M. Taylor (O'Sullivan, Taylor, 2004), M. Morris (Morris, 2002), U. Beck (Beck, 1999)) have introduced synonyms of this term: environmental sensitivity, environmental concern. However, most studies understand it as “interchangeable with the ecological self, the ideal state of being, and self-realization” (P.White (White, 2009), S. Otto, G. Florian (Otto, Kasier, 2014), P.W. Schultz (Schultz et al., 2004)).

P. White has formulated the approach, proposing to consider environmental consciousness as an eco-centric moral norm, orienting a person to inner wealth and environmental rights, the value of humanity as part of "nature". P. White separately singles out “the desire for self-realization, oriented towards meaningful communication with nonhuman others" as "one of the peculiarities of ecological consciousness".

The position of P.W. Schultz (Schultz et al., 2004) is also interesting in the context of the study. He uses the concept of environmental consciousness to fix psychological factors due to the predisposition of cognitive subjects to participate in "pro-ecological behaviors".

I. Tilikidou, Y. Zotos (Tilikidou, Zotos, 1999) formulate the provisions of the concept of environmental consciousness. It describes various conditions and characteristics of ecologically-conscious behavior of a member of society (ecologically-conscious consumer behavior). Here scientists emphasize that environmental thinking has 3 components: cognitive, affective and behavioral.

S. Otto, F.G. Kaiser (Otto, Kasier, 2014) point out the relationship of information about the state of the environment and ecological inclusion of a person. It proves the importance of the cognitive component of ecological thinking in human behavior.

Modern researchers, dealing with environmental education issues, actively study the environmental attitudes of students. For example, M.A. Haşıloğlu, P.U. Keleş, S. Aydın (Haşıloğlu et al., 2011) have analyzed the behavior of students in educational institutions on behavioral and mental aspects and clarified attitudes in several variables. They have introduced a scale of indicators characterizing environmental thinking and environmental behavior. The key conclusion of the scientists was that with the age students were losing orientation towards respect for the environment.

S. Laso Salvador, M. Ruiz Pastrana, J. Marbán Prieto (Laso Salvador et al., 2019) in their studies note that the development of environmental thinking is a priority goal for sustainable human development, an important component of environmental education policy. For the assessment of environmental knowledge, the formation of environmental competence, they propose considering four characteristics: cognitive, conative, affective and active. Their results prove that the quality of environmental knowledge improves after active metacognitive involvement in activities. Thus, they confirm that creative research work and the implementation of projects contribute to the formation of environmental thinking.

As for high-quality engineering training of specialists in demand, we can note works of A.R. Carberry and A.F. McKenna (Carberry, McKenna, 2014). They also point out the importance of project activities in modeling. Crawford R. (Crawford, 2014), D. Tocháček, Lapeš J., V. Fuglík (Tocháček et al., 2016) emphasize that the robotics course has powerful tools for active cognitive activity in the development and management of robots using specific tools.

R. Evangelista, P. Guerrieri, V. Meliciani (Evangelista et al., 2014), Rappitsch, Christoph (Rappitsch, 2015), analyzing changes in society, highlighting the features of digital transformation, underline that "the digital economy is part of the economy, based directly on computer technology." According to Rappitsch, Christoph (Rappitsch, 2015), a significant result is the identification of the environmental aspects of the digital economy and the directions of strategic development: energy, food, health, housing, finance, vehicles.

Thus, the modern model of the digital economy makes people think strategically and focus on the future. New standards and ethics of behavior appear, they give great opportunities for professional activity. Environmental thinking must be seen as an important universal skill that should be taught through problematic creative activity. In the context of digital transformation, such activities should be supported by digital technologies and automated high-tech systems. In addition, training must be focused on the preparing such environmental specialists who can think outside the box in the uncertain future and work in a team.

All of the above-mentioned facts have determined the significance of the research.

3. Materials and methods

3.1. Theoretical and empirical methods

Theoretical methods are the analysis of psychological, pedagogical, scientific and technical literature on the determination of the concepts "green thinking" and "environmental thinking". It is a special style of thinking, with the potential to maintain a stable balance between the challenges of the digital economy and preserve the integrity of the biosphere, between the needs of high-tech industry and the needs of the natural environment.

According to expert reports, development strategies, concepts of education, the Atlas of Future Professions (Cross-professional competences), the "lean production", "environmental thinking" are the demanded professional competencies of engineering and technical specialists of the future. The study of the didactic potential of educational robotics in terms of the formation of a "green style of thinking" was carried out by analyzing specific developments of teachers, interdisciplinary projects for the creation of cyberphysical devices for resource conservation and environmental protection.

When studying the practice of including research interdisciplinary design projects in the digital educational environment, we used practical methods to describe, characterize and analyze the methods, means, forms of organization and control. Systematization and generalization of ideas and patterns, principles of didactics in teaching made it possible to formulate a system of principles for personalized education.

A special group includes empirical methods (observation, analysis of the results of students' research projects) in order to obtain relevant information about the formation of the required personality traits and the lean production skill. Statistical differences in the levels of environmental thinking and the lean production skill were evaluated using the Pearson's chi-square test.

3.2. The base of the research

A pedagogical experiment evaluated the effectiveness of focused cognitive activity of students. It was organized in a personalized educational environment of robotics and included creative interdisciplinary research projects in order to improve the quality of education. Challenges of the digital economy and the requirements of high-tech industrial production for engineers of the future were taken into account. The experiment involved 148 students (5-7 grades) of schools in Kirov and the Kirov region. The consent of subject teachers and parents of students was obtained. If one of the classes in city schools was included in the experimental group, the second class from the parallel (where the subject was taught by the same teacher) was included in the control group. If a rural school had only one class in parallel, then the control group was the corresponding class from another school in the same district. Thus, the control group was 73 students, and the experimental one was 75 students. The experiment was in specially equipped computer science classes, using the same software.

3.3. Stages of the research

The research had three stages.

The first stage was a stating experiment. We investigated the state of didactic problems of the development of environmental thinking as an important skill for obtaining a demanded profession in a modern digital society. Here, we evaluated the potential of the robotics course in terms of formation lean production skills, resource conservation, and maintaining a balance between the challenges of the digital economy and environmental issues.

The second stage was devoted to the development of didactic principles, the description of a robotics education model in a personalized environment for training engineering and managerial specialists of the future for the formation of environmental thinking as the basis for introducing innovations and responding to the challenges of automation, globalization and competitiveness.

The third stage of the study included the experimental teaching and improvement of the basic ideas of the approach in relation to the identified requirements of the digital economy and the formation of key professional competencies. Teaching was accompanied by constant monitoring of the results of students' research projects, which allowed to consistently improve the proposed methodological ideas. Results of the study were discussed in journals and at conferences at various levels.

4. Results

4.1. Clarifying the basic concepts

In the present study, we consider the concept "ecological thinking" as a way of thinking, feeling and the actions, which are characterized by belief in the interconnection of all energy, space, geological, biological and social processes; understanding the inextricable integrity of nature and society; high status of environmental values, especially life; overcoming anthropocentrism and selfishness in relation to nature; a sense of personal responsibility for the future of humanity and nature.

We suggest considering the structure of environmental thinking through the integration of the cognitive, prognostic, practice-transforming and motivation-value components. The criteria for the formation of ecological thinking include the following personality traits: knowledge in the field of environmental science, eco-social ingenuity, development of critical thinking, formation of awareness of the relationships between nature, society and personality.

The key idea of the environmental thinking development is the problematic nature of education aimed to form environmental awareness. Moreover, the corresponding cognitive activity should include the solution of educational and practice-oriented tasks, involving several options for resolution. Such multivariance should take into account various priorities and norms of society.

Environmental competence of a specialist demanded by the digital economy is his ability to observe culture and harmony in communication with nature, to understand global environmental ties, and to apply appropriate ethical standards while performing professional activities. The latter fact is especially relevant for the training of specialists in the profession of the future in the field of energy and ecology (designer of energy storage, hydrologist, designer of accessible environment, etc.).

Lean production in the broad sense should be considered as management of the production process, based on a constant desire to eliminate all types of losses. It means involving each employee in the process of optimizing the business and maximizing customer orientation. In industrial production and mechanical engineering, lean production involves a careful attitude to the environment and people, the ability to apply appropriate skills in cognitive, communicative, social practice and vocational guidance through familiarity with the structure of living organisms in order to create high-tech devices.

Literature review makes it possible to reasonably conclude that robotics has a powerful didactic potential in terms of the formation of a "green thinking style". Moreover, the educational activity in robotics allows to form this thinking, respect for nature and humans, and it also develops the ability to apply it in cognitive, communicative, social practice and professional orientation through acquaintance with the structure of living organisms in order to create robotic devices.

The study of the fundamental theoretical foundations of the ecosphere is very important in the formation of environmental competence. Therefore, special requirements in the study of robotics should be presented both to the general concept of environmental management, and to the knowledge system in its applied fields. It is especially important to comply with these requirements at the stage of introducing relevant knowledge and skills into practice and transformation activities. The skill of lean production is formed in the classroom of a robotics course during a focused search for the most effective way to solve the problem. For example, solving the task to follow the line, it is necessary to pay attention to the most accurate passage of the route (to minimize deviations from a given trajectory) and at the same time maximize the speed of the device; and to the most accurate movement of the robot, including measuring distance and rotation angles. This problem can be solved only as a result of effective interaction of all team members, as it also implies the possibility of changing the design of the machine, for example, by using a multiplexer, which requires changes to the program.

Particular attention in robotics should also be given to energy conservation. It is recommended each time to draw the attention of students to such moments as the efficient use of battery energy: the ability to turn off the control unit in time, use the engine braking mode (requires more power consumption) only if necessary, increase the speed by using a multiplexer, and not increasing the motor power, sound use of sound signals, etc.

Thus, "green" thinking, focused on solving environmental problems, should include the following components: mental operations aimed to solve problems in the field of ecology and energy; environmental knowledge and understanding of the integrity, systematic and processual environment; ability to predict the final result; the ability to put forward hypotheses and choose the most acceptable one; the ability to establish causal relationships.

The practical application of the listed types of cognitive activities focused on the formation of environmental thinking and lean production skills as demanded professional competencies in accordance with the features of the Atlas of Future Professions (Cross-professional competences) will make it possible to change the pedagogical principles applied to programs in the field of robotics and mechatronics (the base of traditional education):

– the systematic principle implemented through the structure of the program at each level of studying robotics, through the logic of each specific lesson. In the program for each level of studying robotics, the selection of topics should provide an integrated system of knowledge in the field of cyberphysical systems, including knowledge from foundations of ecology, mechanics, physics and computer science;

– the humanistic orientation of the pedagogical process: programs for each level of study of robotics should be developed taking into account the requirements of maintaining a balance between the digital and the green economy; priority areas of development in the field of technology and the needs of nature, society; the need for self-determination and socialization of the individual;

– the relations of the pedagogical process with life and practice: training at each level of the study of robotics should be implemented in such a way that the process of developing controlled models is preceded by a mandatory (necessary for life in a modern digital society) thinking process. During an interdisciplinary practice-oriented activity, the student masters such intellectual skills as structuring, planning, optimal interaction with the environment, forecasting results (foresight thinking), information retrieval, classification, building inferences, etc..;

– students' consciousness and activity: implies creative problematic activity, when the perception of theoretical fundamental knowledge in ecology is activated, they are comprehended, independently processed and applied;

– holding strength: achieved by repeated (specially methodically organized through a system of techniques and methods) targeted repetition and training to minimize risk to the environment and all users;

– visibility: allows to take into account all individual psychological styles of cognition in the training of engineering and managerial specialists;

– personality education and support for socialization: the assimilation and translation of own norms, rules of behavior in society go along with increasing the motivation-value component, the development of environmental skills, mental and moral qualities in the training of robots, model management;

– the principle of an individual approach to education: it is realized both through building a system of tasks and at the level of individual personal communication between the teacher and the student, at the level of trilateral interaction "teacher – student – robot", at the level of "human-robot-nature".

For the successful implementation of the proposed principles in the formation of environmental thinking in the course of robotics, it is necessary to have a set of organizational and pedagogical conditions. They include: building an educational process based on personalized education technology; the implementation of interdisciplinary research tasks of a problematic nature with environmental content; actualization of the needs of students in obtaining a demanded profession of the future for successful socialization through the practice of competitive activity, teamwork.

Thus, we have obtained the following theoretical results that are significant for the study: described education objectives, i.e. requirements that the state, society and business have to professionals of the future; defined the necessary principles of training which should be taken into account in the course of studying robotics for the formation of environmental thinking.

4.2. The model of training robotics which supports the formation of environmental thinking and takes into account the requirements of the future economy

We present a model for organizing a robotics course taking into account the orientation of modern education towards its nonlinear continuous personalized nature. As a didactic technology we chose mixed training, in particular the organizational form "flipped classroom". The choice of this form is due to the fact that it allows to combine full participation of the teacher with online learning and involves elements of students' independent control of the trajectory, time, place and pace of learning (Soboleva, 2019).

The organization of the "flipped classroom" model is characterized by a change in the sequence of classical cognitive activities — theoretical material and organization of homework. It suggests that the student independently studies the theory before the lesson. The teacher thinks and includes the possibilities of using the acquired knowledge and skills (completing the task system, interactive tests, project, discussion and other types of educational and cognitive activities).

Let us describe the basic ideas of the methodological approach using the example of studying the line-following algorithm. The expected results are specified in terms of the formation of environmental thinking and lean production skills.

Input conditions for the model (necessary knowledge): color sensor; color sensor operation modes; the ability to design a robot based on a robotic designer without using an assembly scheme; the ability to control the movement of the robot in a software environment, including virtual; the ability to connect a light sensor and read the values of the light sensor; knowledge of basic algorithmic constructions and the ability to use algorithmic constructions of following, conditions and repetitions in a software environment; the ability to download and run the robot control program in the main robot controller.

To reflect the meaningful content of the model, the following stages of the lesson can be distinguished: independent work at home, actualization, experimental research, work in conditions of uncertainty (problem solving), summing up and reflection.

By the stage "independent work at home", the teacher prepares the theoretical material necessary and sufficient for the students to effectively master the lesson. At the stage "actualization", the teacher formulates the topic of the lesson, and determines the purpose and objectives of the lesson together with the students. The general formulation of the problem: in the shortest time, the robot, following the black line, must get from the starting point to the finish, it must not lose the line for more than N seconds.

Then it is necessary to organize a discussion of the practical significance of the problem. Here, the teacher draws an analogy between the route of the robot and roads and organizes a discussion of the construction of roads, focusing the students' attention on the need to minimize the harmful effects on nature and the environment (the formation of environmental thinking).

Further, the teacher offers students to complete a practical task using a computer. At the next stage, the teacher offer students to conduct an independent experimental research, controls the process of assembly, programming and debugging of the robot. Students design a robot, load prepared and adjusted programs into it, debug algorithms for a given path. The most important part of the experiment is to find the optimal combination of the robot design and the program that controls its work. It is necessary to set the motion parameters of the robot in the algorithm so that the robot can not lose the line and can not go off the track, and on the other hand he must pass the track at the highest speed.

When organizing work in conditions of uncertainty, the teacher suggests checking the operability of the developed devices in completely new conditions. Having returned to the general statement of the problem, the teacher can change the usual conditions for the functioning of the robot, check, and, if necessary, correct the behavior of the robot.

At the stage of summing up, the teacher's activity repeats the general formulation of the problem, the main idea of the algorithm for solving it and organizes the discussion of possible ways of applying the studied algorithm in everyday life. The teacher supports the students' initiative, directs the course of their creative search, distributes the children into small groups and determines the task for a creative interdisciplinary project implemented in subsequent classes.

Let us describe the organizational and methodological component of the practice of the "flipped classroom" in terms of the formation of environmental thinking. The example is studying the line movement algorithm using a single color sensor for a robot assembled on the basis of the Lego MindStorms EV3 designer. This algorithm is the slowest, but the simplest and most stable.

Students are invited to watch the video prepared by the teacher and write down the general statement of the problem. Then they study the robot as a system: determine inputs and outputs, comply a diagram of its hierarchical structure. An example of a chain of questions for practice-transforming activities focused on the formation of environmental thinking and the lean production skill:

— Draw the trajectory of the robot along the black line. Describe this trajectory.

— What happens if the algorithm interchanges the actions when the condition is met and not fulfilled?

— What does the robot do if it loses the line?

— Choose the optimal motion parameters of the robot. Draw it.

To test themselves, students can be offered to complete interactive tasks prepared by the teacher, for example, with the tools of the LearningApps service. Expected results of the formation of environmental competence (model output) are:

– ability to analyze a robot as a system;

– ability to determine the possible ways of using the robot in everyday life (including resource saving), to develop ways to modify the device with a view to its use in a certain area of environmental protection;

– ability to find a common solution (when working in pairs) while research an environmental problem;

– experience in analyzing the efficiency and energy efficiency standards of the developed device to solve the problem;

– experience in finding growth points in professional activities when searching for new ways to use the developed device to ensure environmental protection;

– experience in resolving conflicts on the basis of coordinating positions and taking into account interests, formulating, arguing, and defending one's opinion;

– experience in predicting possible ways to change the conditions of the problem, the input conditions of the system;

– experience in determining ways of efficient use of energy, ways of energy conservation.

After studying the necessary theoretical material, students were offered interdisciplinary research projects.

- "Development of a drawing robot". The project goal is to develop an automated device capable of driving across a field by drawing N segments using a fixed marker.
- "Development of a watering robot". The project goal is to develop an automated device capable of automatic watering of a given area. Create a device that allows the robot not only to control the irrigation process, but also to adjust the irrigation zone.

The specification of the topic does not occur on the teacher's initiative, which is characteristic of the traditional education system, but is determined by students, taking into account their individual characteristics and interests. 2-4 students take part in the project. It is important to record the progress of the project, for example, in the form of an engineering book containing a fairly detailed description of the stages of work, including a description of the requirements for resource conservation and environmental protection, design and program of an automated device. The development of an engineering book allows to make the project preparation process more scientific, systematic and practice-oriented.

Let us reveal in detail the contents of one of the projects to develop an algorithm for modeling the behavior of a cyberphysical device during cargo transportation, depending on the type, properties and characteristics of the material. At the beginning of the study, three main problems were formulated: how to use a vehicle with one set of tools to solve new and atypical problems; determination of types, properties and characteristics of materials using various types of technical means; making decisions and performing a set of actions depending on the determination of the type, properties and characteristics of the material.

The analysis of the subject area allowed to formulate three main tasks for finding a practical solution – loading a vehicle, unloading a vehicle and finding the optimal trajectory of irrigation. An additional task is handling critical situations. Each task led to the practical minimization of costs. Problem solving can be used both jointly (the activity of a cyber-physical device in real conditions), and independently (finding the optimal load before sending the vehicle for loading).

An experimental model of the conveyor robot was assembled on the basis of Lego MindStorms EV3 robotic designers and additional Lego Education WeDo parts. The movement of the conveyor robot is carried out according to the algorithm of following the black line using two color sensors in the reflected light mode. Loading and unloading algorithms are based on cargo identification. To solve the logistic problem, the program algorithm uses the function of cargo delivery in the order optimal for a practical industrial problem. Correction of the irrigation zone is carried out by controlling the movement of the motor left-right and can vary within the range from 1 to 15 cm. The intensity of irrigation depends on the speed of the robot.

In practical conditions and taking into account the possible dimensions of a real robot, you should pay attention to safety precautions and handle critical cases that are possible in the conditions of production and transportation.

1. Commands are given to the robot by pressing buttons on the control unit. Therefore, it is necessary to put protection on accidentally pressed buttons, confirm actions by double-clicking and cancel actions.

2. The movement of the robot across the territory will occur along a pre-marked line, that is, fully automated. In order to avoid injuries associated with the unexpected appearance of obstacles on the line of movement, it is necessary to use an infrared sensor in the “Approach” mode, which respond to an obstacle on the track.

3. When a power outage occurs, that is, when two color sensors recognize black, the robot must make an emergency stop and wait for a command to the control unit.

Taking into account these situations, using the robot in real conditions is safer. Students reflect all stages in the engineering book.

Thus, the presented personalized model for teaching robotics provides pedagogical support for the formation of environmental thinking in the framework of interdisciplinary research activities of students as future specialists capable of making a breakthrough in modern science and technology.

4.3. Experimental evaluation

4.3.1. The ascertaining stage of the experiment

At the first stage of the experiment, the students were given a control task to work with information, with the model in accordance with the demanded resource-saving and energy-saving skills. Thus, it was possible to collect experimental data on 148 students of various educational institutions: 70 respondents in the first half of the academic year of 2018, and 78 students in the second half. The reason for this selection is explained by the structure of curricula in various educational institutions, where the corresponding module for the development of research projects is prescribed. Since, as a result of the preliminary control evaluation, almost the same initial level of students – participants in the pedagogical experiment was revealed, we can consider them as a general sample of 148 students. Thus, the experimental (75 students) and control (73 students) groups were formed. The experimental group had 65 % of girls and 35 % of boys.

4.3.2. The forming stage of the experiment

Classes for students in the control group were conducted according to the traditional methodology of teaching robotics, without special organization of cognitive activity to solve environmental problems and resource conservation. They were active and independent in the research, which was organized in the form of practical work on the design, performing tasks on specific topics. The training of schoolchildren from the experimental group was carried out using the “flipped classroom” technology and included project activities to develop creative interdisciplinary projects with environmental content.

In order to evaluate the effectiveness of the proposed approach, at the end of the educational process, students were offered the test. The test involved the implementation of an interdisciplinary project focused on lean production and supported by an automated high-tech system.

To determine the level of environmental thinking and the lean production skill, we used the criteria “very low”, “low”, “average”, “high”, “very high”. As it was previously noted, we actually assessed the formation of the conscious component of environmental thinking; environmental literacy (knowledge of fundamental environmental laws, the ability to take these laws into account, forecasting probabilistic events). We determined levels according to the methods of generalization; disclosure of essential features of concepts and their relationships; practical and intellectual actions of the child, directly related to the content of mastered concepts, knowledge and ideas; the ability to make assumptions and choose the most optimal option; the ability to express new innovative ideas.

Levels of environmental thinking:

1. "Very high" level: the ability to whole, causal, probabilistic analysis of environmental situations; independence of hypotheses, the choice of the most optimal option, the ability to accurately predict the final result; the desire to disseminate environmental knowledge and

participate in environmental practices; the ability to express attitude to nature through models, information systems.

2. "High" level: the transfer of individual knowledge to general; comparison on a substantial basis with the definition of two or three reasons, lack of knowledge of terminology, classification according to one or two essential features. Cognitive motivation for solving engineering problems is sustainable. The student offers his own hypotheses, but they do not quite correspond to the modeling conditions; predicts the result of the robot activity, records it in the form of a flowchart; suggests one or two non-standard ideas of model behavior.

3. “Average” level: the ability to answer the question, but with additional help. The students offers more than one traditional idea in modeling behavior or structure, compares an insignificant basis on 2-3 grounds, he is emotionally responsive. He can classify on 1 basis: insignificant features, does not take into account the knowledge of terminology; can simulate a software solution to perform engineering tasks only with the assistance of others; tries to predict the behavior of a model or structure.

4. "Low" level: the allocation of one reason, a comparison of one non-essential attribute. Classification is performed inconsistently, according to an inessential attribute of a model of behavior or structure. The students operates with specific individual knowledge of the environment. The emotional attitude to nature is ambiguous. The hypotheses are put forward with difficulty, using the method of "trial and error", asks for the help of a teacher to model the system.

5. “Very low” level: he cannot abstract, predict, put forward hypotheses, classify, does not have a comparison in the course of cognitive modeling, has a lack of positive emotions towards nature. There is no understanding of how the constructed model will affect energy saving, environmental protection.

To diagnose the input conditions in the model of the pedagogical experiment, we conducted a survey consisting of a series of tasks. Examples of tasks for the input survey:

1. It is known that one discarded battery infects 20 sq. m. of land or 400 l. of water. In 2013, 565 million batteries were sold in Russia. Develop an information model that allows to calculate how many sq. m. of land and how many liters of water would have been contaminated with these batteries if everyone who bought it threw it into the street.

2. Indicate the type of interaction that is most effectively formed in environmental education. Options are: "man – society – nature"; "man – technology – society"; "man – man – society".

3. All batteries have graphite. Pencils are made of graphite. Determine if the statement “all batteries are pencils” is true or false.

4. The company engaged in the processing of packages Tetra Pak, produces "eco handles", clips for bags, corners for furniture, funnels. Currently, 100,000 packages have already been processed. One eco-friendly pen in a recycled cardboard envelope symbolizes the second life of one completely redesigned Tetra Pak bag. 85 thousand pens were sold. Develop an information model that allows to calculate how many bags were processed into clips, furniture corners and funnels.

The survey results were evaluated on a five-point scale in accordance with the criteria described above. The “excellent” mark corresponded to the levels “high” and “very high”, “good” for the “average”, “satisfactory” for “low level”. In all other cases, the mark was “unsatisfactory”. A qualitative change in levels in accordance with the results of an independent research project focused on the development of environmental thinking is shown in the diagram (percentage) in Figure 1.

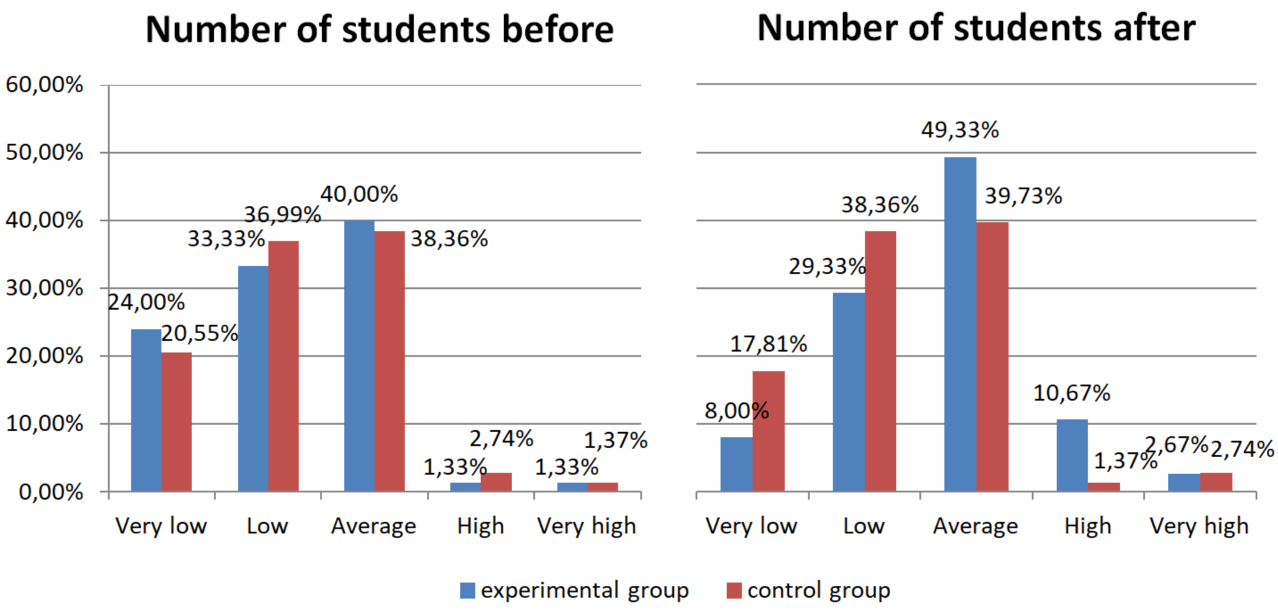

Fig. 1. Test results

Table 1 shows the results of the test before the experiment

Table 1. The results of the test before the experiment

Groups	Mark				
	5	**4**	**3**	**2**	
The experimental group	2	25	30	18	75
The control group	3	28	27	15	73
	5	53	57	33	148

Table 2 shows the results of an interdisciplinary project aimed at energy conservation and environmental protection, information security, means and technological solutions of a robotics course after the experiment.

Table 2. The results of the test after the experiment

Groups	Mark				
	5	**4**	**3**	**2**	
The experimental group	10	37	22	6	75
The control group	3	29	28	13	73
	13	66	50	19	148

Performing a quantitative analysis of the results, we can conclude that after the experiment, 62 % of the students of the experimental group had a high level of the demanded resource-saving skills and energy-saving skills for future specialists (marks 4 and 5), while initially this percentage was 36 %. It means a qualitative improvement of students' outcomes. At the same time, the level of skills in the control group also increased, but not so significantly: after the experiment only 44 % of the students showed good results (compared to 42 % before the experiment). The remaining 56 % had medium and low level of environmental culture.

4.3. 3. The control stage of the experiment

Let us accept the following hypotheses: the level of environmental thinking and lean production skills corresponding to cross-professional competencies of future engineers studying in the experimental group is statistically equal to the level of environmental thinking and lean production skills of students in the control group. Hypothesis H1: the level of environmental thinking and lean production skills, corresponding to cross-professional competencies of future engineers studying in an experimental group is higher than the level of students in the control group.

We calculate the value of the statistic of the criterion before ($\chi2_{набл.1}$) and after ($\chi2_{набл.2}$) the experiment, using the online resource http://medstatistic.ru/calculators/calchit.html. A significance level is $\alpha = 0{,}05$. In this case $c = 4$, which means that the number of degrees of freedom is $\nu = c - 1 = 3$. According to the distribution tables χ^2 for $\nu = 3$ and $\alpha = 0{,}05$, the critical value of the statistic is 7,82. Thus, we obtain: $\chi2_{набл.1} < \chi2_{крит}$ (0,88 < 7,82), a $\chi2_{набл.2} > \chi2_{крит}$ (8,13 > 7,82). According to the decision rule, this means that the hypothesis H_0 is true before the experiment, and the hypothesis H_1 is true after the experiment.

5. Discussion

Thus, the experimental assessment confirms the qualitative difference in the level of skills of caring for the environment and man, the ability to use environmental consciousness in cognitive, communicative, social practice and professional orientation through familiarity with the structure of living organisms in order to create robotic devices.

Students of the experimental group significantly increased the level of the demanded skills. For solving future professional tasks in the implementation of innovations is very important that the concretization of the content of each interdisciplinary project does not mean the teacher's initiative, which is characteristic of the traditional training system, but is determined by the students. When programming, propaedeutics of working with technical documentation was also carried out.

On the other hand, during the experiment, we had to solve didactic and methodological problems: the manifestation of interdisciplinary knowledge and creativity in the formulation of the project themes; the study of specialized literature on the problems of the ecosphere; the need for a lot of teacher's preparatory work for video clips, interactive resources; insufficient level of language training when working with foreign sources of information; large time and labor costs for the technical execution of the project results.

6. Conclusion

The results of the study prove that the new challenges and requirements of society, state, and business to the education system underline the need for the purposeful formation of environmental thinking as a demanded competence of the specialists of the future.

The study clarifies the basic concepts necessary for the implementation of robotics training in a personalized environment while preparing engineers of the future, the principles of environmental education. Analysis of the cognitive performance of students shows that the proposed model allows to qualitatively change teaching methods and means, increase the level of environmental skills, prepare students to master a high-tech profession for the digital economy.

The effectiveness of the proposed approach is confirmed by a pedagogical experiment, during which the result of cognitive activity was evaluated according to a set of criteria that correspond to the essence of the competencies of future professions and the priorities of the digital economy.

The results obtained can be used:

– to solve environmental problems caused by the introduction of high-tech production and the need to maintain a stable balance between the technosphere and the ecosphere;

– within the framework of an ongoing model for teaching robotics to prepare highly qualified professionals in the professions of the future;

– to ensure the personalization of the educational trajectory due to specially organized areas of support for creative, intersectoral, cognitive research activities of students at all levels of robotics studies, focused on their intellectual development (systemic, environmental and foresight thinking), and carried out in the conditions of training future specialists, capable of making an innovative breakthrough in modern science and technology;

– for a qualitative change of participants' interaction in the educational process and the environment, for the formation of environmental competence corresponding to the level of human information culture, determined by the conditions of life in a robotic society.

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