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Educational Robotics as an Inovative Educational Technology

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Abstract

The problem of introducing the educational robotics into practical work of Russian secondary schools has been analyzed. Preferential development of technical creativity of students in robotics is pointed out in additional education system. The practice of introducing robotics into the academic process is still at the initial stage of its development and is not always efficient. In this study, educational robotics is considered as an element of polytechnic orientation of the academic process. The possibility of its use as a special educational technology in classes on subjects of science and math cycle is substantiated. Three areas of professional work of the teacher are distinguished in the structure of the technology: robotics as an object of study, as a tool of cognition and as a means of teaching, development and upbringing of students. The paper reveals the activity of the teacher in each direction. The results of teaching experience of the authors related to the application of this technology in teaching physics are presented.

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1. Introduction

Innovative transformation of modern technical environment and update of technical activities of society have to be reflected in the content of school education. Teaching should focus on forming the knowledge, abilities and competencies enabling the younger generation to be successfully integrated into the modern socio-technical systems, to efficiently maintain and develop the scientific and technological potential of the society. The content of polytechnic education in this regard should include sections concerning areas of technical innovation. One of such areas is robotics.

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Robotics has been operating in the world education system for over 15 years. The activity of Russian schoolchildren in robotic creativity has significantly increased only in the last 6-7 years. The experience of class organization on robotics for students is reflected in published works of teachers and pedagogues of additional education, resource specialists, and engineers involved in popularizing this area of technical knowledge. Educational robotics is considered as a means of forming the engineering thinking in schoolchildren, developing their interest in technical creativity, focusing on opting for the engineering professions and working specialities. However, study materials designed for robotics classes are focused mainly on the support of additional education of children.

Restriction of robotics classes by the sphere of extracurricular activities is not conducive to a complete solution of polytechnic education problems. This approach does not match the growing change in modern technical environment due to the rapid development of robotics. Robots have already become an integral part of it. Production is developing and mass introduction of robotic systems is carried out into various spheres of social practice (industry, military science, science and culture, service and life). A new robotic infrastructure is formed, resulting in global socio-cultural transformation (Paraskevov & Levchenko, 2014). People will cease to do anything that is dangerous for their health handing over to robots all services people perform less efficiently, as well as the work that they just do not want to deal with (Nof, 1989). The change will have a large-scale character comparable to the scientific and technological revolution that determined the beginning of the information era. The next to IT-competency level of development of technical human culture will be in demand that is determined by conditions of human life in robotic technical environment (Ospennikova, 2003).

Graduates of modern school have to be prepared to life activity in this environment. In connection to this, new and quite complex educational objectives must be set to secondary school: 1) updating the content of polytechnic education of students, taking into account such areas as robotics technology innovation; 2) targeted training of future consumers of robotic environment services; 3) introduction to preparation of future robotic systems manufacturers (*research engineers, design engineers, planning engineers*).

Knowledge of the basics of robotics has to become a basic element of youth education and enter the content of secondary school curriculum. The appropriate decisions have already been taken at the state level in several countries of the world community. So, the objectives of schoolchildren (or even pre-school children) preparation in the sphere of computer science and robotics, formation of their readiness to perform a variety of technical projects are priority objectives in the education systems of the US and UK (Fizicheskie issledovaniya s Vernier i LEGO Mindstorms NXT: laboratornye zanyatiya po nauke i tekhnologiyam, proektirovaniyu i matematike s ispol'zovaniem datchikov Vernier, 2009).

The Russian education system mainly develops contest and competition robotics, themed events are held which are attended only by students – enthusiasts of technical creativity (Vyazovov, Kalyagina & Slezin, 2014; Kashirin & Fedorova, 2013; Filippov, 2013). Nowadays it is only in some schools in some regions of Russia that the courses in educational robotics are included in the educational program. As a rule, such courses are optional or elective ones.

The "Complex program of educational robotics development and continuous IT-education in the Russian Federation" (2014-2020) was launched in 2014. One of the areas of the program is related to systematization and generalization of the experience of teaching robotics. The objective of forming a unified conception of introducing the educational robotics into the academic process of secondary school has been set. It has become apparent that sustainable educational results in this field of engineering education of students can only be ensured by its inclusion in the system of basic education.

Directions and methods of teaching robotics in secondary school are currently not defined quite well. This is a new direction of polytechnic education theory and methodology. Its development should take into account the specific character of robotic systems as both new and significant in the scale of technical environment objects distribution, opportunities of various areas of subject knowledge in their study, as well as particularities of school education at various levels and profiles.

2. Objectives, methodology and research design

The objectives of this research are development and testing with students during exploratory work of a *systemic approach* to studying the robotics at subject classes. Within the framework of this approach, robotics was seen as an element of polytechnic orientation of the academic process. The analysis and generalization of the first domestic developments (Beliovskaya, 2013; Koposov, 2014; Halamov, 2011 etc.), published works of a number of foreign researchers (Bers, Ponte, Juelich, Viera & Schenker, 2002; Carberry & Hynes, 2007; Korherr, 2014) as well as the results of exploratory pedagogical experiment conducted by the authors of this article allow us to consider robotics as a special teaching technology(Ospennikova, Iljin, Ershov & Ospennikov, 2014). We have identified three components of this technology structure. Robotics can be presented in the academic process on the subject: 1) as an object of study, 2) as a tool of cognition, 3) as a means of teaching, development and upbringing of students.

The proposed in this study approach to robotics introduction into the academic process was tested in the practice work of secondary schools of the city of Perm (Russia). Schoolchildren of 7-9 grades were taught (186 members). Experimental work was carried out with students for three years. The training was organized within one school subject (physics). Interdisciplinary communications of physics, mathematics, computer science and technology courses were carried out during the training. Working with the students was systematic and covered three components of training technology: robots as an object of study, robots as a tool of cognition and robots as a means of teaching, development and upbringing of students.

The educational modules that include sets of teaching and study materials were developed and tested during the exploratory pedagogical experiment. The materials are: 1) for the study of physical foundations of robot element base; 2) for setting demonstration of robot experiment; 3) for demonstration of robotic models of technical objects; 4) for conducting robotic laboratory works of different levels of complexity; 5) for organization of students' project work on robotics. Each training module includes: photo and video materials, control software for robotic demonstrations and laboratory works. The content of all module elements is closely connected with the training program on the subject and is aimed at mastery thereof. Robotics in each module is presented as an area of technical applications of physical science foundations.

3. Discussion of the research outcomes

During the preparations for pedagogical experiment methodical bases of this technology were designed as a three-component system. Let us consider the content of the teaching methods.

2.1. Robot as an object of study

For the positioning of robot as the object of knowledge in the academic process it was necessary to first develop a program of study. The key principles of selecting the material for the program became *availability* of its mastering by the students and *providing the integrity* of formation of students' ideas of robotics as a modern technical environment object. The educational program included the following issues: 1) information on the history of robotics and its development prospects, the place and role of robotic systems in modern technical environment; 2) foundations of philosophy and methodology of robotics (general, special): the term "robot"; features of robot as a technical object; types of robots; laws of robotics; cybernetic model of robot; main approaches to the design of robotic systems, including computer and field modeling; 3) modern solutions and technologies in the field of designing and programming robots: providing physical manipulation of robot and of such its properties as a "sense of touch", "sense of smell", "sense of sight", "hearing sense", "speech", "memory", "nervous system", artificial intelligence; design of group robots (distributed robotic systems) and use of different communication means in order to organize their interactions; modeling and software of humanoid robots behavior.

Further in the study, parts of the curriculum to be the object of study within individual subjects of the curriculum were identified. It was necessary to clarify the possible levels of depth and completeness of mastering by schoolchildren the robotics basics in subject courses. The solution of these research problems in its present stage was associated with organization of academic process in physics. The basis of the solution is analysis of the cybernetic model of robot, physical principles of operation of its element basis, as well as opportunities of school physics course in their study.

Robot from the standpoint of management theory consists of three main systems: *control system* (microcontrollers, microprocessors, computers and additional hardware), *runtime system* (drives, intermediate transmissions, working bodies) and *data collection system* for providing feedback (sensors of different types and kinds). Each system is implemented using its own components. The bulk of phenomena and laws ensuring the work of the basis is studied in the framework of natural science and mathematical cycle subjects. This allows quite successfully illustrating the technical applications of science through creation and operation of a variety of robotic systems.

Our study analyzed the composition and operation of main devices implementing the work of each system of the robot cybernetic model. As a result, for physics teachers, tables were compiled showing the main physical phenomena and laws and principles on the basis of which the operation of these devices can be revealed. The relevant topics of physics course were determined in which these devices can be studied as examples of technical applications of science.

In each system of robot cybernetic model a number of "lines" of study can be singled out. Here are some examples of individual lines: 1) *control system* → hardware → central unit → microprocessor → ... etc.; 2) *runtime system* → drives → electric drives → stepping, vibration, etc.; 3) *data collection system* for providing feedback → parametric sensors → temperature sensors → thermistor, pyrometer, acoustic sensor, and others. It should be noted that the system of robot cybernetic model may have in some cases very long "lines" of implementation levels (see e.g. the control system). The branched chain of element base "lines" of robot cybernetic model forms a kind of "root" robot system and provides all its functionality. Physical basis of this system is the subject of study in physics classes.

An insight into the "depth" of scientific basis of robotics is determined by the degree of readiness of students to these activities. According to the principle of availability in organizing the experimental teaching, the level approach to studying robots as complex cybernetic and technical objects was carried out. Four levels of study can be usually distinguished in each "line" of robot element base (see. the above examples of study "lines" of robot cybernetic model). When designing robot the first, second and third levels correspond to making of common design decisions associated with selection and combination of mostly finished units of its future structure. The fourth level is related to understanding the scientific basis of robotic systems functioning and algorithms of its work. This is already the "fine" element structure of robot, the choice and quality of which influence the accuracy and efficiency of robot executing the necessary functions. At this level, a design engineer, planning engineer and software engineer can change the basic elements of robots and create its new components.

During the exploratory pedagogical experiment students learned the physical basis of robot operation used in various spheres of society, as well as robotic systems of training physical experiment. The subject of analysis were physical principles of robotic systems, created on the basis of educational robotics kits. Two main methods were used in teaching: *explanatory and illustrative* one – demonstration of various types of robots, followed by analysis of scientific bases of their functioning; *project* method – studying physical bases of robot functioning during the work of its creation conducted by schoolchildren.

2.2. Robot as a tool of cognition

Robots as cognitive tools are already very widely used in scientific and technical research. In scientific cognition robots are used in conducting various experiments. In scientific and technical study, they are in demand for studying other technical objects (detection, condition diagnostics, etc.). Scientific and technical research can be carried out with the purpose of modeling and creation of fundamentally new robots or upgrading the existing ones, and the search for the most efficient modes of their operation.

The above variants of applications of robotics as a cognition tool were implemented in experimental teaching of schoolchildren. Let us briefly examine their content.

Robotic experiment. In many areas of research, such experiments are no longer a rarity (astronautics, microcosm studies, archeology, underwater exploration, and others). Higher-quality course of study, wide range and high accuracy of data logging are the features of robotic experiment.

The inclusion of full-value robotic experiment into the academic process on the subject is of utmost importance. Not only automatic data logging and processing, but also automatic control of the course of experiment should be provided. Such robot must perform necessary mechanical manipulation and adjust to the desired operating mode, for example, regulate the temperature of researched objects, "bypass" resonant frequencies, correct the parameters of electrical circuit etc. The presence of electronics in the robot control system hardware in combination with high-speed computers and advanced software allows achieving high speed of its response to a variety of external and internal effects. If necessary, the robotic system can in real time transmit the acquired data to the computer for their operational processing (via a USB cable, Wi-Fi, Bluetooth), or send signals directly to the experimenter. A feature of the robotic experiment is the ease of its repetition.

The inclusion of robotic experiments (demonstration, laboratory ones) in the process of physics teaching is aimed at introducing the students to new technology research, improving their academic and research competencies and special competencies in solving technical problems. During the pedagogical experiment more than 20 robotic demonstration and laboratory physical experiments were developed and used in the training of schoolchildren (on mechanics, thermal and electrical phenomena, technical applications of atomic and nuclear physics).

Modelling of robots and their systems. Modeling is one of the important methods of cognition of the world. With the help of models we can quite successfully study properties and functionality of real technical objects. In carrying out pedagogical experiment, the tasks of modeling different types of robotic systems were set before schoolchildren (as part of individual and team projects). The objects of modeling were robotic settings for study physical experiments, as well as technical devices for other purposes. It is important in the modeling process to provide a variety of features and functions of robot. It is necessary to model the movements of robot and its properties such as "sense of touch", "sense of sight", "hearing sense". There is the possibility of modeling "speech", "memory", "nervous system", elements of artificial "intelligence". Subsequently, the students performed assembly and testing of the created models in their various combinations in a single robotic design, and interaction of this structure with the external environment was studied. Full-scale and computer modeling are distinguished. When teaching students (just like in the real scientific and technical research), technologies of full-scale and virtual modeling of robots, as a rule, have to be implemented jointly. A variety of designer kits in educational robotics are created and used for *full-scale modeling*. In Russia, the most popular line of robotic kits is Lego (Lego education WeDo, Lego MINDSTORMS EV3, Tetrix). Kits by Huna are also known and used in the school practice (Fun & Bot, Kicky, Class, Top, Human-robot, etc.) Methods of *computer modeling* at the present stage of development of robotics gain particular importance. Modeling of designs and functionality of robots in a virtual environment enables engineers to find the most efficient conceptual and design solutions. Using special software, not only modeling of robot constructions is implemented, but also the development of their complete digital dummies. In connection to this, certain requirements are imposed on the software environments for development of modern robots: 1) opportunity to create a virtual model of robot similar to its real physical model; 2) opportunity to model virtually the behavior of robot in an environment similar to the real physical world; 3) three-dimensional visualization model of robot and its behavior in a virtual environment; 4) opportunity to use programs written for a virtual model of robot for a real similar robot. Attempts to create similar environments also for the system of secondary education are made. Their development is an urgent problem of educational robotics. Today the opportunities of computer modeling of robots by secondary school students are still significantly limited. Within the exploratory pedagogical experiment, students were engaged in a variety of robotic objects modeling in the study of physics course. In Figures 1 and 2 two robotic systems for physical experiment are shown created by students for studying the mechanical phenomena: 1) free fall of bodies, 2) mechanical vibrations of a load suspended on a spring. In the first experiment (Figure 1, a) we study the particularities of free fall as a kind of mechanical motion.

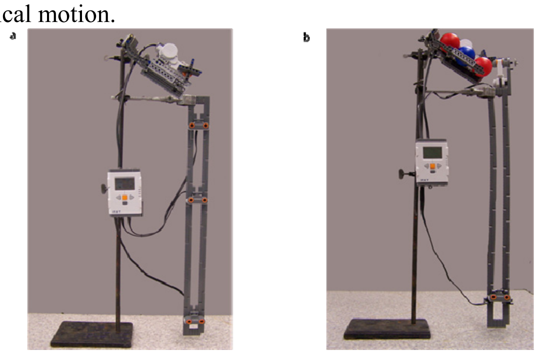

Fig. 1. The model of the robotic setting for studying the phenomenon of free fall:
(a) with three stationary sensors; (b) with one movable sensor.

The following data are output on the screen of microprocessor: 1) values *N* of free fall acceleration of the identical balls and average acceleration value; 2) time of the balls covering the distances related in length as a sequence of odd numbers – 1:3:5 (for proving the constant acceleration of the free fall of bodies). During the experiment the weight and shape of the falling body can be changed. Designing such an installation requires from the students the understanding of physical phenomenon and methods of its experimental studies, update of knowledge and abilities in computer science and technology.

After the creation of the first version of this robotic experiment (Figure 1, a), the students may be given tasks for further elaboration of the robot design. The objective of the first task is to ensure automatic delivery of the falling balls into the discharge device. The second task may be associated with replacement of three stationary sensors with one movable sensor in the experimental installation (Figure 1, b).

Figure 2 (a) shows another installation designed by students. It is designed for studying the dependence of the cycle of oscillation of spring pendulum on its weight and stiffness of the spring. The experiment was done in two phases. The mechanisms are launched in sequence that changes the weight of the pendulum due to larger quantity of weights in the suspension and higher rigidity of the spring which is achieved by reducing the length of its working section. The system is unbalanced and free vibrations are stopped automatically. The values of the oscillation periods of the pendulum appear on the screen of microprocessor. A graphical presentation of the results of the experiment is available (Figure 2, b). After the creation of the installation for studying the patterns of free oscillation of the pendulum the students were given a new task: to create a robotic experiment model for demonstrating the phenomenon of mechanical resonance.

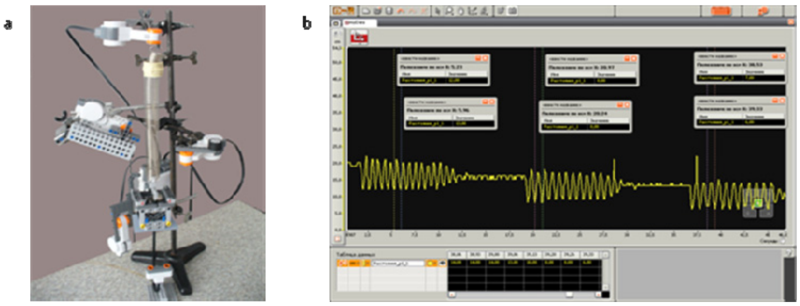

Fig. 2. The study of free oscillation of the spring pendulum: (a) model of the robotic installation,
(b) graphic processing of the results of the experiment.

So, the second component of the proposed teaching technology (*robot as a tool of cognition*) was presented in the pedagogical experiment by means of demonstration to the students of the robotic experimental installations and other robotic technical objects as tools of scientific, scientific and technical research, as well as the independent modeling and creation of the various kinds of full-scale and virtual models of robots.

2.3. Robot as a means of teaching, development and upbringing

In the course of this study the most significant educational functions of robotics were identified. Knowledge and distinction of these functions by a practicing teacher is crucial, since it promotes his focused efforts on implementing them in the learning process in a certain subject.

Educational function. Studying the robotics the students explore a new and socially important layer of modern technical culture: they acquire current polytechnic knowledge and abilities, master the relevant technical and technological competencies.

Robotics classes facilitate the consolidation and advancing of subject knowledge, formation of subject cognitive and practical skills, mastering the universal academic actions.

A special role of robotics classes is the implementation of the interdisciplinary links, because robotics is an interdisciplinary field of activity. There are various fields of application of robots. Students' preparation of interdisciplinary projects is also possible in robotics classes. Today there are a lot of examples of the integration of robotics not only with the fields of mathematical and scientific knowledge, but also with humanitarian spheres of activity (historical events reenactment, modeling and study of interactions of various social groups, solving the problems of social adaptation, social services, etc.).

An interdisciplinary nature of the robotics classes contributes not only to identification and understanding the interrelation of sciences, but also to the classification and generalization of knowledge (scientific and mathematics, humanities), the students' achievement of *metasubject educational results* in this regard.

Robotics is a new demonstrative means stimulating the active understanding of the course study material. Robotic demonstrations feature high quality, adjustable speed of data presentation, they allow for the appropriate number of repetitions, they can be accompanied by visual, mechanical and sound effects drawing the attention of schoolchildren to the most important elements of the study material and raising the interest in learning it.

Robotics can be regarded as an efficient means of individualization of learning – taking into account the interests, inclinations, the level of students' knowledge in the subject. This is provided not only by the relevant techniques of teacher's work, but also owing to a variety of educational robotics kits, as well as accompanying study materials targeted at developing the technical creativity in children of various age and level of readiness for lessons of technical modeling and design. An additional factor stimulating the use of individual training technology is the implementation of the relation between the academic process and competitive robotics movement which can involve the students interested in technical creativity.

Pedagogical and *educational functions.* The use of educational robotics in the educational process on the subject provides active development in students of the entire complex of the cognitive processes (perception, presentation, imagination, thinking, memory, speech). The special effect of this influence is associated, as a rule, with high motivation for classes in robotics. Direct manual work and active practice of solving specific technical problems independently, succeeding in resolving the problems are even more significant factors of this influence.

Robotics classes contribute to shaping a wide range of personal qualities in a child (his needs and motives, independent behavior and initiative, diligence, sense of responsibility for quality of work performed, sociability and tolerance, striving for success, need for self-fulfillment etc.). The role of educational robotics is particularly important in the development of the personal qualities improving one's efficiency in interaction with others. These are the communication and interpersonal skills. The most important skills, according to many authors, are the ability to work in a team. In fact, it is quite difficult to do make a high quality robotic system alone with regard to interdisciplinary solutions required in its development. It is, first of all, working in a team that ensures the favorable conditions for development of a wide range of communicative competencies of students.

Team work on creation of robotic systems is generally associated with the project-oriented learning. The students have developed three types of projects within our study: 1) *creation of a new robot* to solve the research or applied study problem based on robotics sets by a specific manufacturer; 2) *modernization of the robot* (updated elements, design and software solutions) based on the robotics sets by a specific manufacturer; 3) *creation of a new robot* or *its modernization* to solve the research or applied study problem on the basis of: (a) development of new sensors and other robot systems, enhancing the opportunities of using a specific robotics kit; b) designing of the robot in its reference to other technical systems for solving complex practical tasks.

Figure 3 shows an example of a team project "Model of nuclear reactor" designed by secondary school students.

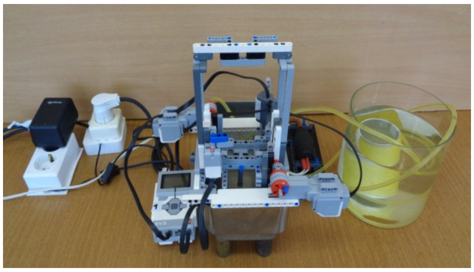

Fig. 3. A model of thermal regulation for nuclear reactor and adjusting the intensity of the nuclear reaction

This model is designed for demonstrating some of the reactor elements and heat transfer processes in its power unit. The increase in temperature of the reactor active zone is simulated with the water heating (using the electric heater). The water is also the heat-carrying medium in this model. The "active zone" temperature can be adjusted, on the one hand, by water heating, and on the other hand, by water cooling due to the circulation of the fluid flows between the vessel heater and external vessel with cooled water. The circulation is provided by a pump. The heater and the pump are controlled by software using the microprocessor through the electromagnetic relay. To control the temperature in "active zone", there is a temperature sensor installed. The system simulating the movement of control rods is mounted at the top of the reactor to adjust the nuclear reaction activity. Initially, the rods are outside the active zone. As the temperature increases above the allowed value, the sensor is activated, and the rods are moved down into the active zone "ensuring" a reduction in the nuclear reaction intensity. The decrease in temperature is achieved by initiating the water circulation process. As soon as the temperature drops below a certain value, the sensor is reactivated, and the rods are withdrawn from the active zone. The "reactor" control system has two operating modes: manual and automatic. In the automatic mode, the system maintains the temperature around a set value at the software level by switching the heater and the pump in turns. The value of the temperature in the "reactor" is displayed on the microprocessor screen.

It should be pointed out that the project described above belongs to projects of the third kind. In designing such projects, it is not only the parts of robotic kit that are used but also equipment of the school study rooms of physics and technology, household appliances, additional tools and materials. It is within such projects that difficult technical tasks are solved, and the project itself can prove to be not just interesting, but also unique.

The students' project activity in robotics must be associated with the content of the academic process on the subject. It is useful to support such project activity by the system of municipal, regional and national competitions and Olympics in robotics. This allows ensuring a high level of team work activity of students and the quality of solving the creative problems within the project. The subject and interdisciplinary projects should be determined as one of the most important trends of using the robotics in educational practice.

All the above mentioned trends of using robotics as a means of teaching, development and upbringing of students were implemented in the course of the exploratory pedagogical experiment.

4. Conclusion

The analysis of research results allows us to make a number of important conclusions.

The necessary study of robotics in secondary school as a field of knowledge and technical creativity is conditioned by modern trends of social infrastructure development associated with its enrichment with robotic objects.

The introduction of elements of the system of robotics knowledge into the subject educational program and the forming of the initial mastering experience in students as a field of modern technical knowledge should be organic in nature and not contradict to the subject education objectives. Robotics can and shall be presented in the subject education (e.g. in physics) as a significant component of its polytechnic orientation.

The exploratory pedagogical experiment has allowed to move the robotics from the field of additional education only and to find efficient methodological solutions for its inclusion into the basic academic process. The introduction of robotics as a three-component educational technology on the basis of the proposed solutions can significantly enrich the education program with the necessary applied knowledge and study activities, create additional conditions for better mastery thereof.

The educational equipment kits, the educational robotics kits and a complex of special study and instructional materials are necessary for implementing the technology. A set of such materials was prepared within the pedagogical experiment conducted. The efficiency of its use in teaching physics has been proven. It has been demonstrated that the efficiency of learning increases when implementing the interdisciplinary links of the disciplines of natural-mathematical cycle and "Technology" educational area.

The performances of experimental physics teaching using robotics are: 1) interest of schoolchildren for studying the subject, 2) the quality of mastering the study program in physics, 3) readiness to opt for physics and mathematics profile of learning in senior high school (grades 10-11), 4) the content of vocational aspirations in the area of natural sciences and engineering. Three year long teaching of students based on the technology suggested provided the evident increase of the said performances. The average value in three years of study was as follows: the first indicator – 34% of the total number of students who participated in the experiment during every year of study; the second one – 18%; the third one – 19%; the fourth indicator – 16%.

Another indicator of the practice of experimental work with students is their stable success in various competitions and contests on educational robotics, including the all-Russian competitions. The implementation of the proposed educational technology provides the necessary conditions for identifying and targeted teaching the students interested in robotics and capable of technical creativity – for fostering the future generation of engineers and inventors.

The workshops and further training courses for teachers were conducted using the materials of the study, and a monograph was prepared where the educational robotics is regarded as an important component of polytechnic orientation of teaching the principles of science in secondary school (Ospennikova, Iljin, Ershov & Ospennikov, 2014). Currently, new educational modules are worked out as means of implementing the proposed teaching technology. The opportunity and techniques for its application are considered for not only the basic academic process, but also for optional courses, elective studies and in extramural work of students on the subject.

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