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Improving educational process quality in the lessons of natural and mathematical cycle by means of stem-training

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Abstract

Currently, significant changes that actively take place in modern Russian society affect all spheres of its development. Today, due to economic globalisation and high rates of innovative technologies development, special attention is paid to the education system, where profound changes occur. Today, the educational process is focused on the development of personal characteristics that meet the requirements of a modern educated person. In this regard, the task of educational institutions is to adopt the educational process to today's realities. To achieve this goal, STEM education is implemented. It helps children to delve into the logic of the events, understand their relationships, systematically explore the world and thereby generate curiosity, engineering style of thinking, the ability to get out of critical situations, to develop teamwork skills and learn the basics of management and self-presentation, which, in turn, provides a fundamentally new level of personal development.

Keywords: Science education, STEM education, innovation, technology, robotics, microcontrollers, sensors, programming.

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1. Background

Almost 2 years ago, Vladimir Putin said that the shortage of qualified engineering and technical personnel was even more important problem for Russia's economy than corruption and administrative barriers. Currently, this situation has not changed and there is still a serious deficit of engineering professions in the labour market.

To solve this problem in the long term, it is necessary to develop children's interest in the inventive activity and scientific and technical creativity. Educational environments have to be organised which allow us to develop the ability to analyse the situation, to apply theoretical knowledge to solve the problems of the real world.

Current pupils and students, i.e., future specialists require comprehensive training and knowledge in a variety of educational fields of natural sciences, engineering and technology. The center of integration of these areas is STEM-education.

STEM is an acronym first introduced by Rita Rossi Colwell, an American environmental microbiologist and scientific administrator. This term came into common use shortly after an interagency meeting on science education held at the US National Science Foundation in the early 2000s. STEM groups together the following academic disciplines: Science, Technology, Engineering and Mathematics.

This term is typically used when addressing education policy and curriculum choices in schools to improve competitiveness in science and technology development.

STEM-training is aimed to develop new technologies, innovative thinking, to ensure the need for well-trained engineering personnel. STEM is such a relationship, such close interaction of knowledge areas that allow the child to understand the complex and extremely interesting world in all its diversity. Science organises knowledge in the form of testable explanations and predictions about the world around us. Technology is increasingly penetrating all aspects of our lives. Engineering is used to design machinery and tools, bridges and skyscrapers, vehicles and spaceships, in global climate change and environmental improvement (Davis, 2014, pp. 63–65). Mathematics applies to every profession, every occupation of our everyday life.

STEM helps children to delve into the logic of happening phenomena, to understand their relationship, to study the world systematically and thereby to generate curiosity, engineering style of thinking, the ability to get out of critical situations, to elaborate teamwork skills and learn the basics of management and self-presentation, which, in turn, provides a radically new level of child's development.

Learning in the STEM context develops critical thinking, increases scientific literacy and produces a new generation of innovators and inventors.

Instead of separate studying of science, technology, engineering and mathematics, STEM integrates these disciplines in the united educational system. STEM differs from traditional education implementing a mixed learning environment. It shows students how the scientific method can be applied to everyday life. STEM helps to realise project and educational research activities at school and outside (Musaeva, 2016, pp. 120–121).

The process of implementing STEM technologies in educational institutions is a great responsibility for the teacher. It is a challenge for his/her cultural and organisational position. In fact, learning based on STEM technology leads to a change in the teacher's position. From a translator of ready-made knowledge, he turns into an organiser of his students' knowledge extraction. Creative, non-standard teacher's approach to the organisation of classes leads students to increase the level of motivation and orientation to independent activity. The main goal of the teacher is to create favourable conditions for the active development of the cognitive activity of his wards, which depends on the proposed means of training and their diversity (Dotsenko, 2016, pp. 130–131). STEM-education easily copes with the task of learning tools variety, with its help, the material can be represented not in one but in many different ways. However, the teacher's pedagogical qualification should also be based on the unity of knowledge and well-developed skills that correspond to the current level of science. Teacher's information culture and literacy should be based on a professionally oriented system of knowledge that provides a certain set of knowledge for each category of users, in other words, the ability to use specific programmes in their subject area. Consequently, the teacher needs to constantly replenish his knowledge about new technologies, as they develop and change very quickly (Floyd-Smith et al., 2010; Frantskevich, 2014; Tarakanova, 2017).

2. Purpose of study

Students' activity is one of the most important components of the educational process, so the purpose of this study is to guide them in the course of training to the active management of the creative process based on the principles of partnership (Morse, Khladun & Dzyuba, 2018).

3. Sources of evidence

Two groups of keywords are set to search papers through an academic search engine and academic databases. Total 68 literature reviews about STEM-education have been accumulated and categorised into three main categories and five sub-categories. The authors adopt a multi-method approach to analyse the survey result. A literature review is going into the depth of the literature surveyed. It is a process of re-examining, evaluating or assessing the short-listed literature (literature survey phase). Review of literature gives clarity and better understanding of the research/Project (Cronin, Ryan & Coughlan, 2008; Rhodes, 2011).

4. Main argument

Students with the help of STEM—technologies are immersed in the creative process, where they learn new information based on the already accumulated knowledge. In addition, students in solving practical or scientific problems can always rely upon the teacher' support. As a result, involving in this work, the student gets new knowledge (Konyushenko, Petrushchenkov & Zhukova, 2017).

In fact, STEM education in a modern school is becoming increasingly important. It helps to realise all studying, developmental and educational tasks facing the teacher and his wards. In addition, STEM-education integrates various activities, which makes the learning process fun, interesting and therefore more effective.

One of the real ways to increase students' motivation and interest in engineering professions is to give them the possibility to create at the lessons of the natural and mathematical cycle. The products of their creativity should have contemporary practical application. It is difficult to realise such projects at traditional lessons of physics and mathematics because of various reasons. The most interesting ideas and inventions can appear at the junction of academic disciplines. With STEM programme, pupils can study the basics of robotics, computer science in addition to basic courses. Physics and mathematics will be also necessary when students will design and program their own robots. Special technological laboratories and modern educational equipment, such as 3D printers, visualisation tools and other instruments will increase pupils' material mastering and also skills of cooperative work.

One of the most appropriate platforms for STEM methods realisation at the lessons of the mathematical and natural cycle is Arduino-based platform. It unites physics, computer science, engineering, new technologies, that are nothing without mathematics, in one integrated development environment (IDE).

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs—light on a sensor, a finger on a button or a message of the social network–and turn it into an output—activating a motor, turning on a light emitting diode, publishing something online. Pupils at first with the help of their tutors and then without any assistance can explain Arduino system what to do by sending a set of instructions to the microcontroller on the board. The instructions should be written using object-oriented Arduino programming language and the Arduino software IDE.

Over the years, Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers, including students but also professionals—has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and experts alike.

Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for Internet-of-Things (IoT) applications, wearable, 3D printing and embedded environments. All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software, too, is open-source, and it is growing through the contributions of users worldwide.

Arduino software is flexible enough and runs on Mac, Windows and Linux. Students can use it to build low-cost scientific instruments, to prove chemistry and physics principles or to get started with programming and robotics. Designers and architects can build interactive prototypes, musicians and artists use it for installations and to experiment with new musical instruments. Ideas can be shared online with other members of the different communities.

Arduino system meets all requirements of STEM education.

First of all, it is integrated. Basic knowledge of mathematics and computer science is necessary to write a computer program, which should be correctly executed only if the pupil understands laws of physics, knows how to compute parameters of electrical and electronic elements, etc. Knowledge of modern technologies is needed to choose the most convenient approach and suitable components; engineering skills will be helpful in the design process.

According to STEM, good results are achieved when the chosen research topic unites all disciplines and in this way helps pupils to consolidate versatile knowledge. For example, creating a self-training robot can deal with such concepts as coordinate axis, angles, curves and even basics of neuro networks (mathematics), algorithms of finding the shortest way in shortest time (computer science, energy and time saving), different sensors based on fundamental mechanical, optical, electromagnetic laws (physics). Such topic is also engineering, design and sometimes even an art challenge.

Pupils should aim to create things with practical advantages. The above-mentioned robot can find a variety of applications and implementations from quick getting goods from the store shelves to finding lost people in the remote places. It is also necessary for these robots to communicate with people and with each other. So mobile and other telecommunication technologies will also be in the sphere of pupils' interest, thanks to STEM education and to Arduino system. Most of these applications are currently under investigation, so there is time to involve students in this job.

Students meet real challenges not only at the stage of robot design and programming but also during testing and enhancement. In most cases, this job is even more labourious and time-consuming. So, this stage will develop critical thinking and problem-solving skills, especially when students are divided into teams (Carnevale, Smith & Melton, 2011).

5. Realisation

In this article, we present one Arduino kit that can be very helpful at the lessons of the natural and mathematical cycle. In includes Arduino Uno board that can be programmed with the help of C++

sketches in Arduino IDE and a variety of sensors, which can be used in different situations and models, e.g., while designing smart home applications, in presenting information, in robots training, in alarm systems, etc. Several lesson topics have been proposed, such as:

Display by I2C LCD1602

Analog Hall Sensor

Switch Hall Sensor

Analog Temperature Sensor

Temperature Detection by Thermistor

Auto-flash LED

Barometer

Real-time Clock (RTC) Module

Flame Alarm

Flammable Gas Detection

Humiture Detection

Joystick PS2

Controlling an LED by Button

Vibration Switch

Touch Switch

Photo-interrupter

Photoswitch

Reed Switch

Relay

Blinking an LED by Potentiometer

Tilt Switch

Buzzer

Digital Temperature Sensor

Rainbow LED

Infrared Receiver

Dual-color LED

Sound Sensor

Rotary Encoder

Laser Transmitter

IR Tracking Sensor

IR Obstacle Avoidance Sensor

Color Detection

Analog–Digital Converter

Raindrop Detection

Distance Detection by Ultrasonic

Thermostatic Water Tank

Some sensors and lessons based on their usage for STEM-education are described below.

Though LCD and some other displays greatly enrich the man-machine interaction, they share a common weakness. When they are connected to a controller, they occupy many outer ports which are in most cases necessary for other critical applications. Also, it restricts other functions of the controller. Therefore, LCD1602 with an I²C bus is developed to solve the problem.

I²C (Inter-Integrated Circuit) bus is a type of serial bus invented by Philips. It is a high-performance serial bus which has bus ruling and high or low-speed device synchronisation function required by the multiple-host system. The blue potentiometer on the I²C LCD1602 is used to adjust the backlight for the better display. I²C uses only two bidirectional open-drain lines, a serial data line (SDA) and serial clock line (SCL), pulled up with resistors. Typical voltages used are + 5 V or + 3.3 V although systems with other voltages are permitted. In this lesson, the Arduino Uno board is used to control LCD1602 display. SDA has to be connected to A4 PIN of the board and SCL has to wired with A5. The aim of the lesson is to let I²C LCD1602 display ‘hello, world’ after loading the corresponding program (scetch) into the board (Dweck, Walton & Cohen, 2014).

Based on the Hall Effect, a Hall sensor is a one that varies its output voltage in response to a magnetic field. Hall sensors are used for proximity switching, positioning, speed detection and current sensing applications.

Hall sensors can be categorised into linear (analog) Hall sensors and switch Hall sensors. A switch Hall sensor consists of voltage regulator, Hall element, differential amplifier, Schmitt trigger and output terminal and it outputs Boolean value (0/1). A linear Hall sensor consists of Hall element, linear amplifier and emitter follower and it outputs analog values. If a comparator is added to a linear (analog) Hall sensor, it can output both analog and digital signals.

Hall Effect is a kind of electromagnetic effect. It was discovered by Edwin Hall in 1879 when he was researching conductive mechanism about metals. The effect is seen when a conductor is passed through a uniform magnetic field. The natural electron drift of the charge carriers causes the magnetic field to apply a Lorentz force (the force exerted on a charged particle in an electromagnetic field) to these charge carriers. The result is what is seen as charge separation, with a buildup of either positive or negative charges on the bottom or on the top of the plate. A Hall sensor is a magnetic field sensor based on it.

Electricity carried through a conductor will produce a magnetic field that varies with current, and a Hall sensor can be used to measure the current without interrupting the circuit. Typically, the sensor is integrated with a wound core or permanent magnet that surrounds the conductor to be measured.

In this lesson, when the sensor approaches the magnet, the value of pin A0 (analog PIN) on the board has to change. When the value exceeds the threshold set by the potentiometer before, D0 (digital PIN) has to output low level and the corresponding LED has to light up.

In an experiment with switch Hall sensor, it has to be connected to pin 8 of the Arduino Uno and the buzzer has to be wired to pin 7. When an energised conductor approaches the module, the output terminal SIG has to output low level; the buzzer has to beep and at the same time, the corresponding LED has to light up.

A temperature sensor is a component that senses temperature and converts it into output signals. By material and component features, temperature sensors can be divided into two types: thermal resistor and thermocouple. The thermistor is one kind of the former type. It is made of semiconductor materials; most thermistors are negative temperature coefficient (NTC) ones, the resistance of which decreases with rising temperature. Since their resistance changes acutely with temperature changes, thermistors are the most sensitive temperature sensors.

The Analog Temperature Sensor module uses an NTC thermistor, thus measuring temperature sensitively. It also has a built-in comparator LM393 which enables the module to output both digital and analog signals at the same time. The module can be used for temperature alarm and temperature measurement.

There is a comparator LM393 on the analog temperature sensor module. A threshold can be set up by the potentiometer. When the thermistor is touched, the value of A0 has to decrease. Once the value is lower than the threshold, D0 has to output high level and the indicator LED on the analog temperature sensor module and that attached to pin 13 of the Arduino Uno has to go out. The value of A0 and D0 can be checked on Serial Monitor.

The 7-color auto-flash LED module can automatically flash built-in colours after power on. It can be used to make quite fascinating light effects.

A barometer is a scientific instrument used to measure air pressure. In this experiment, the Arduino Uno board is used as the master board to read the value from BMP180 and display it on Serial Monitor.

Nowadays, there are many popular serial clock circuits such as DS1302, DS1307, PCF8485, etc. They are widely used for the simple interface, low cost and ease of use. In this lesson, the DS1302 RTC module will be used to obtain the current date and time.

DS1302 is a trickle charging clock chip, launched by Dallas. With a built-in RTC/calendar and a 31-byte static RAM, it can communicate with MCU through simple serial ports. The RTC/calendar circuit provides information about second, minute, hour, day, week, month and year. DS1302 can automatically adjust the number of days per month and days in leap year. The usage of a 24-hour or 12-hour system can be determined by AM/PM selection. It can simply communicate with MCU in synchronous serial way and only needs to use three port cables: Reset (RST) cable, I/O data SDA cable and SCL cable.

A flame sensor module performs detection by capturing infrared wavelengths from the flame. It can be used to detect and warn of flames. In this experiment, such sensor is used to make a flame alarm.

There are several types of flame sensors. In this lesson, a far-infrared flame sensor is used. It can detect infrared light with a wavelength ranging from 700 nm to 1000 nm. A far-infrared flame probe converts the strength changes of the external infrared light into current changes. And then it converts analog quantities into digital ones.

In the lesson, Pin D0 has to be connected to the digital port 8 of Arduino board. Then, when the flame sensor detects flame signals, the buzzer has to beep and the corresponding LED has to light up. When it detects no flame signals, the buzzer stops and the LED goes out.

Gas Sensor MQ-2 is a sensor for flammable gas and smoke by detecting the concentration of combustible gas in the air. They are often used in gas detecting equipment for smoke and flammable gasses such as LPG, i-butane, propane, methane and alcohol in household, industry or automobile.

The digital temperature and humidity sensor DHT11 is a composite sensor that contains a calibrated digital signal output of temperature and humidity. The technology of a dedicated digital modules collection and the temperature and humidity sensing technology are applied to ensure that the product has high reliability and excellent long-term stability.

The sensor includes a resistive sense of wet component and an NTC temperature measurement device and is connected with a high-performance 8-bit microcontroller.

Only three pins are available for use: VCC, GND and DATA. The communication process begins with the DATA line sending start signals to DHT11, and DHT11 receives the signals and returns an answer signal. Then, the host receives the answer signal and begins to receive 40-bit humiture data (8-bit humidity integer + 8-bit humidity decimal + 8-bit temperature integer + 8-bit temperature decimal + 8-bit checksum).

A reed switch is also a sensor used to detect the magnetic field. Hall sensors are generally used to measure the speed of intelligent vehicles and count assembly lines, while reed switches are often used to detect the existence of a magnetic field.

A reed switch is a type of line switch component that realises control by magnetic signals. It induces by a magnet. The ‘switch’ here means dry reed pipe, which is a kind of contact passive electronic switch component with the advantage of simple structure, small size and convenient control. The shell of a reed switch is commonly a sealed glass pipe in which two iron elastic reed electroplates are equipped and inert gases are filled. Normally, the two reeds made of special materials in the glass tube are separated. However, when a magnetic substance approaches the glass tube, the two reeds in the glass tube are magnetised to attract each other and contact under the function of magnetic field lines. As a result, the two reeds will pull together to connect the circuit connected with the nodes.

After the external magnetic force disappears, the two reeds will be separated with each other because they have the same magnetism, so the circuit is also disconnected. Therefore, as a line switch component controlling by magnetic signals, the dry reed pipe can be used as a sensor to count, limit positions and so on. At the same time, it is widely used in a variety of communication devices.

In this experiment, since an LED has been attached to pin 13, pin SIG of the reed switch has to be connected to digital pin 7 of Arduino Uno board. When the reed switch identifies magnetic field signals, the LED will be on. Otherwise, it will be off.

An IR Obstacle Sensor works in accordance with the infrared reflection principle to detect obstacles. When there is no object, the infrared receiver receives no signals; when there is an object ahead which blocks and reflects the infrared light, the infrared receiver will receive signals.

An obstacle avoidance sensor mainly consists of an infrared transmitter, an infrared receiver and a potentiometer. According to the reflecting character of an object, if there is no obstacle, the emitted infrared ray will weaken with the distance it spreads and finally disappears. If there is an obstacle, when the infrared ray encounters it, the ray will be reflected back to the infrared receiver. Then, the infrared receiver detects this signal and confirms an obstacle in front.

In this experiment, Obstacle Avoidance Sensor module and the LED attached to pin 13 of the board will be used to build a simple circuit.

Since the LED has been attached to pin 13, the pin SIG should be wired to digital pin 7 of the Uno board. When the Obstacle Avoidance Sensor detects an obstacle, the LED has to be on. Otherwise, it has to be off.

Arduino-STEM practice combines an interdisciplinary and project approach, the basis for which is the integration of natural sciences in technology, engineering and mathematics (Romanov, 2017; Tang & Karunanithi, 2017). Such education through practical training demonstrates the application of scientific and technical knowledge in real life. At each lesson, pupils study a specific project, developing, building and creating prototypes of modern industry products. STEM training programs are characterised by active communication and teamwork. Arduino designing, programming and especially testing processes create a free atmosphere for discussion and opinion expression and presentation. Creation of Arduino models increases pupils’ interest in natural and mathematics cycle disciplines in the form of the game and helps them to understand the whole production process during lessons. So, the Arduino system is ideal for STEM education and can help to bring up a new generation of engineers (Duckworth & Yeager, 2015).

If talking about STEM-training in general, it should be noted that it provides maximum efficiency of creative activity, which includes:

- function of Gnostics—i.e., the cognitive interest and ability to conduct analysis of its activities;
- design function—modelling, selection of tools and methods;
- communicative function—relations between students and teachers;
- organisational function that aims at mobilising, coordination, interrelation of actions of trainees during the training process.

Thanks to STEM-technology, students can delve into the logic of the phenomena to understand their relationship, to study the world systematically and thus develop a cognitive interest based on the selective orientation of the individual to the objects and phenomena of surrounding reality. Only when a certain area of science, a specific subject of the study appear important and significant to a person, he studies them with special enthusiasm, trying to go deeper and more thoroughly learn all aspects of those phenomena and events that are related to the area of knowledge that are interesting to him. Otherwise, interest to the subject cannot be of a genuine cognitive nature: it can be random, unstable and superficial (Dickey, 2016).

STEM-learning as a technology of students' creative abilities development is such studying that is not only full of thoughts and feelings, actions and activities but also a purposeful search for the best ways to solve cognitive and often practical problems. Therefore, it is an important incentive in the development of such valuable qualities of the individual as commitment, perseverance in achieving the goal, the desire for actions completion and achievement of the intended results.

Also, a characteristic feature of STEM learning is its strong-willed orientation, which focuses not only on the process of cognition but also is always associated with the pursuit of goals, with overcoming difficulties. STEM-learning is one of the most important motivations for students. Under its influence, learning even for weak students becomes more productive. This motif emotionally paints all educational activity. STEM-training motivates to independent activity, where the process of learning becomes more active, creative, which, in turn, affects the increased interest in the subject (Meteleva, 2016).

6. Conclusion

With proper pedagogical and methodological activities, STEM education can transform the systematic students' activities into targeted ones. STEM-training has a strong impact on the development of cognitive interest, which manifests itself in all circumstances, is used in any situation, in any conditions where the sphere of interest develops mental activity (Jang, 2017).

STEM also acts as a stimulator of interesting learning, which is full of spectacular experiments, demonstrations of colourful guides and the solution of interesting scientific and practical problems. Another characteristic feature of STEM-learning is that it colours the emotions of mental and intellectual activity. The feeling of labour recovery, joy, satisfaction from the work done reinforces the cognitive interest and makes it more resistant. Favourable emotional atmosphere of the learning involves two main sources for the development of the student: the activities and communications that lead to meaningful relationships and create the tone of the student's morale. Both these sources are not isolated from each other; they are constantly intertwined in the educational process. If a student considers a certain school subject, field of science or hobby to be significant and important, his studies inspire him with enthusiasm and interest. When students are doing their favourite thing for them, they try to delve into the topic to study all aspects of phenomena and events that interest them. If this is not observed, then it is too early to talk about cognitive interest or it may be unstable, accidental or superficial. The use of STEM technologies as an addition to the school curriculum will help to avoid this problem.

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