The Use of Software and Hardware Arduino for the Students' Formation of Research and Engineering Competencies

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Abstract: The article shows the experience of using the Arduino hardware and software complex in order to develop research competencies of secondary school and high school students. Here are some examples of research projects that allow children to demonstrate their engineering skills and encourage them to further study subjects such as physics and computer science. The possibilities of Arduino to improve ready-made projects and develop their own engineering ideas are outlined. Particular attention is paid to the development of measuring devices and installations for school physical experiment, in particular devices for the study of uniformly accelerated motion. The results of research received by students during the experiment are shown. The results of students' research activities and their devices can be reproduced by other teachers and students for use during the teaching of physics in a specialized school, especially during a school experiment.

1 INTRODUCTION

The development of computer technology has greatly accelerated the exchange of information in any field of human activity. In education, the use of personal computers allows not only to increase the amount of information that the teacher passes on to his students, but also to create his own methodological developments, which allow to improve the assimilation of the obtained information by adapting it to age characteristics, social views, intellectual abilities and more (Vlasenko et al., 2021, 2020b). Also, continuous software upgrades allow teachers to create software products that previously required special engineering education to develop. But the needs of today have already gone beyond the acceleration of information processes. Now not only the speed of information processes but also their automation is important. Automated devices are increasingly appearing in our lives, so modern education should keep up with the needs of society.

Along with technological advances, the methods of student research change (Babkin et al., 2021).

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Involving children in advanced study of physical processes, it is difficult to limit only to the study of Physics, researchers must have some knowledge of Computer Science or engineering. The article shows the personal experience of the combination of Physics, Computer Science, Engineering and elements of robotics in the study of physical processes by students of Kryvyi Rih Science Lyceum of the Kryvyi Rih City Council in Dnipropetrovsk oblast.

The study of robots and robotics is already very popular (De La Cruz Vaca et al., 2020; Goncharenko et al., 2019; Hrybiuk et al., 2020; Valko and Osadchyi, 2021). The simplest and most understandable tool for researching and creating robots is LEGO kits. They do not require special knowledge of programming and understanding of the processes occurring in the devices that provide the models. It is enough to have a computer, a designer and a wealth of imagination. But the high price limits access to robot modeling by LEGO. The average student is able to model on such equipment only within the limits of classes and cannot afford to make his own model and leave it to himself. More affordable by price is the Arduino hardware and software package. This software package allows the student to show their creativity to a greater extent, but at the same time, and requires a deeper knowledge of

programming and radio engineering.

The purpose of the article is to show the possibilities of applying elements of robotics in the project activity of high school students and to use the results of their work in physics lessons. To combine robotics with physical research, the Arduino hardware and software system was chosen as a research tool. This complex was developed by Massimo Banzi in 2005 as a tool for students at the Interaction Design Institute Ivrea in Ivrea, Italy, aiming to provide a low-cost and easy way for novices and professionals to create devices that interact with their environment using sensors and actuators (John, 2020). The name Arduino comes from a bar in Ivrea, Italy, where some of the Arduino founders used to meet. The bar was named after Arduin of Ivrea, who was the margrave of the March of Ivrea and King of Italy from 1002 to 1014 (Kushner, 2011). The main purpose of the development of the complex is to teach students how to design electronic devices, but then the capabilities of this complex went far beyond conventional engineering.

2 ANALYSIS OF PREVIOUS STUDIES

The use of Arduino has been repeatedly addressed by other educators. Andreev and Kulinich (Andreev and Kulinich, 2017) examines the problem of using information tools in the educational and research activities of students. The educational possibilities of the Arduino hardware and software complex in the context of preparing future physics teachers to organize students' innovative activities are highlighted, in particular, examples are given of its use for setting and solving physical problems, as well as for students to create their own innovative products. The authors suggest using Arduino boards to measure temperature, light and humidity at different points in the room. As well as obtaining the dependence of the photoresistor resistance to light and the resistance of the thermostat to temperature. Some examples of experimentation covering various topics (light and electrical phenomena, molecular physics) are given in their work. Somenko and Somenko (Somenko and Somenko, 2016) analyze the advantages of using the Arduino hardware and computing platform to create training physical equipment using electronic computing equipment. There are advantages of the complex, such as: convenient open source software for processing research results, availability of component parts for the manufacture of equipment, the ability to change the software and component measurement equipment independently.

The example of an experiment for the study of convection in a liquid is given.

Martyniuk (Martyniuk, 2014) considers actual problems of development of methodological bases of using microelectronic circuitry in the system of professional training of students-physicists. He describes the possibilities of using the Arduino platform in the research of physics and in the design and manufacture of new training equipment. He recommends the use of such equipment for measuring humidity, temperature, light, speed, distance, etc. He recommends using different sensors to measure the same magnitude for accurate results and uses third-party software to process experiment data. Petry et al. (Petry et al., 2016) offer "Extracurricular project training in physics: integrating Arduino into the laboratory" with the help of the Arduino platform, carry out experiments in physics from optics and thermodynamics. In total, there are 11 laboratory works offered for elective classes (Petry et al., 2016). Among the proposed works are: refraction and reflection, spherical lens, sensitive and latent heat, thermal expansion in solids and liquids, photoelectric energy. The authors provide examples of experiments conducted by high school students.

Huang (Huang, 2015) has developed a series of experiments, activities and lab work to study, measure, and analyze physics phenomena in the classroom using low-cost microcontrollers and open source electronics. Based on his own research, he has proposed a number of activities that demonstrate scientific research using inexpensive and easily accessible electronics and equipment. Huang (Huang, 2015) describes two experiments. The first, in mechanics, uses a self-made device, called the "rotation". The second, on the topic of "Thermal phenomena", uses a semiconductor temperature sensor.

3 METHODS AND TECHNIQUES

For the development of engineering skills it is advisable to use the methods of project-based learning technology (Balyk et al., 2021; Glazunova et al., 2021; Gryshchenko et al., 2021; Horbatiuk et al., 2020; Iatsyshyn et al., 2020; Pavlenko and Pavlenko, 2021; Shuhailo and Derkach, 2021; Valko et al., 2020; Vlasenko et al., 2020a), which is based on the development of cognitive skills and abilities of students; ability to navigate in the information space; ability to independently construct theoretical or real models; ability to integrate their knowledge from different fields of science; ability to think critically. Project methods are focused on independent activity of students (individual, pair, group) in the time allotted for

it (from several minutes to months). The sequence of research can be shown in the form of the following series: problem definition – hypothesis – problem solving – discussion of research methods – registration of final results – analysis of the obtained data – summarizing – correction – conclusions. The main thing in the interaction between teacher and student is the independence of the student, the teacher should only adjust the activities of the researcher without imposing his own ideas and decisions.

Arduino applications are written in C or C++ programming language (Arduino, 2021). The Arduino concept does not include body or mounting parts. The developer chooses the method of installation and mechanical protection of processor boards and expansion components independently. Other manufacturers offer a large number of various sensors and actuators that are compatible with Arduino processor boards. These manufacturers also produce sets of electromechanical elements that work in conjunction with Arduino boards, and develop special libraries (programs) that link the work of hardware and software. Arduino IDE software allows students to develop algorithms (firmware, sketches) for microprocessors and sensors. Working with the complex, students are able to see the principles of communication between the software and the devices for which it is designed. Creativity of students is always associated with the application of ideas. When creating robots or automated devices, students are involved in the processes that take place in the technical devices. Applied research, design, construction, development of manufacturing technologies are a list of activities that a child is involved in during the process of creating a new or reproducing an existing device. Children work with microprocessors and other radio electronics make housings and parts for devices, design and plan work for moving parts. Thus, it can be seen that using Arduino enables them to become true engineers, show their creativity and gain experience in electrical engineering.

Working with the complex, researchers are constantly dealing with electric current. It should be noted that the maximum voltage used to power the Arduino boards does not exceed 12 V, which is quite safe. And the constant connection and disconnection of sensors, the use of resistors, LEDs, etc., allows students to understand the laws of direct current, serial and parallel connection of conductors. Development of connection schemes can be carried out in two stages. The first step is to do a theoretical development with the online service Tinkercad (Autodesk, Inc., 2021), which has almost all sensors connected to the Arduino UNO board. Develop and test connec-

tion scheme. And then, in the second stage, work with real devices. This can prevent damage to the parts or board.

The end result of the above student research is the creation of an automated or controlled device. One of the ways to improve the quality of physics study is to involve children in the manufacture of measuring devices, which can then be used in laboratory physics. Microprocessor data processing enables more accurate measurements of physical quantities. Arduino sensors allow you to measure atmospheric and mechanical pressure, temperature, humidity, time, distance, resistance, voltage, current, light, etc., and the combination of several sensors with a program written in the Arduino IDE allows you to determine the value of other physical quantities, such as average speed of movement.

4 EXAMPLES OF USING READY-MADE PROJECTS WITH ARDUINO

A simple project that students can be involved in is assembling a D2-1 work robot and making a track for the movement of such a device. Robot D2-1 (figure 1) performs only one task – moving along the black line in one direction. At first glance, a ready-made set, which has only one version of the assembly, will develop little creativity and will not allow a better understanding of physical phenomena.
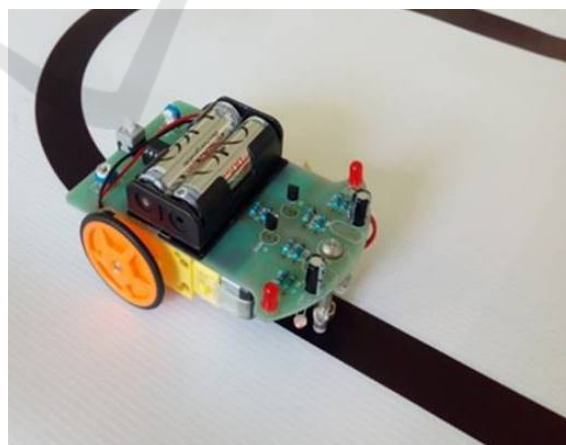

Figure 1: Robot D2-1 on the track.

But it should be noted that children working with such a set have the opportunity to work with the electronic circuit and its components, learn to work with a soldering iron, develop skills to adjust the operation of electric motors. Also, the creativity of the pupils of

the afterschool activity allows to improve the ready-made basic model. So one of the improvements was the addition of a photoresistor and LEDs to the Arduino board, which in turn expanded the capabilities of the device: when the robot enters a darkened area of the room, the light is automatically turned on. This feature can be used on cars to automatically turn on the light when entering a tunnel or other dimming. Thus, a simple radio constructor allows students to have practical skills in working with radio circuits, and the device itself can be an example of photoresistor when studying the topic of "Semiconductors" in physics lessons, as coordination is provided by changing the current in the photoresistor.

Another project that was initially carried out according to ready-made instructions is a meteorological station (figure 2), which measures temperature, humidity and atmospheric pressure. In 10th grade, students study the topic "Fundamentals of molecular kinetic theory. Fundamentals of thermodynamics", so it is convenient to interest this age category in the implementation of such a project.
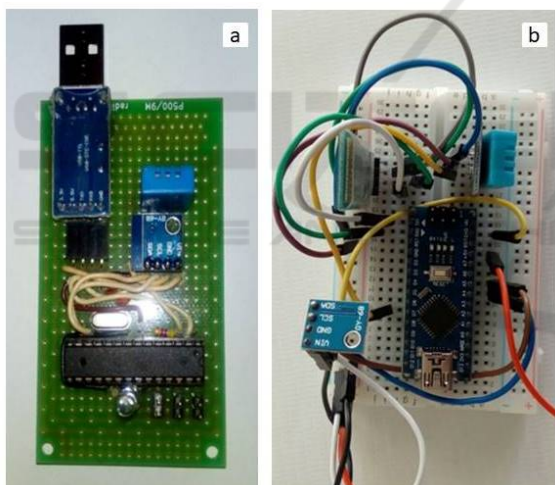

Figure 2: Meteorological station: a) with Atmega8 chip, data transmission via wire; b) with Arduino Nano board and wireless data transfer.

As part of the above topic, children learn concepts such as temperature, humidity and pressure. Physical experiments to measure these quantities are in the program of the physics course, so the manufacture of the device will not only develop the engineering skills of students, but also strengthen the material base of the physics classroom and bring the school physical experiment to a new level.

The meteorological station made by the students did not initially have an Arduino board in its design, but worked on the basis of the Atmega8 chip (figure 2a). But the student who worked on the project

suggested her own design of the device (figure 2b), which not only works from the Arduino board, but also transmits data at a distance of up to 60 meters using a Bluetooth device.

It is very important to involve students in teamwork, so continuing to look at the weather station, we can give an example of a computer science project that has improved the measurement efficiency of the above-mentioned device. Another student developed an application for a mobile phone (figure 3), which displays the results of measurements, as well as allows you to save and view them. In this way, cooperation develops students' ability to work in a team and brings them closer to the realities of life, because large and complex projects are not performed by one person, and the end result depends on the interaction of the team.

Figure 3: The meteorological station – an application for a mobile phone.

Another project the students were working on was the Equal Acceleration Study. The purpose of the project is to measure the time of evenly accelerated body movement. In conventional studies, time measurements are performed using a mechanical stopwatch. As a rule, the measurement of time itself gives the greatest error in human factor studies (the timing of the stopwatch on and off). The measuring device (figure 4) was assembled on the basis of the Arduino UNO board and its compatible elements: the actuator

and the button. This device allows you to measure the travel time up to a microsecond. The measurement results can be seen on the LCD connected to the board. Such a device can be used in laboratory work with the topics "Determination of acceleration of equal acceleration of movement" (10th grade), "Determination of average speed of movement" (7th grade), "Determination of acceleration of free fall" (10th grade).
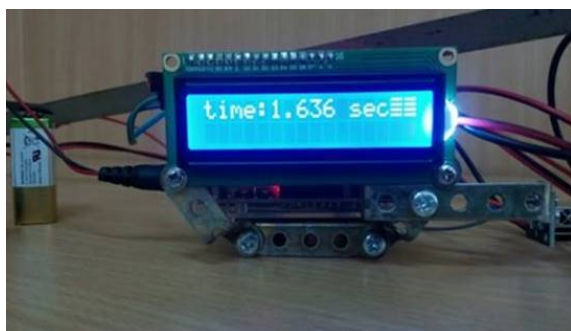

Figure 4: The stopwatch to measure the time of uniformly accelerated motion.

The device for measuring the time of accelerated motion (figure 5) consists of an Arduino UNO card, LCD display, servomotor, button, remote control, infrared receiver, chute, ball and tripod with holder.

Figure 5: Installation for measuring the time of uniformly accelerated motion.

The measurements are as follows: The Arduino board is connected to the power supply; the ball is set to the starting position; at the remote control press the start button at this moment the servo is turned to 900 and the program loaded into the board begins the countdown; when the ball reaches the button, when pressed, the countdown stops and the fixed time can be seen on the display; return the servomotor to the starting position with the help of the control panel; further the following experiment can be performed. Usually at laboratory work the ball is released by the hand and try to turn on the stopwatch synchronously, and stop the countdown when hitting the ball against

a metal cylinder. It is these actions that lead to a great deal of error when doing research. The results of the studies are shown in tables 1 and 2.

Table 1: Measurement of time of uniformly accelerated motion in the classical way.

No	t, sec	t(av), sec	error, sec	relative error, %
1	1.46	1.48	0.02	1.35
2	1.35	1.48	0.13	8.78
3	1.40	1.48	0.08	5.40
4	1.47	1.48	0.01	0.67
5	1.37	1.48	0.11	7.43
6	1.63	1.48	0.15	10.13
7	1.48	1.48	0	0
8	1.62	1.48	0.14	9.45
9	1.63	1.48	0.15	10.13
10	1.45	1.48	0.03	2.02
			maximum error 10.13 %	

Table 2: Measurement of acceleration time using an Arduino-based device.

No	t, sec	t(av), sec	error, sec	relative error, %
1	1.432	1.458	0.026	1.78
2	1.489	1.458	0.031	2.12
3	1.458	1.458	0	0
4	1.455	1.458	0.003	0.2
5	1.468	1.458	0.01	0.68
6	1.430	1.458	0.028	1.92
7	1.442	1.458	0.016	1.09
8	1.486	1.458	0.028	1.92
9	1.457	1.458	0.001	0.06
10	1.469	1.458	0.011	0.75
			maximum error 2.12 %	

Studies have been shown that the measurement results obtained with an Arduino-based device have an error of five times less than the results obtained with the classical measurement used in laboratory work. It can be concluded that the use of microcontrollers can improve the quality of the experiments.

This setting can also be used to measure free fall acceleration. To do this, simply attach the sensors on a tripod along the vertical line (figure 6).

In addition to producing a pre-fabricated installation, working on the project, the students conducted research whose content went beyond the curriculum of the profile school. To investigate the value of free fall acceleration, five balls of different masses were taken (figure 7).

The scientific research method used for this is called extrapolation. Throwing in the air all the balls in turn, you can get the value of the free fall acceleration in vacuum, extrapolating the dependence of this

Figure 6: Installation for the acceleration of the accelerated fall.

acceleration for each ball in the air on the inverse of their mass. That is, it is possible to determine the acceleration of free fall for a ball of infinite mass, and in this case it is possible to neglect the resistance of air to the ball. As bodies with different mass used ordinary table tennis balls with a diameter of 40 mm.

In order to measure the time of falling of different balloons by weight, it would give the most accurate result, it is desirable to achieve the greatest difference in the masses of balloons. For mass change, they were filled with different material (figure 7). Therefore, the lightest used ball is empty and the hardest filled with metal with small nails. The masses of the balls were in the range from 3 g to 40 g.

A servomotor with a tube fixed by the holder (figure 6) was attached from above to a regular school tripod, a mechanical button was attached to the bottom, on which the ball would fall. With the help of movable holders you can change the distance from the point of launching the ball to the button, experimenting with different height of fall. To insert the ball into the button, and to prevent the heavy ball from breaking into the iron holder and the floor, a shield is attached to the button. Studies have been shown that the measurement results are not affected by the shield.

After adjusting the device so that the ball falls exactly on the button without the slightest deviation, measure the distance and determine the time of free fall of the balls. Studies have shown that the time during which the same ball falls from its average by approximately 5 ms. This is due to the fact that the ball, falling downwards, may deviate from the vertical on which the central axis of the installation is located, due to the moving air flows, or if the tripod oscillates

slightly at startup. Deflecting the ball each time falls into a point different from the button on the shield, which causes a time delay. Also the reason for the different values of time is that the Arduino processes the information coming into the payment processor at different times, which causes the timer on the device to work with delays. To minimize the time discrepancy, we performed 15 measurements for all five beads and determined the average fall time. They also set an average delay of 8 ms due to microprocessor processing.

Taking into account the above, and having worked out the results of measurements, we determined the acceleration of free fall in vacuum for the study room of physics. The obtained value of the acceleration of free fall in vacuum was equal to 9.8093 m/s^2. The research was presented at the competition for the protection of research works of the Dnipropetrovsk Department of the Junior Academy of Sciences of Ukraine, the student who conducted the research was highly praised by the jury and won the competition.

5 CONCLUSIONS

Students worked on the above projects under my guidance. All manufactured devices work and are used in teaching children. These examples demonstrate the possibility of using microcontrollers and compatible sensors during individual and team work of children, for the manufacture of simple devices according to ready-made instructions and devices that allow scientific research, for the manufacture of toys and measuring instruments used during physical measurements.

With regard to physical measurements, it should be noted that the use of automated devices is only appropriate for measuring some physical quantities, and should not be replaced by all classic measuring devices. For example, when performing laboratory work on the topic "Determining the acceleration of accelerated motion" in grade 10, you need to measure two values – time and path. To measure time, it is advisable to use the above-mentioned device instead of a stopwatch, since the human factor gives a significant error that cannot be calculated in the future, and the use of a ruler makes it possible to make accurate measurements, to calculate the measurement error, and to improve the ability and skills to measure length (width, height, path, distance, etc.). Also, when measuring humidity, it will be correct, based on the results of measurements of relative humidity and temperature, to ask students to determine the absolute humidity.

Therefore, the use of the Arduino hardware and

Figure 7: Manufacture of balls to measure the acceleration of free fall.

software in educational and research activities is an effective tool for increasing interest in such areas as computer science, engineering, and physics. A comprehensive approach will allow students to be interested in the science of mathematics, solve modern problems of engineering and electronics, as well as develop their creative abilities. Working on your own projects allows children to showcase their abilities and present their projects at various competitions, which further motivates young researchers. The devices developed by the students allow to significantly improve the accuracy of measurements during the experiment, increase the level of theoretical preparation for laboratory work, increase the general interest in the laboratory work by the students by modernizing the equipment and form new ideas about phenomena and processes of physics.

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