*CTE Workshop Proceedings*, 2024, Vol. 11, pp. 427-441 https://doi.org/10.55056/cte.663

# Using Arduino to develop research competencies of students in school physics education

*Vitalii M.* Zadorozhnii[1,2]

[1]*Kryvyi Rih State Pedagogical University, 54 Gagarin Ave., Kryvyi Rih, 50086, Ukraine*
[2]*Kryvyi Rih Science Lyceum of the Kryvyi Rih City Council in Dnipropetrovsk oblast, 32A Volodymyra Velykoho Str., Kryvyi Rih, 50071, Ukraine*

**Abstract.** Arduino is a popular hardware and software platform that enables the development of various engineering projects, especially in physics and computer science. Arduino can be used as a powerful tool to foster the research competencies of secondary and high school students and stimulate their interest and creativity in science and technology. In this paper, we present some examples of research projects that involve using Arduino in the context of school physics education. These projects include designing and implementing measuring devices and installations for studying physical phenomena, such as uniformly accelerated motion, free fall, pendulum motion, etc. We also show how Arduino can improve existing projects and create new ones based on the students' engineering ideas. We demonstrate the results of the experiments conducted by the students using their Arduino-based devices and discuss the benefits and challenges of using Arduino in school physics education.

**Keywords:** Arduino, research competencies, physics education, engineering projects, school experiment

## 1. Introduction

The rapid development of computer technology has revolutionised the exchange of information in various domains of human activity. In education, the use of personal computers enables not only to increase the amount of information that the teacher delivers to the students, but also to create innovative methodological developments that can improve the learning outcomes by adapting the information to the students' age characteristics, social views, intellectual abilities, and more [4, 14, 20, 21, 23, 25, 26]. Moreover, the continuous software upgrades allow teachers to create software products that previously required special engineering education to develop. However, the current needs of society have already surpassed the acceleration of information processes. Now, not only the speed but also the automation of information processes is important. Automated devices are increasingly appearing in our lives, so modern education should keep pace with the demands of society.

Along with technological advances, the methods of student research change [9, 13, 15–17]. Engaging students in the advanced study of physical processes is insufficient to limit them to the study of physics only. Researchers must have some knowledge of Computer Science or engineering as well. In this paper, we share our personal experience of combining physics,

vitaliy_zadorozhniy@ukr.net (V. M. Zadorozhnii)
https://kdpu.edu.ua/fizyky-ta-metodyky-ii-navchannia/naukova-robota/aspirantura/104-fizyka-ta-astronomiia/aspiranty/18635-zadorozhnii-vitalii-mykolaiovych.html (V. M. Zadorozhnii)
0000-0002-1003-930X (V. M. Zadorozhnii)

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 [12]. The most straightforward and most understandable tool for researching and creating robots is LEGO kits. They do not require special programming knowledge and understanding of the processes occurring in the devices that provide the models. It is enough to have a computer, a designer and a rich imagination—however, the high price limits LEGO's access to robot modelling. The average student can model on such equipment only within the classes and cannot afford to make and keep his model for himself. A more affordable option is the Arduino hardware and software platform. This platform allows the student to show their creativity to a greater extent, but at the same time, it requires a more profound knowledge of programming and radio engineering.

The *aim* of this paper is to demonstrate 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. We chose Arduino as a research tool to combine robotics with physical research. Arduino is a hardware and software platform that 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 [6]. The name Arduino comes from a bar in Ivrea, Italy, where some Arduino founders used to meet. The bar was named after Arduin of Ivrea, the margrave of the March of Ivrea and King of Italy from 1002 to 1014 [8]. The primary purpose of developing Arduino was to teach students how to design electronic devices, but then its capabilities went far beyond conventional engineering.

## 2. Related works

Other educators have repeatedly addressed the use of Arduino. Andreev and Kulinich [1] examines the problem of using information tools in students' educational and research activities. The educational possibilities of the Arduino hardware and software complex in preparing future physics teachers to organise students' innovative activities are highlighted; in particular, examples are given of its use for setting and solving physical problems and for students to create innovative products. The authors suggest using Arduino boards to measure temperature, light and humidity at different points in the room. It also obtained 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 [24] analyse the advantages of using the Arduino hardware and computing platform to create training physical equipment using electronic computing equipment. The complex has advantages, such as convenient open-source software for processing research results, availability of parts for manufacturing equipment, and the ability to change the software and component measurement equipment independently. An example of an experiment for studying convection in a liquid is given.

Martyniuk [11] considers actual problems of development of methodological bases for using microelectronic circuitry in student-physicist professional training. The author describes the possibilities of using the Arduino platform in physics research and designing and manufacturing new training equipment. He recommends using 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. [19] offer "Extracurricular project training in physics: integrating Arduino into the laboratory" with the help of the Arduino platform, carrying out physics experiments from optics and thermodynamics. In total, there are 11 laboratory works offered for elective classes [19]. The proposed works include refraction and reflection, spherical lenses, sensitive and latent heat, thermal expansion in solids and liquids, and photoelectric energy. The authors provide examples of experiments conducted by high school students.

Huang [5] has developed a series of experiments, activities, and lab work to study, measure, and analyse physics phenomena in the classroom using low-cost microcontrollers and open-source electronics. The author has proposed several activities demonstrating scientific research using inexpensive and easily accessible electronics and equipment. Huang [5] 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 [7, 10, 18, 22], 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 focus on students' independent activity (individual, pair, group) in the allotted time (from several minutes to months). The research sequence can be shown as the following: problem definition, hypothesis, problem-solving, discussion of research methods, registration of final results, analysis of the obtained data, summarising, correction, and conclusions. The main thing in the interaction between teacher and student is the student's independence, and the teacher should only adjust the researcher's activities without imposing his own ideas and decisions.

Arduino applications are written in C or C++ programming language [2]. The Arduino concept does not include body or mounting parts. The developer independently chooses the installation method and mechanical protection of processor boards and expansion components. Other manufacturers offer a large number of various sensors and actuators that are compatible with Arduino processor boards. These manufacturers also produce electromechanical elements that work 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. While working with this complex, students can see the communication principles between the software and the devices for which it is designed. The creativity of students is always associated with the application of ideas. When creating robots or automated devices, students are involved in the processes of the technical devices. Applied research, design, construction, and development of manufacturing technologies are a list of activities a child is involved in while creating a new device or reproducing an existing one. Children work with microprocessors and other radio electronics, make device housings and parts, and design and plan work for moving parts. Thus, 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 relatively safe. Moreover, the constant connection and disconnection of sensors, the use of resistors, LEDs, etc., allow students to understand the laws of direct current, serial and parallel connection of conductors. The 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 [3], which has almost all sensors connected to the Arduino UNO board. Develop and test connection scheme. And then, in the second stage, work with real devices. This can prevent damage to the parts or board.

The result of the above student research is the creating of an automated or controlled device. One of the ways to improve the quality of physics study is to involve children in manufacturing measuring devices, which can then be used in laboratory physics. Microprocessor data processing enables more accurate measurements of physical quantities. Arduino sensors allow one 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 one 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 with only one version of the assembly will develop little creativity and will not allow a better understanding of physical phenomena.

However, it should be noted that children working with such a set can work with the electronic circuit and its components, learn to work with a soldering iron and develop skills to adjust the operation of electric motors. Also, the pupils' creativity in the afterschool activity improves the ready-made basic model. So, one of the improvements was the addition of a photoresistor and LEDs to the Arduino board, which expanded the device's capabilities. 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 a photoresistor when studying the topic of "Semiconductors" in physics lessons, as coordination is provided by changing the current in the photoresistor.

Another project 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 implementing such a project.

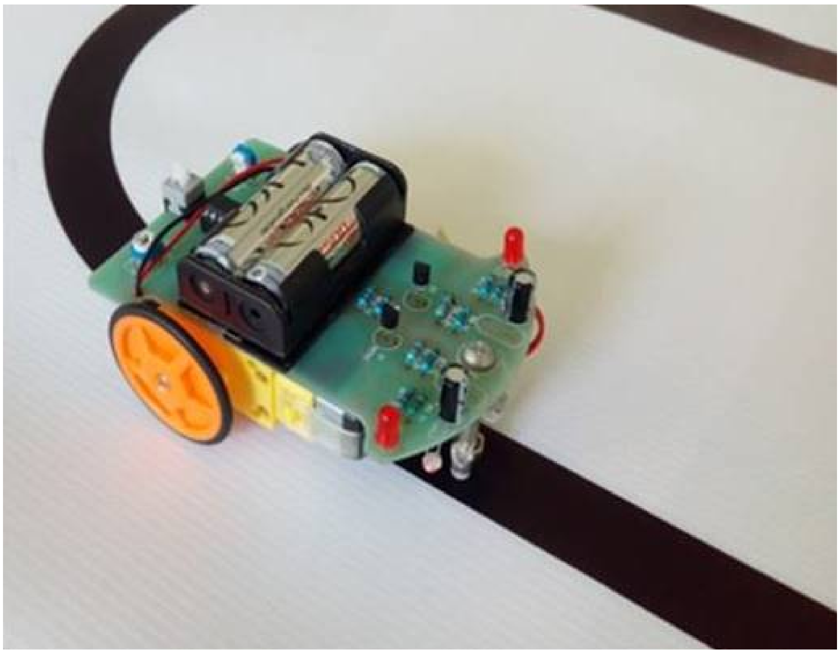

**Figure 1:** Robot D2-1 on the track.

School students learn about temperature, humidity, and pressure as part of the above topic. 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's 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 based on the Atmega8 chip (figure 2a). Nevertheless, the student who worked on the project suggested her device design (figure 2b), which works from the Arduino board and transmits data at a distance of up to 60 meters using a Bluetooth device.

It is crucial 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 device. Another student developed an application for a mobile phone (figure 3), which displays the results of measurements and allows you to save and view them. In this way, cooperation develops students' ability to work in a team. It brings them closer to the realities of life because one person does not perform large and complex projects, and the result depends on the team's interaction.

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

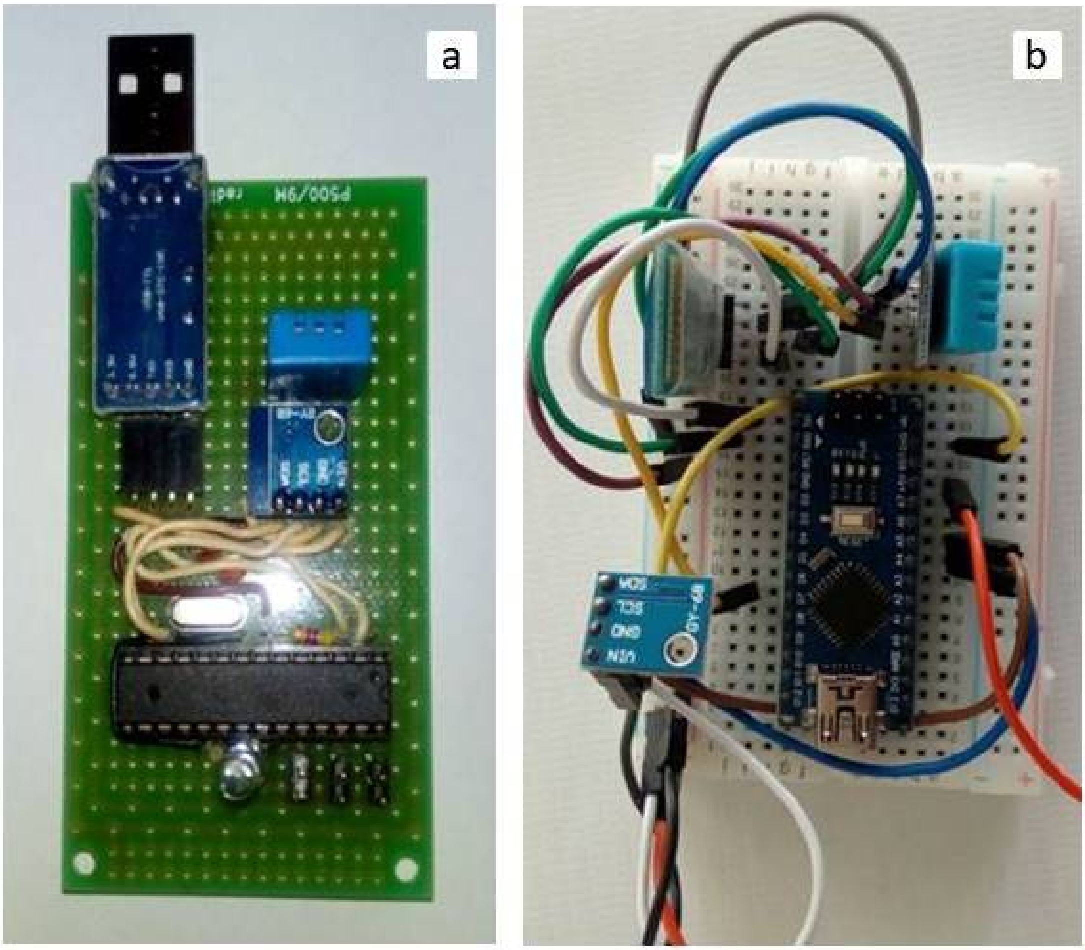


**Figure 2:** Meteorological station: a) with Atmega8 chip, data transmission via wire; b) with Arduino Nano board and wireless data transfer.

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), and "Determination of acceleration of free fall" (10th grade).

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

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 display; return the servomotor to the starting position with the help of the control panel; further the following experiment can be performed. Usually, in laboratory work, the ball is


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

released by the hand, and the hand tries to turn on the stopwatch synchronously and stop the countdown when hitting the ball against a metal cylinder. These actions lead to a great deal of error when doing research. The results of the studies are shown in tables 1 and 2.

Studies have 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. The use of microcontrollers can improve the quality of the experiments.

This setting can also be used to measure free-fall acceleration. 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. Five balls of different masses were taken to investigate the value of free fall acceleration (figure 7).


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

**Table 1**
Measurement of time of uniformly accelerated motion in a 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 %

The scientific research method used for this is called extrapolation. Throwing all the balls in the air in turn, one can get the value of the free-fall acceleration in a vacuum, extrapolating the dependence of this 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. Bodies with different masses used ordinary table tennis balls with a diameter of 40 mm.

Measuring the time of falling of different balloons by weight would give the most accurate result; achieving the most significant difference in the masses of balloons is desirable. For a

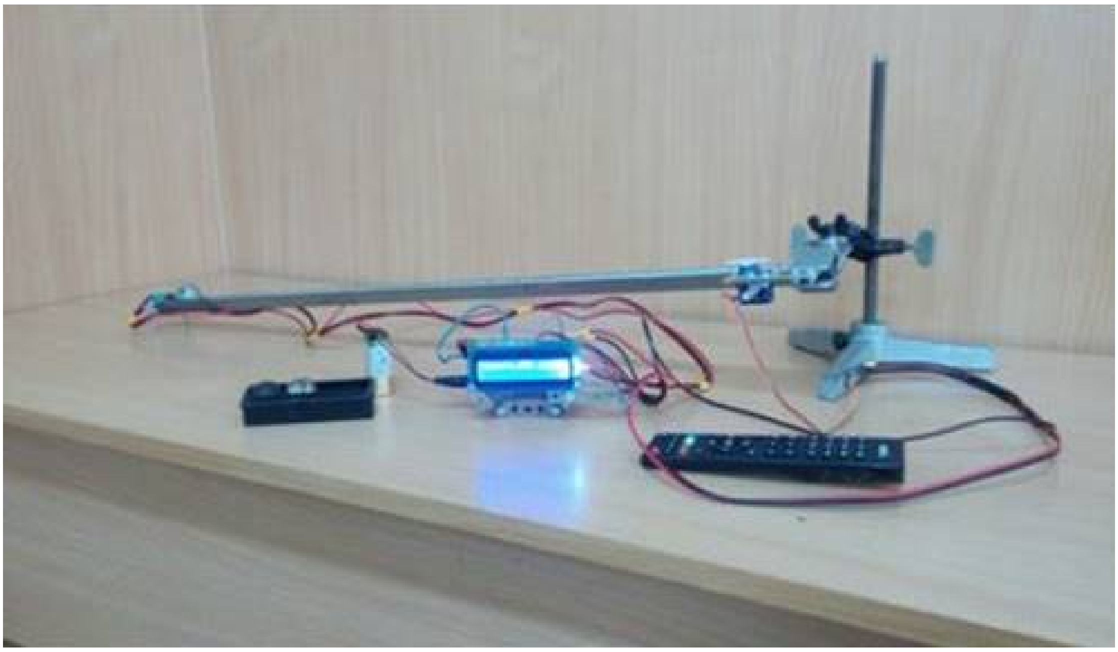

**Figure 5:** Installation for measuring the time of uniformly accelerated motion.

**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 % |

mass change, they were filled with different materials (figure 7). Therefore, the lightest used ball is empty, and the hardest is 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, and a mechanical button was attached to the bottom, on which the ball would fall. With the help of movable holders, one can change the distance from the point of launching the ball to the button, experimenting with different fall heights. A shield is attached to the button

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

to insert the ball into the button and prevent the heavy ball from breaking into the iron holder and the floor. Studies have 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 because the ball, falling downwards, may deviate from the vertical position 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,


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

which causes the timer on the device to work with delays. We performed 15 measurements for all five beads to minimise the time discrepancy 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 a vacuum for the study room of physics. The obtained value of the free-fall acceleration in a vacuum was equal to 9.8093 $m/s^2$. The research was presented at the competition to protect the 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

In this paper, we have presented our experience using the Arduino hardware and software platform to develop research competencies for secondary and high school students. We have shown some examples of research projects that allow students to demonstrate their engineering skills and explore various physical phenomena and processes. The projects include creating simple devices, such as a thermometer, a hygrometer, a light sensor, etc., as well as more complex devices, such as a device for measuring the acceleration of free fall, a device for studying the motion of a pendulum, etc. The projects also involve the use of Arduino-compatible sensors, such as ultrasonic sensors, humidity sensors, light sensors, etc.

The Arduino-based devices the students have developed work well and are used in physics teaching. These examples illustrate the potential of using microcontrollers and compatible sensors in the individual and teamwork of students for making simple devices following ready-made instructions and devices that enable scientific research, for making toys and measuring instruments used during physical experiments.

We also discuss the appropriate use of automated devices in physical measurements and argue that they should not replace all classic measuring devices. For example, when performing laboratory work on the topic "Determining the acceleration of accelerated motion" in grade 10, it is advisable to use an Arduino-based device instead of a stopwatch to measure time since the human factor introduces a significant error that cannot be calculated later. However, using a ruler to measure distance is preferable since it allows one to make accurate measurements, calculate the measurement error, and improve the ability and skills to measure length (width, height, path, distance, etc.). Similarly, when measuring humidity, it is reasonable to ask students to determine the absolute humidity based on the results of measuring relative humidity and temperature.

Therefore, using Arduino in educational and research activities effectively increases interest in computer science, engineering, and physics. A comprehensive approach enables students to be interested in mathematics, solve modern problems of engineering and electronics, and develop their creative abilities. Working on their projects allows students to showcase their talents and present their projects at various competitions, which further motivates young researchers. The devices developed by the students significantly improved the accuracy of measurements during the experiment, increased the level of theoretical preparation for laboratory work, increased the general interest in laboratory work by modernising the equipment, and formed new ideas about phenomena and physics processes.

## References

[1] Andreev, A. and Kulinich, A., 2017. The use of hardware and software Arduino in innovation activity of future physics teachers and students. *Journal of Information Technologies in Education (ITE)*, (31), pp.020–031. Available from: https://doi.org/10.14308/ite000630.

[2] Arduino, 2021. Arduino - Home. Available from: https://www.arduino.cc/.

[3] Autodesk, Inc., 2021. Tinkercad | From mind to design in minutes. Available from: https://www.tinkercad.com/.

[4] Budianskii, D., Drushlyak, M. and Semenikhina, O., 2021. Analysis of e-resources for the specialist's rhetorical culture development. *Educational Technology Quarterly*, 2021(1), p.87–102. Available from: https://doi.org/10.55056/etq.15.

[5] Huang, B., 2015. Open-source Hardware – Microcontrollers and Physics Education – Integrating DIY Sensors and Data Acquisition with Arduino. *2015 ASEE Annual Conference & Exposition, Seattle, Washington*. pp.26.1205.1–26.1205.13. Available from: https://doi.org/10.18260/p.24542.

[6] John, 2020. Story and History of Development of Arduino. Available from: https://www.circuitstoday.com/story-and-history-of-development-of-arduino.

[7] Kukharchuk, R.P., Vakaliuk, T.A., Zaika, O.V., Riabko, A.V. and Medvediev, M., 2022. Implementation of STEM learning technology in the process of calibrating an NTC thermistor and developing an electronic thermometer based on it. In: S. Papadakis, ed. *Joint Proceedings of the 10th Illia O. Teplytskyi Workshop on Computer Simulation in Education, and Workshop on Cloud-based Smart Technologies for Open Education (CoSinEi and CSTOE 2022) co-located with ACNS Conference on Cloud and Immersive Technologies in Education (CITEd 2022), Kyiv, Ukraine, December 22, 2022*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 3358, pp.39–52. Available from: https://ceur-ws.org/Vol-3358/paper25.pdf.

[8] Kushner, D., 2011. The Making of Arduino: How five friends engineered a small circuit board that's taking the DIY world by storm. Available from: https://spectrum.ieee.org/geek-life/hands-on/the-making-of-arduino.

[9] Kuzminska, O., 2021. Selecting tools to enhance scholarly communication through the life cycle of scientific research. *Educational Technology Quarterly*, 2021(3), p.402–414. Available from: https://doi.org/10.55056/etq.19.

[10] Lovianova, I., Krasnoschok, A., Kaluhin, R., Kozhukhar, O. and Dmytriyev, D., 2021. Methodical preparation as a means of developing prospective mathematics teachers' ICT competency. *Educational Technology Quarterly*, 2021(2), p.331–346. Available from: https://doi.org/10.55056/etq.14.

[11] Martyniuk, O.S., 2014. Osoblyvosti metodyky navchannia studentiv (maibutnikh uchyteliv fizyky ta zahalnotekhnichnykh dystsyplin) osnov mikroelektroniky ta osvitnoi robototekhniky [Features of methods of teaching students (teachers of physics and general technical disciplines to be) fundamentals of microelectronics and educational robotics]. *Naukovyi chasopys Natsionalnoho pedahohichnoho universytetu imeni M. P. Drahomanova. Seriia 3 : Fizyka i matematyka u vyshchii i serednii shkoli*, (14), pp.50–58. Available from: http://enpuir.npu.edu.ua/handle/123456789/15554.

[12] Merzlykin, P., Kharadzjan, N., Medvediev, D., Zakarliuka, I. and Fadieieva, L., 2018. Scheduling Algorithms Exploring via Robotics Learning. In: V. Ermolayev, M.C. Suárez-Figueroa, V. Yakovyna, V.S. Kharchenko, V. Kobets, H. Kravtsov, V.S. Peschanenko, Y. Prytula, M.S. Nikitchenko and A. Spivakovsky, eds. *Proceedings of the 14th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kyiv, Ukraine, May 14-17, 2018*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 2104, pp.359–365. Available from: https://ceur-ws.org/Vol-2104/paper_167.pdf.

[13] Nechypurenko, P., Evangelist, O., Selivanova, T. and Modlo, Y.O., 2020. Virtual Chemical Laboratories as a Tools of Supporting the Learning Research Activity of Students in Chem-

istry While Studying the Topic "Solutions". In: O. Sokolov, G. Zholtkevych, V. Yakovyna, Y. Tarasich, V. Kharchenko, V. Kobets, O. Burov, S. Semerikov and H. Kravtsov, eds. *Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 2732, pp.984–995. Available from: https://ceur-ws.org/Vol-2732/20200984.pdf.

[14] Nechypurenko, P. and Semerikov, S., 2017. VlabEmbed - the New Plugin Moodle for the Chemistry Education. In: V. Ermolayev, N. Bassiliades, H. Fill, V. Yakovyna, H.C. Mayr, V.S. Kharchenko, V.S. Peschanenko, M. Shyshkina, M.S. Nikitchenko and A. Spivakovsky, eds. *Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 1844, pp.319–326. Available from: https://ceur-ws.org/Vol-1844/10000319.pdf.

[15] Nechypurenko, P., Semerikov, S., Selivanova, T. and Shenayeva, T., 2021. Selection of ICT tools for the development of high school students' research competencies in specialized chemistry training. *Educational Technology Quarterly*, 2021(4), p.617–661. Available from: https://doi.org/10.55056/etq.22.

[16] Nechypurenko, P.P., Chernova, M.P., Evangelist, O.O. and Selivanova, T.V., 2023. Enhancing student research activities through virtual chemical laboratories: a case study on the topic of Solutions. *Educational Technology Quarterly*, 2023(2), p.188–209. Available from: https://doi.org/10.55056/etq.603.

[17] Nechypurenko, P.P. and Soloviev, V.N., 2018. Using ICT as the Tools of Forming the Senior Pupils' Research Competencies in the Profile Chemistry Learning of Elective Course "Basics of Quantitative Chemical Analysis". In: A.E. Kiv and V.N. Soloviev, eds. *Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 2257, pp.1–14. Available from: https://ceur-ws.org/Vol-2257/paper01.pdf.

[18] Oleksiuk, V.P. and Oleksiuk, O.R., 2022. Examining the potential of augmented reality in the study of Computer Science at school. *Educational Technology Quarterly*, 2022(4), p.307–327. Available from: https://doi.org/10.55056/etq.432.

[19] Petry, C.A., Pacheco, F.S., Lohmann, D., Correa, G.A. and Moura, P., 2016. Project teaching beyond Physics: Integrating Arduino to the laboratory. *2016 Technologies Applied to Electronics Teaching (TAEE)*. pp.1–6. Available from: https://doi.org/10.1109/TAEE.2016.7528376.

[20] Polat, E., 2023. Gamification implementation for educational purposes: a scoping review (2013-2018). *Educational Technology Quarterly*, 2023(3), p.367–400. Available from: https://doi.org/10.55056/etq.589.

[21] Rashevska, N.V., Semerikov, S.O., Zinonos, N.O., Tkachuk, V.V. and Shyshkina, M.P., 2020. Using augmented reality tools in the teaching of two-dimensional plane geometry. In: O.Y. Burov and A.E. Kiv, eds. *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 2731, pp.79–90. Available from: https://ceur-ws.org/Vol-2731/paper03.pdf.

[22] Seidametova, Z., Abduramanov, Z. and Seydametov, G., 2022. Hackathons in computer science education: monitoring and evaluation of programming projects. *Educational*

*Technology Quarterly*, 2022(1), p.20–34. Available from: https://doi.org/10.55056/etq.5.

[23] Shepiliev, D.S., Semerikov, S.O., Yechkalo, Y.V., Tkachuk, V.V., Markova, O.M., Modlo, Y.O., Mintii, I.S., Mintii, M.M., Selivanova, T.V., Maksyshko, N.K., Vakaliuk, T.A., Osadchyi, V.V., Tarasenko, R.O., Amelina, S.M. and Kiv, A.E., 2021. Development of career guidance quests using WebAR. *Journal of Physics: Conference Series*, 1840(1), p.012028. Available from: https://doi.org/10.1088/1742-6596/1840/1/012028.

[24] Somenko, D. and Somenko, O., 2016. Using the capabilities of the Arduino hardware computing platform in a laboratory workshop in physics. *Naukovi zapysky. Seriia: Problemy metodyky fizyko-matematychnoi i tekhnolohichnoi osvity*, 1(9). Available from: https://phm.cuspu.edu.ua/ojs/index.php/NZ-PMFMTO/article/view/988.

[25] Vakaliuk, T.A., Kontsedailo, V.V., Antoniuk, D.S., Korotun, O.V., Mintii, I.S. and Pikilnyak, A.V., 2019. Using game simulator Software Inc in the Software Engineering education. In: A.E. Kiv and M.P. Shyshkina, eds. *Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 2547, pp.66–80. Available from: https://ceur-ws.org/Vol-2547/paper05.pdf.

[26] Vlasenko, K.V., Volkov, S.V., Lovianova, I.V., Sitak, I.V., Chumak, O.O. and Bohdanova, N.H., 2023. Exploring usability principles for educational online courses: a case study on an open platform for online education. *Educational Technology Quarterly*, 2023(2), p.173–187. Available from: https://doi.org/10.55056/etq.602.