Formation of Programming Skills among Students of Scientific, Technical and Natural Science Areas of Training Using the Arduino Platform

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Abstract—The problem of improving the educational process of students of scientific, technical and natural science areas of training is one of the relevant aspects of modern pedagogical research. During training, it is necessary to apply new approaches, educational technologies and techniques in order to prepare graduates who are able to independently solve complex scientific, technical and engineering design tasks in the process of modern production. Programming is a universal tool for modeling objects and processes, as well as a powerful tool in developing the thinking of students of scientific, technical and natural science fields of training. The article discusses the issues of formation of programming skills of students based on the use of the Arduino platform. The professional standards are analyzed, the main contradictions of the existing system of training future bachelors in the field of radio electronics and control systems are revealed. The method of organizing effective programming training based on the use of the Arduino platform is presented. The criteria and indicators of the levels of competence formation are given. The results of an experiment on the implementation of the described methodology of teaching programming on the basis of the I.N. Ulyanov Chuvash State University are shown. Using the chi-square criterion, statistical processing of the results of a pedagogical experiment was performed, which convincingly proves that when using the Arduino platform, most students have reached high and advanced levels of programming skills formation.

Keywords—programming training, computer science, information technology, radio electronics, Arduino platform, microcontroller systems, C++ programming language

1 Introduction

The priority direction of modern vocational education is the improvement of the educational process system, the development of new teaching tools and methods. The consistency of the general education material studied by students of technical and natural science areas of training with professional and practical activities allows students to demonstrate the real, concrete application of knowledge in their future professional activities. The formation of the basics of programming is one of the necessary skills for the formation of future specialists in the field of radio electronics and control systems, as well as in other spheres of human activity. When studying the basics of programming in the field of radio electronics and control systems, good knowledge in the field of mathematics is necessary.

One of the disciplines that allow you to form programming skills at the Faculty of Radio Electronics and Automation of the I.N. Ulyanov Chuvash State University is the discipline "Computer Science and Information Technologies in Radio Electronics". The purpose of studying the discipline is to instill the skills of algorithmic thinking; teaching the basics of programming; familiarizing students with the principles of information presentation and with modern technical means designed to automate work with information; as well as in the application of competencies acquired in the learning process, in practice. The working program of the discipline includes the section "Fundamentals of Programming", in which students are taught programming in a high-level C++ language. The C++ programming language is widely used in programming embedded systems, microcontrollers and microcontroller systems. Senior students use it to solve applied problems in electronics, radio engineering and automation. Such extensive use of the programming language is due to its advantages: cross-platform program portability, high performance with a relatively small size of executable files, a large number of educational literature and reference materials, a wide selection of ready-made libraries of routines, the availability of freely distributed free compilers.

Modern control systems and radio electronics are complex hardware and software complexes. The possibilities of using such systems are largely determined by the software. The C++ language allows programming the operation of such devices. Therefore, in order to develop programming skills among students studying at the Faculty of Radio Electronics and Automation, the program of the discipline "Computer Science and Information Technology in Radio Electronics" includes the creation of prototypes of radio electronic devices based on the Arduino hardware and software complex.

The improvement of real-time computing systems is one of the priorities of the development of world science, technology and technology. In order for graduates of technical and natural science faculties to be involved in this trend in specific industries, they need to master programming of real-time systems in the process of studying at the university.

The use of the Arduino platform is a good start for teaching programming to students of technical and natural science specialties. This tool allows you to quickly learn how to program electronic devices from the simplest basics (button control and LED control) to complex prototypes (for example, robots supporting production processes).

When studying microcontrollers, interdisciplinary integration of such fields as discrete mathematics, electronics, microprocessor technology, computer science, computer technology, automatic process control systems, etc. takes place; the development of skills of system and algorithmic thinking, creative approach in solving research and applied problems. The learning process becomes more interesting, emotionally and personally meaningful.

The solution of the problem of introducing future students to design, scientific, technical and experimental research activities through the inclusion of university students in various types of creative activity is analyzed in the papers [1,2]. The possibility of developing the professional competence of students of technical universities while studying at the student design bureau is justified in the article [3]. Quite a large number of articles are devoted to the formation of programming skills. For example, for beginners [4], for schoolchildren [5,6] and for students [7], both based on Scratch blocks [8] and Python programming environments [9] and Java [10]. The article is devoted to the assessment of the level of competence formation in the field of programming of future computer science teachers and IT specialists [13]. The analysis of the problem of professional training of a programmer is considered in [14]. The use of the Arduino platform in the training of first-year students provides an easy entry into programming and reduces the threshold for entering the specialty. The article [15, 16] analyzes studies related to programming training based on the use of Arduino. The study of the method of teaching programming using Arduino in the era of the Internet of Things is considered in [17]. Articles [18, 19] reveal scientific and methodological aspects of the use of microcontroller platforms in training. Despite this, the process of forming programming skills for students of technical and natural sciences has not been studied enough.

2 Research methods

The purpose of the study is the possibility of substantiating the educational methodology of teaching students programming using the Arduino platform and checking the effectiveness of its application in experimental work.

The object of research is the process of professional training of students of technical faculties.

The subject of the research is the use of the Arduino platform in the formation of programming skills among first-year students of technical and natural science fields of training.

The materials for this study were both foreign scientific sources and domestic research. In the course of the research, we used theoretical (analysis, comparison, classification, systematization, generalization)—analysis of scientific, psychological, pedagogical and methodological literature on the problem, study of the experience of teaching programming and the features of practical training of students in technical and natural science areas of training, empirical (questionnaires, observation, interviewing, the method of expert assessments)—to determine the level of professional training of university students, experimental methods—to test the effectiveness of the proposed methodological system and methods of mathematical statistics for analyzing the data obtained, determining quantitative indicators for the studied phenomena and processes, testing the hypothesis of the study.

The empirical basis of the study is the data of experimental work conducted at the I.N. Ulyanov Chuvash State University. A total of 78 university students participated in the study at various stages.

3 Results of the research and discussion

In the Federal State Educational Standard 3++ in the direction of bachelor's degree 11.03.01 "Radio Engineering", 11.03.04 "Electronics and nanoelectronics", special attention is paid to the formation of computer literacy of students. This category (group) of general professional competencies is represented by the following competencies: OPK-4—student is able to understand the principles of modern information technologies and use them to solve problems of professional activity and OPK-5—student is able to develop algorithms and computer programs suitable for practical use.

Based on the analysis of competencies, it can be concluded that the effectiveness of the course "Computer Science and Information Technologies in Radio Electronics" will be significantly higher if students are shown the real need for programming. The practical part of training in this discipline is directly related to the design and development of software. The best result of the practical application of knowledge, skills and abilities is achieved by solving tasks that carry a payload. This requirement can be fully fulfilled by using the Arduino software and hardware platform in teaching programming to students of the Faculty of Radio Electronics and Automation.

Arduino is an open source platform used to create projects in the field of electronics. Arduino consists of both a physical programmable printed circuit board (often called a microcontroller) and a piece of software or IDE (integrated development environment) that runs on a computer and is used to write and download computer code to a physical board.

The Arduino IDE development environment allows you to insert codes written in the low-level machine-oriented programming language Assembler to solve real-time system problems.

The peculiarity of Arduino is that for its first use, voluminous, specific knowledge concerning the device and the principle of operation of the microcontroller is not required, and there is also no need for programming skills. This is due to the fact that the controller was created to solve one difficult problem—how to teach students to create electronic devices, and quickly. A simple project can be created by a beginner in a very short period of time, but at the same time Arduino allows you to create large-scale projects with complex algorithms for controlling various peripheral devices. This turns the Arduino platform into a flexible tool for designing automated and automated control systems at the physical and software levels. The use of the platform in the preparation of bachelors in the field of radio electronics and control systems will allow students to form knowledge about the design and principles of electronic systems, and will also contribute to the development of skills in the design, prototyping and programming of such systems. The physical (hardware) level involves the assembly of electrical circuits of prototypes of various devices, as well as their debugging. At this stage, the simplest and most effective solution is to use standard samples of radio components and a special breadboard—bredboard. The breadboard consists of holes-sockets with a pitch of 2.54 mm (0.1 inches), the size corresponds to the pitch of the terminals of modern radio components. The assembly of prototypes on such a board is carried out without etching and soldering contacts.

The C/C++ language is used for programming Arduino devices. The programs are created in the Arduino IDE development environment, which is provided free of charge on the official website of the project.

The intuitive shell, written in Java, contains a text editor, a project manager, a preprocessor compiler, as well as tools for directly loading the program into the controller. The development environment is connected to the controller hardware via a USB cable. The editor has examples of programs (sketches) frequently used by users and a lot of various libraries for easier and more productive work.

The creation of electrically controlled devices based on the Arduino microcontroller gives students the opportunity to study the main points of modeling, designing and programming devices and obtain the necessary knowledge and skills for self-realization in the field of engineering, information technology and programming. Students, having created a program, can immediately observe the results of their work. The program turns into an algorithm for controlling a real device that has just been assembled with your own hands. This motivates, arouses interest in this activity.

The pedagogical condition for the formation of programming skills among first-year students using the Arduino platform is the development and implementation of a structural and functional model in the educational process.

The model is considered as a system consisting of hierarchically subordinate components: motivational-target block, methodological block, substantive-procedural block, evaluative-effective block. The components of this model reveal the internal organization (structure) of the process of forming programming skills among students of scientific, technical and natural science fields of training using the Arduino platform, are responsible for the adequate reproduction of the interaction between the elements of this process and have a functional purpose.

The first component of the model (motivational-target block) is based on the requirements of the Federal State Educational Standard based on the social order of society and the state and orienting the higher education system to the formation of general professional competencies of students in the category of computer literacy.

To achieve this goal, the following tasks are set:

1. Familiarization of students with the software of the Arduino product line and the ability to find their application depending on the tasks set using a programming language tool.
2. Development of skills to link programming and design of electronic devices of various levels of complexity.
3. In-depth study of physics, mathematics, computer science and information technology.
4. Inclusion of students in research and project activities.
5. Involvement in solving real (production and technological) problems.

The methodological block of the model contains approaches and corresponding principles for the formation of programming skills among students of scientific, technical and natural science areas of training using the Arduino platform.

We use the following methodological approaches: systemic, activity-based and personal. The following principles correspond to these approaches: integrity, development, activity, variability, accessibility, psychological comfort and creativity, development of independence and initiative.

In the third, substantive and procedural block of the model, the stages of the formation of programming skills among students of technical and natural science areas of training using the Arduino platform are presented.

1. Problem statement, search for ways to solve it.

At this stage, the goal of solving the problem is formulated, the content is comprehended. The prototype of modeling, its properties, parameters that are the initial data and results, the relationship between the initial data and results, build a course of action to achieve the goal of modeling. Thus, in the form of asking questions and searching for answers, the formalization of the task is performed

2. Prototyping, designing and writing a program.

At the second stage, a prototype of a working model is created. During prototyping, a more detailed picture of the system device is visible. At the second stage, two levels are viewed: reproductive (work on a sample) and creative (development of own devices and programs).

Prototyping, according to some developers, is the most important stage of development. The selected hardware and software solutions are evaluated, potentially problematic issues are studied from the point of view of subsequent implementation. A conclusion is formed about the correctness of the choice of the target platform.

After the prototyping stage, the stages of revision of the system architecture, development, implementation and testing of the final product necessarily follow.

3. Testing and adjustment

At the third stage, the student must check the created model for compliance with the specified sample and command execution options. The third stage may be the longest of all, since testing and adjusting the device can take quite a long time.

4. Analysis of simulation results

This stage determines the further sequence of actions: either the study ends with a decision, or it continues. If the results of the experiment do not correspond to the objectives of the task, it means that mistakes were made at the previous stages of modeling. Errors must be identified and corrected by the model at any of the previous stages, i.e. a return to one of the modeling stages is performed. The process is repeated until the results of the experiment meet the objectives of the simulation. At this stage, students develop the skills of evaluating and understanding the result, as well as a semantic personal attitude, which consists in understanding the role of programming as a modeling tool.

In the fourth, evaluative and effective block of the model, criteria are reflected that allow identifying the dynamics of the process of formation of programming skills among students of technical and natural science areas of training using the Arduino platform based on the developed diagnostic tools.

Here is an example of a practical task using the Arduino and LabVIEW platform for students of the Faculty of Radio Electronics and Automation.

The task is focused on the study of methods for filtering the signal received from the microphone based on the fast Fourier transform algorithm. The hardware is implemented on the basis of the Arduino UNO board. The KY-037 sound detection sensor has two outputs: analog and digital. Widely used in robotics and automation systems.

The principle of operation of this module is based on a change in the voltage level at its output D0 when the microphone detects a certain volume level. The module also allows you to use the built-in microphone directly—that is, to connect to a pre-amplifier and then amplify and reproduce the resulting sound. The sensitivity of the sensor is adjusted using a multi-turn tuning resistor located on the board. With his help, it turns out quite accurately. Both the analog signal level and the comparator trigger threshold are regulated. The sensor operates at a voltage from 3.3 to 5 V, which makes it compatible with most microcontrollers.

Visualization of the obtained data was performed using the LabVIEW environment (Laboratory Virtual Instrument Engineering Workbench), which allows to create a convenient user interface of a virtual instrument (Figure 1).

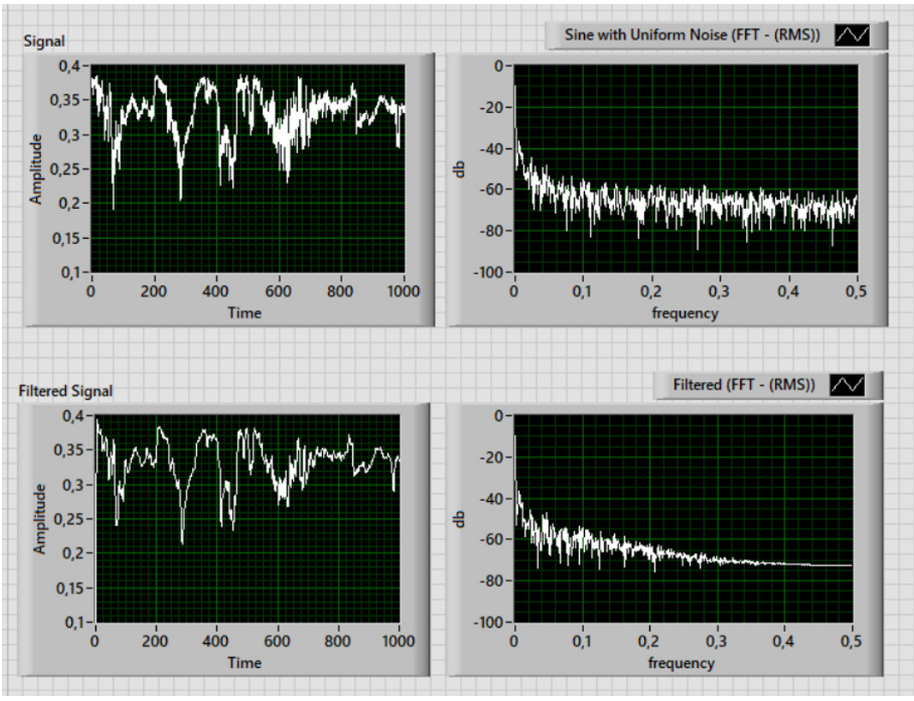

Fig. 1. Front panel with graphs of the original and filtered signal

The advantage of LabVIEW is the implementation of graphical programming, which makes it possible for students to quickly study it, and knowledge of special commands, functions and operators is not required. To share Arduino and LabVIEW, the LIFA library (LabVIEW interface for Arduino) is used.

Experimental work to assess the effectiveness of the formation of programming skills among students of scientific, technical and natural science areas of training using the Arduino platform was carried out at the I.N. Ulyanov Chuvash State University, while the experiment was conducted under normal learning conditions, with respect to the uniformity of respondents [20]. The study covered 78 students of the Faculty of Radio Electronics and Automation.

Statistical processing of the experimental results was carried out using the Pearson agreement criterion χ^2 (chi-squared). This criterion is used to compare the distributions of objects of several aggregates according to the state of a certain property based on measurements on the scale of names of this property in several independent samples from the considered population. The essence of the method is to check the degree of discrepancy between the observed and expected frequencies—the greater this discrepancy, the greater the value of the chi-square criterion.

In order to assess the effectiveness of the formation of programming skills, the levels of evaluation of programming skills were identified: basic, advanced, high.

Table 1. Criteria for evaluating programming skills

Level	Basic	Advanced	High
OPK-4	Lack of confidence in the use of modern information technologies to solve problems related to professional activity	A significant degree of confidence in the use of modern information technology tools to solve tasks related to professional activity	Knowledge of the principles of modern information technologies, developed ability to use them to solve problems related to professional activity
OPK-4	The skills of writing an algorithm and a computer program are at the template level	The ability to choose the most effective algorithm and computer program	The ability to be creative when writing an algorithm and a computer program

In accordance with the selected criteria, the students of the experimental and control subgroups were divided into three groups according to the level of training (Figure 2).

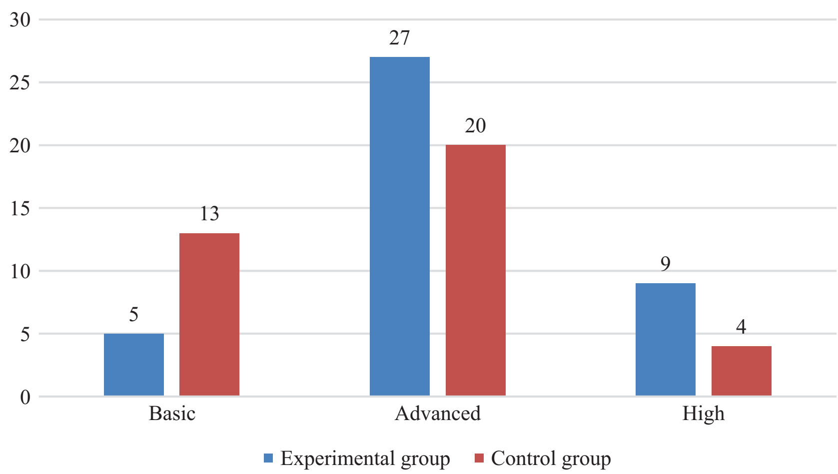

Fig. 2. Levels of formation of students' programming skills

To test the hypothesis, the criterion χ^2 was used, because in the conditions of our study, all the conditions for applying this criterion are met: both samples are random; the samples are independent, and the members of each sample are independent of each other; the measurement scale is larger than the scale of names with several categories.

For hypothesis H_0, it is accepted that the level of programming skills formation among students of scientific, technical and natural science areas of training is not affected by the use of the Arduino hardware and software system. In the case of an unconfirmed H_0, an alternative hypothesis H_1 is accepted: if the use of the Arduino hardware and software system is introduced into the educational process of students of scientific, technical and natural science areas of training, a higher level of programming skills can be expected.

A table of empirical frequency distributions is obtained for the observed frequencies (Table 2).

Table 2. Distribution of empirical frequencies

Group	Experimental Group	Control Group	Total by Level
Basic	5	13	18
Advanced	27	20	47
High	9	4	13
Students	n_1=41	n_2=37	n=78

A table of theoretical frequencies is constructed (Table 3). To do this, the sum of the row is multiplied by the sum of the column and the resulting number is divided by the total sum (*n*).

Table 3. Table of distribution of theoretical frequencies

Group	Experimental Group	Control Group	Total by Level
Basic	(18×41)/78=9,46	(18×37)/78=8,54	18
Advanced	(47×41)/78=24,71	(47×37)/78=22,29	47
High	(13×41)/78=6,83	(13×37)/78=6,17	13
Students	n_1=41	n_2=37	n=78

For convenience of calculations, the data are presented in the form of a summary table (Table 4).

Table 4. Summary table of frequency distribution

Group	Level	Empirical	Theoretical	(E − T_{cr})2/T_{cr}
Experimental group	Basic	5	9,46	2,10
	Advanced	27	24,71	0,21
	High	9	6,83	0,69
Control group	Basic	13	8,54	2,33
	Advanced	20	22,29	0,24
	High	4	6,17	0,76
The value of the criterion χ^2				Σ 6,33

In the table of critical values, we find the value for our case at the error level α = 0.05 and the degree of freedom 2, the critical value of *Tcr* = 5.99. The observed value of the criterion $\chi^2 = 6.33$ is greater than the critical one, which means that the hypothesis H_0 is rejected and the alternative hypothesis H_1 is accepted.

The degree of formation of programming skills in the discipline "Computer Science and information technology in radio electronics" among students of scientific, technical and natural science areas of training of the experimental group studying the discipline using the Arduino platform is higher than among students of the control group studying the discipline without using this platform (Figure 2). Obviously, the use of the Arduino hardware and software system contributes to the formation of programming skills of students of scientific, technical and natural science areas of training.

4 Conclusion

The following conclusions can be drawn from the article: the use of Arduino in the educational process, in the training of specialists in the field of radio electronics and control systems provides students with the opportunity to apply the knowledge, skills and abilities acquired during training at the hardware and software levels, which will create additional motivation for further study of the device and principles of automated and automatic systems.

The creation of prototypes of real devices based on Arduino will allow students of various specialties and training areas to be involved in scientific work. Further development of programming skills involves the improvement of knowledge and skills in the process of preparing bachelor's (master's) theses and competitive works in the field of embedded control systems. On the basis of the Arduino hardware-software (instrumental) system, it is possible to organize effective links between theoretical knowledge and practical skills formed in the process of learning programming. At the senior undergraduate courses, with the advent of specialization disciplines, students study more complex systems based on STM32, MSP430 and FPGA programming, and at the master's degree they already solve specific tasks provided by partner enterprises.

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