



Zhytomyr Ivan Franko State University Journal.
Pedagogical Sciences. Vol. 1 (108)

Вісник Житомирського державного
університету імені Івана Франка.
Педагогічні науки. Вип. 1 (108)

ISSN (Print): 2663-6387
ISSN (Online): 2664-0155

UDC 62:374:004.231.3

DOI 10.35433/pedagogy.1(108).2022.198-208

THE USE OF VISUAL ELECTRONIC CIRCUITS MODELLING AND DESIGNING SOFTWARE FRITZING IN THE EDUCATIONAL PROCESS

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The article analyzes the current state of the issue of STEM-education in general secondary education of Ukraine, considers the prospects of introducing elements of circuitry within the school course of computer science (CS) as one of the elements of STEM-education, moreover, it reviews the possibility of implementation of the mentioned part as one of the components of professional training of computer science teachers. The analysis of the recent researches and publications on a problem of use of electronic devices in educational process is carried out; the choice of the open software platform Arduino as an auxiliary didactic tool for studying the elements of computer circuitry is substantiated. The most common Arduino model series are described and the examples of their applied use in real-life projects are given. The main technical specs and features of Arduino Uno electronic components are given and explained. The Atmega328P microcontroller, the main computing center of the platform, and its main structural elements are considered in detail; in order to substantiate the offered method, a program suite for creating visual electronic circuits – Fritzing is taken as an example with detailed description of its functions and capabilities. This software product provides the opportunity to visually present the project in different forms (layout, scheme and/or printed circuit board). Any of these views can be used as the main work environment of the project and can be selected at any time. Fritzing has a library of ready-made projects, which greatly facilitates the learning process. For greater clarity, all the processes of creating a prototype of the electronic game "Hunter" in the Fritzing environment are described and illustrated, as well as a description of the process of creating the game itself. Mentioned software product is used in the process of professional training of future teachers of computer science, mathematics and physics at Zhytomyr Ivan Franko State University. The authors outline prospects of research in this area.

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Key words: STEM-education, systems for modeling, Arduino, electronics, training project, constructors.

ЗАСТОСУВАННЯ ВІЗУАЛЬНОГО РЕДАКТОРА ЕЛЕКТРОННИХ СИСТЕМ FRITZING У ОСВІТНЬОМУ ПРОЦЕСІ

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В статті проаналізовано сучасний стан проблеми впровадження STEM-освіти в закладах загальної середньої освіти України, розглянуто перспективи запровадження елементів схемотехніки в межах шкільного курсу інформатики, як одного з елементів STEM-освіти і як одного з компонентів фахової підготовки вчителя інформатики. Здійснено аналіз досліджень та публікацій з проблеми використання електронних пристроїв в навчальному процесі. Авторами статті обґрунтовано вибір відкритого програмного комплексу Arduino, як допоміжного дидактичного засобу вивчення елементів комп'ютерної схемотехніки. Описані найбільш розповсюджені платформи модельного ряду Arduino та наведено приклади застосування зазначених платформ в реальних проектах. Представлено основні технічні характеристики електронних елементів, що входять до складу Arduino Uno. Детально розглянуто мікроконтролер Atmega328P, основний обчислювальний центр платформи, та основні складові зазначеного мікроконтролера. Для обґрунтування запропонованої методики розглянуто та описано програму для створення наочних електронних схем Fritzing. Даний програмний продукт надає можливість візуального представлення проекту у різних видах (макет, схема та друкована плата). Будь-яке з цих представлень може використовуватися в якості основного робочого середовища проекту та може бути вибрано в будь-який час. Зазначений програмний продукт має бібліотеку готових проектів, яка значно полегшує процес навчання. Для більшої наочності описано та проілюстровано усі процеси створення прототипу електронної гри "Hunter" в середовищі Fritzing, а також опис процесу створення самої гри. Програмний продукт Fritzing використовується в процесі фахової підготовки майбутніх вчителів інформатики, математики та фізики в Житомирському державному університеті імені Івана Франка. Авторами окреслено подальші напрями досліджень з даної галузі.

Ключові слова: STEM-освіта; системи для моделювання; Arduino, електроніка, навчальний проект, конструктори.

Introduction of the issue. In the Ukrainian system of secondary education, STEM-learning (STEM-education) is becoming more and more widely discussed, combining design and interdisciplinary approaches based on the integration of natural sciences into technology, engineering and mathematics.

STEM-education is the basis for training employees in the field of high technology. Therefore, many countries, including United Kingdom, China, Australia, Israel, Singapore, South Korea, USA, implement government programs in the field of STEM-education [1].

STEM training is extremely important in future perspective. According to data published on the STEMconnector.org website, the need for 8.65 million employees for STEM-related jobs was projected for 2018. Therefore, currently the manufacturing sector needs almost 600,000 specialists with the necessary skills and qualification. It is expected that over the next 10 years the need for such specialists will increase 4 times compared to other professions.

The distinctive feature of STEM-education is the blended learning environment, which shows students how the scientific method can be applied in everyday life. Thus, it helps to develop

students' practical and analytical thinking and focuses on real-world solutions. Such education should begin as early as possible, preferably even at primary school [2].

Unfortunately, due to lack of experience and knowledge, most teachers are not able to implement this program into the educational process. To resolve this contradiction in the United States, for example, a national program was introduced to train teachers who are willing to work in a single system of natural sciences and technologies [3].

The current form of STEM-education, which is implemented in Ukrainian schools, exists as the extra-curricula selectives and clubs. In addition to physics and mathematics, students learn the basics of robotics, programming, creating and programming their own robots. The classes use, if available, specific technological laboratories and training equipment: 3D printers, visualization tools and more. At the state level, STEM-education is implemented in the form of a number of competitions and contests, namely: Intel Techno Ukraine; Intel Eco Ukraine; Sikorsky Challenge Science Festival, FERREXPO ROBOT FEST.

To support talented youth in most regions STEM-centers were created, which serve as a start-up base that provides the necessary scientific and technical means for further professional development and formation [4].

One of the areas of implementation of STEM-education is circuitry. This is a scientific and technical direction that covers the problems of design and research of electronic circuits.

For teachers and HEI educators, Arduino platform can be the main element for research, which allows to experience and learn the basic elements of circuitry, computer technology and electronics in practice.

Current state of the issue. The works of many scientists and educators reflect the problem of using electronic devices during the educational process

and the development and description of new devices, including the development of creativeness and creative thinking, therefore a number of specific activities were designed by: Ye. Milerian, H. Altshuller, I. Roitman, A. Davydenko, T. Kudriavtsev, V. Moliako, P. Yakobson and other. Such scientist as V. Bykov, P. Atamanchuk, M. Shut, N. Sosnytska, Ye. Smyrnova-Trybulksa in their works paid attention to the methodological and theoretical foundations of the use of information technology in the training of future teachers [5, 6, 10].

Aim of research is to conduct analysis of the hardware component of the Arduino platform, identify its functionality and technical characteristics on the example of the Arduino Uno board; review the Fritzing software package, as well as to determine prospects for its application in educational activities and creation of a visual electronic scheme by its means on the example of an electronic game.

Research methods. The research was conducted within the scientific topic "STEM-education in Ukraine" of the Department of Applied Mathematics and Informatics of Zhytomyr Ivan Franko state university. During the investigation the following methods were used: generalization and systematization of foreign and domestic experience on the problem of introduction of information technologies in the educational field, modeling of prototypes, creation of hardware with use of controllers on the Arduino platform.

Results and discussion. Arduino is a platform designed for prototyping (i.e. development) of various devices. Today, the Arduino has become one of the most popular platforms among amateur engineers. It attracts with its simplicity, compatibility with most operating systems and relatively low cost. Also, the Arduino platform is quite flexible and suitable for a wide range of tasks.

Currently, in addition to the first Arduino Extreme platform, there are a large number of other boards specifically

designed for particular tasks, thus Arduino Uno platform appears to be the most common today.

Arduino Uno is a board with components placed on it, the main of which is a microcontroller ATmega328 with a clock frequency of 16 MHz, the outputs ("legs") of which are conveniently spaced along the edges of the board and signed. This platform has 20 such "legs", 6 of which are analog and the remaining 14 are digital; the platform uses 32 KB of Flash memory. The Arduino Uno is designed to program stand-alone microprocessor objects. It can also connect to software running on a computer.

Let's start with a detailed review of the Arduino Uno power platform. In general, the Arduino has three ways to get power up: via a USB bus using a power connector on the board or the V-in input. When the platform is connected to a computer via USB, the board is powered by a four-wire USB bus structure, where two wires are responsible for transmitting commands and the other two are assigned for powering devices. Thus, the Arduino receives an operating voltage of 5 V. This voltage is fed to the input of the voltage stabilizer, which reduces it to +3.3 V, which is necessary to power some individual components that are connected to the board. To protect against high power consumption (overpower protection – OP), the developer has installed a small 500 mA fuse at the input of the power line, which, in some circumstances, will protect the computer's USB port and the Arduino board from possible power failure or hardware damage. The board has a power connector, such as an AC / DC power adapter, battery, or battery pack. Unlike a USB port, where a stable voltage of 5 V is provided, the power connector is designed to connect power supplies of different voltages. The range of these values ranges from 6 to 20 V. In the case of direct connection, it is not suitable for circuit components. Therefore, at the power input, the

developers put voltage stabilizers (one at 5 V, the other at 3.3 V), as well as two capacitors and a diode as elements of noise control and protection against polarity. If you connect the power supply to the V-in output on the Arduino board, the voltage will fall on the 5 V stabilizer and the board will receive power. This is convenient when using batteries or accumulators without special power connectors. The Arduino itself chooses the power supply with the highest voltage. In this case it is helped by a special element – a comparator – a device that compares the signal applied to it with any reference value. If this signal exceeds the reference value, the comparator outputs a logic unit (in our case +5 V).

Arduino Uno provides a number of options for communicating with a computer, another Arduino platform or other microcontrollers. ATmega328 has a USART receiver, which means "universal synchronous-asynchronous transceiver". It allows serial communication via digital outputs 0 (RX) and 1 (TX). The ATmega16U2 microcontroller on the board connects this receiver to the computer's USB port and allows the Arduino to be defined as a virtual COM port when connected to a PC. The RX and TX LEDs on the board will flash on the board during the USB connection to the computer during data transfer via the USB-USART converter chip.

The Atmega328P microcontroller is the main computing center of the platform. In generalized form, any microcontroller can be divided into three components:

1. Computing unit (arithmetic-logic device or processor). This block is the main part of the system and is designed to perform various operations with numbers. The sequence of these operations is called a program. Each operation is encoded as a number and written to the memory of the microcontroller.

2. A memory module, which is a specialized electronic device that is a set

of cells, each of which can store one number. This is where the program and other microcontroller commands are stored. Memory is divided into random access memory – random access memory (random access memory- RAM) and permanent – ROM (non-volatile storage device – NVSD). The main difference between these types of memory is that in the case of RAM, when the power of the microcontroller is turned on, the recorded values are not saved and exist only as long as there is power. For example, such memory is used to store any intermediate calculation results. But the data stored in non-volatile memory does not depend on the availability of power and can be used by the microcontroller immediately after turning on.

3. I/O ports ("legs"). Some ports are responsible for power and other components connected to the microcontroller, but most of them are I / O ports that are responsible for directly accessing the microcontroller in order to connect various sensors, modules, LEDs, transistors to it. The vast majority of these ports were brought by Arduino developers around the perimeter of the board for convenience.

On the Arduino Uno board two quartz resonators with a frequency of 16 MHz for two microcontrollers are installed respectively. The microcontroller counts the pulses and according to their number reports how much time has passed since the start of any procedure. The Arduino Uno platform has a button called the reset button. Pressing it moves the microcontroller to the starting position from which it began its work.

The most popular environments for working with Arduino are Arduino IDE (basic environment based on the Processing language), FLProg (graphical environment focused on FBD and LAD languages), Fritzing (prototype design program), Minibloq (graphical environment focused on programming training) and Tinkercad (online resource

for simulating the workflow of prototyping) [9].

The Fritzing software package can be useful at such stages of development as assembly of the prototype of the scheme on a mock-up board, and also for automatic generation of the schematic diagram and the printed circuit board. The target audience of the program is creative people, researchers, designers, radio amateurs working with interactive electrical devices.

Fritzing was created for the Arduino. It was developed in 2009 at the University of Applied Sciences in Potsdam with subsidies from the state for research on a program called "From prototype to product". The Fritzing development environment has been translated into English, Danish, Spanish, French, Italian, Portuguese, Japanese, Chinese and Russian. The software is distributed free of charge and works on all operating systems.

The Fritzing software package can be downloaded from the official website <http://fritzing.org/>. The interface of the program is not complicated, but requires some memorizing at the initial stage. When user starts the program, a welcome window opens (Figure 1), displaying a blog, advice of the day, link to the latest sketches and services offered to create professional printed circuit boards.

The main window of the environment is a desktop with the option to design a board. Work on a new project in Fritzing begins with the selection of ready-made components, the full list of which is located in the upper corner of the work window on the right side. There is a whole set of radio parts: capacitors, transistors, resistors, LEDs, batteries, buttons, etc. As the user hovers over the device, a tooltip appears, and below the component list window, an inspector shows the appearance, schematics, and properties of a selected model.

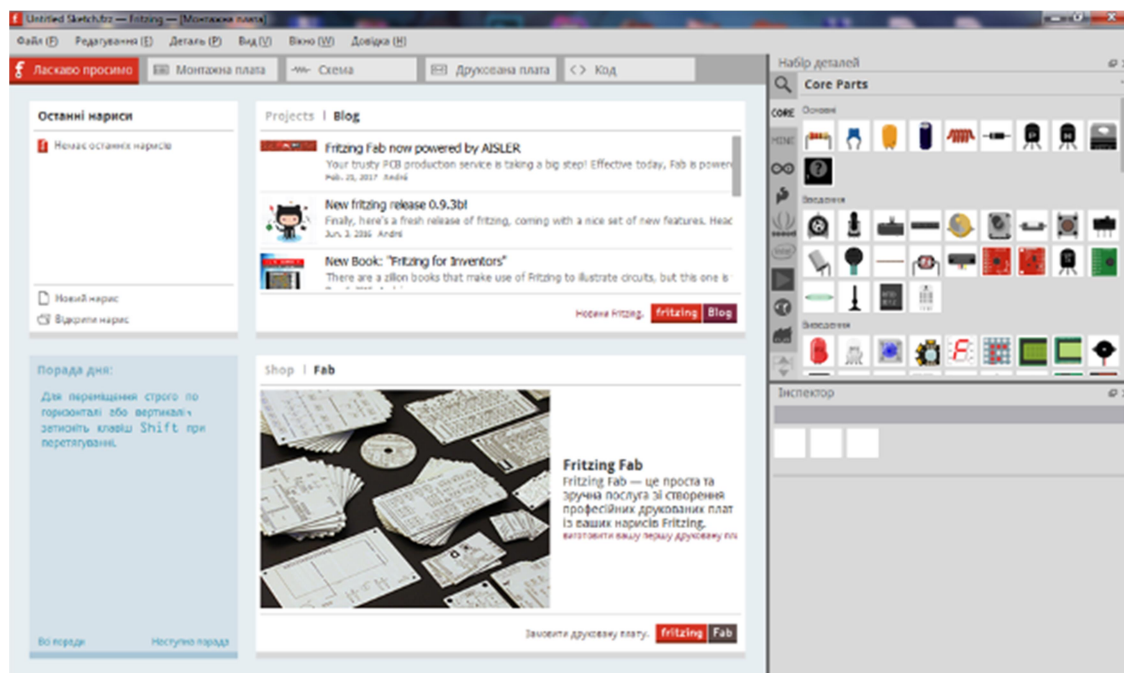


Fig. 1. Fritzing welcome window

Fritzing software supports a wide range of Arduino platforms, namely: Uno, Galileo, Yun, BT, Mega 2560 (rev 3), Due, Nano (rev 3) and others. If the required board in the "Inspector" window is selected, a description of the main characteristics of the platform is displayed.

In addition, there is a large collection of devices for robotics, including: motors, rangefinders, speakers, whistles, servos, stepper motors, LCD and digital indicators and much more. The user can also create his/her own items and update the existing database. The scheme is available for drawing (both in the "Layout" window and in the "Schematic" window) by simply dragging the desired components to the workspace, an auto-trace function is also available.

When the PCB (printed computer board) window is selected, start wiring and placing the elements procedures can be commenced. The result of the work is exported to a pdf-file for printing with the subsequent manufacture of the board by drawing on foil textolite with a hot iron.

The Fritzing software package contains its own software development

environment, which allows to write and edit sketches, as well as send it to the microcontroller of the platform, pre-determining through which serial port it is connected to the PC.

For those who are just beginning to learn how to build electronic circuits-based on Arduino, there are many examples of connecting expansion cards and electronic components with software code. According to the ready-made schemes, it is possible to start implementation of projects at once.

Convenient software tools are designed to make it as easy as possible to turn an idea into a digital project. The created schemes are reliable and do not require refinement to start the production of boards.

Fritzing can be used in elective or computer science classes (recommended for 8-graders), for by this time, students already know Ohm's law, the connection of conductors, the basic algorithmic structures, and are able to assemble electrical circuits.

In the process of working with ready-made mini-projects on Arduino, students learn to use instructions, which have a theoretical part, assembly diagram,

example sketch and tasks for self-execution. But having conducted a large number of projects, the student, unfortunately, will almost never be able to assemble the scheme on their own. In this case, the Fritzing software package comes in handy, which intuitively hints the user how to correct a schematic. However, in most cases, this software is used by those who develop long-term and complex projects, such as Smart Home and others.

In computer science or robotics classes, students can be asked to develop a schematic diagram of the device and create it as a connection of element layouts using special Fritzing software.

Fritzing also allows its user to successfully exploit long-term projects implemented in the educational institution by high school students. In addition, the software allows to see which components are best to use during the project. Thus, necessary purchases are optimized with minimal financial costs, which is now very important.

On the official website of the Fritzing software there are a number of links in the "Learning" tab to resources and materials, thanks to which the user can get acquainted with the peculiarities of the environment, for example, consider all the stages of creating an electronic game "Hunter".

Let's describe the idea of the game "Hunter": 8 LEDs are present on the board: 7 single color (red), and one is also of a single color, but of different color group (blue); a switch is used in the gameplay. The LEDs light up in random order. The players' task is to press the switch after the blue LED lights up and before any red LED lights up, so we need an Arduino Uno board, 8 LEDs (7 red and 1 blue), 8 resistors, a switch and connecting wires.

Before starting work on a new project, the developers recommend building a real electronic circuit and make sure that it works properly, and then move on to reproducing the circuit in Fritzing.

Having constructed the scheme, we are convinced that it works. Therefore, you can start playing it in the environment.

By dragging spare parts from the library located in the upper right corner of the program window, a visual diagram of the project is created. We create wires instantly by clicking on the exit and dragging the cursor from the part. The conductor can be bent, so you can create bend points simply by clicking on the wire and dragging them to the desired location. The scheme can be edited, namely: drag, copy, paste elements options can be applied. There is multiple selection, rotation, history of differences and much more – all these functions are integrated into sections of the Fritzing environment. Using them in the menu bar below the part, you can rotate and mirror the components of the diagram. In order to delete a part, select it by clicking on it and press BACKSPACE. Connectors that are joined correctly are highlighted in green and those that are incorrectly placed are shown in red. If the user clicks and holds any output, Fritzing will select all equipotential connectors. This is useful if you want to see the full set of connections associated with this particular output. When the circuit component is selected, the relevant part information is displayed in the "Parts Inspector", where you can change its properties immediately.

We connected 8 5-mm diameter LEDs to the D2-D9 outputs on the Arduino Uno board, of which seven are red and one is blue. In order to change the color of the LED (in our case, red to blue), you need to select it and in the "Inspector" by choosing the desired color from the list.

The next step is to connect the resistors. The nominal value of the resistors depends on the type of LEDs used in the project. You also need to know the maximum operating current and voltage drop across the LED. For red LEDs, the voltage drop is 2 V and the maximum current is 20 mA.

Thus, we have that for one red LED we need a limiting resistor with a resistance

of 15 ohms; for blue LEDs the voltage drop is 3.6 V and the maximum current is 20 mA. Similarly, let's calculate the value of the resistor – 7 Ohms. Select denominations in the "Inspector" window. If the list does not have a resistor of the desired value, choose it with the closest characteristics. Therefore, for the blue LED, you can choose a resistor with a nominal value of 6.8 Ohms from the list.

The last step is to connect the button to the output D10. For all electronic components of the circuit there is a common output, which goes to the output of the GND platform Arduino Uno. Notes or labels can also be added (bottom menu, right-click – details) to a sketch.

By arranging all the details of the circuit and connecting them with wires, a sketch is obtained, which is very similar to the real circuit (Figure 2).

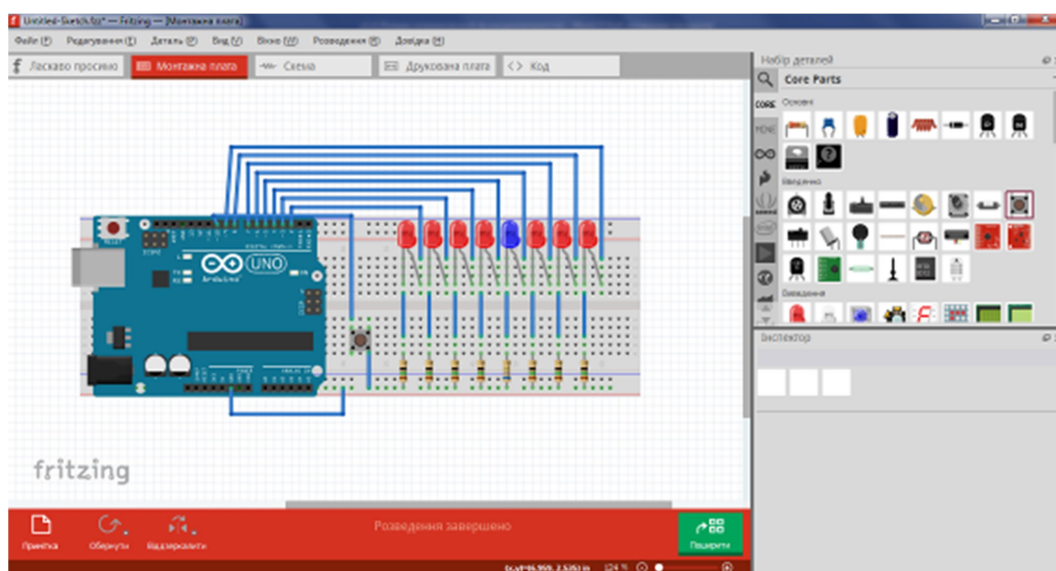


Fig. 2. Visualization of game layouts on the Arduino Uno platform

Fritzing provides the ability to switch between project presentation methods: layout, schematic and circuit board. Any of these views can be used as the main work environment of the project and can be selected at any time. Since the project layout is ready, via "Scheme" tab the automatically generated scheme can be accessed. The components in the diagram are randomly arranged, so their location must be changed by the user.

Having arranged the components in a logical order, the conductors diluting can be started. The Fritzing software environment offers a useful "Spreading" feature. After clicking on the appropriate button in the menu bar at the bottom of the window, the program will start the auto-trace process. As can be seen (Figure 3), not all the generated

conductors are necessary for the operation of the circuit, as well as many unnecessary bends were created.

By performing the spreading on our own, we get a game scheme on the Arduino Uno platform. Each element in the diagram is signed. It has a name and characteristics. Signatures and denominations can be changed in the "Inspector" menu in the same way as in the "Layout" view.

The production of a printed circuit board for our project is not expedient, as the scheme is small and easy to perform on a mock-up board. So, we can start writing program code. After going to the "Code" menu, the procedure can be performed right away.

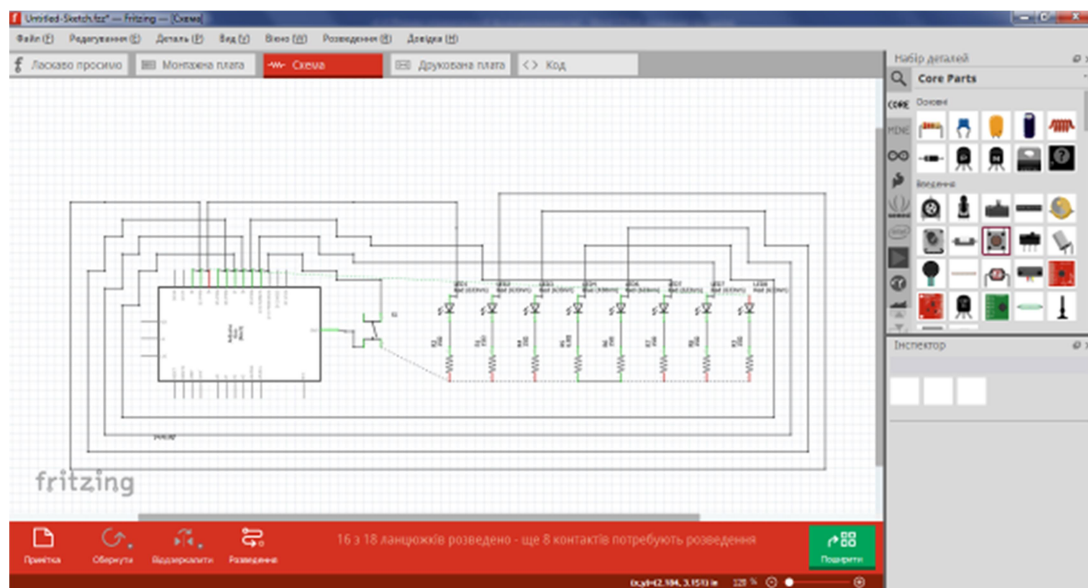


Fig. 3. Circuit elements connection viewed via "Spreading" feature

First, we initialize the outputs to which the LEDs are connected: `int pin = 0`. Next, the `setup ()` function is executed. It starts once: after each power-up or automatic reset of the Arduino board. In the body of the specified function we will add a fragment of the configuration code at which outputs D2-D9 will have values OUTPUT and the light-emitting diodes connected to them will be switched off. You also need to give the output D10 a value of HIGH, i.e. a high signal level.

```
void setup () {
  for(int i = 2; i<= 9; i++) {
    pinMode (i, OUTPUT);
    digitalWrite (i, 0);
  }
  pinMode (10, INPUT);
  digitalWrite (10, 1);
}
```

The `pinMode (pin, mode)` function sets the operating mode of the specified output (`pin`) as input or output. The specified output is set to INPUT or OUTPUT, respectively. The `digitalWrite (pin, value)` function returns HIGH (1) or LOW (0). If the output was set in OUTPUT mode by the `pinMode ()` function, then for HIGH the voltage at the corresponding output will be 5V, for LOW – 0V (ground).

After executing the `setup ()` function once, the `loop ()` function is started. It is an infinite loop, i.e. the code contained in it will be repeated. In our program code,

the `loop ()` function contains a sequence of functions that perform the logic of the game: one LED is illuminated at random. If the button is pressed when the red LED is lit, the `flub` function is performed: the LEDs on the left and right of the blue one alternate. If the button is pressed when the blue LED is lit, the `vin` function is performed: all LEDs are lit in turn.

In the menu bar at the bottom of the window, you can select from the list the platform, board and serial port to which the Arduino is connected.

Next, we need to connect the Arduino Uno platform to the computer and install the driver. To do this, download the driver folder to a personal computer, for example, by following the link <http://www.arduinoed.eu/ch340g-converter-windows-7-driver-download/>. Once the driver is downloaded, we can proceed to install it.

The Arduino Uno platform connects to a personal computer via USB. After connecting the board, the green power LED-on indicator should light up. Then, in Computer Device Manager, look for a new device connected via USB. We see that the device is defined as USB2.0-Serial. In the context menu, select "Update drivers". The menu for selecting the software search method for the device appears. We search for the driver

on the computer manually. A window will then appear informing you that the device driver installation was successful. In the device manager we check the correctness of the connection, there should be a new device connected via the COM port.

Conclusions and research perspectives. Our research analyzed the computer science curricula for grades 5-11 in order to verify the awareness of pupils about the elements of circuitry provided during the school course of computer science and identified that above mentioned elements are considered when studying the technical characteristics and purpose of the main components of a personal computer. This material is more widely reviewed in the 8th grade in schools with in-depth study of computer science. The possibilities of using the Arduino microcontroller platform to study the elements of circuitry in the school course of

computer science by means of the Fritzing software package were investigated and its main advantages were revealed as following:

- providing a fast and automated workflow;
- user-friendly interface with a ready set of chips and electronic components;
- creation of full-fledged layouts of printed circuit boards;
- the ability to export documents;
- free distribution.

A visual electronic circuit was created by means of the Fritzing software package on the example of an electronic game. Thus, this open software package for projects of varying complexity should be used to study the elements of circuitry during the school course of computer science in order to simplify the learning process.

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Received: February 02, 2022

Accepted: March 23, 2022