

FROM SCRATCH TO PYTHON - LEGO ROBOTS AS MOTIVATIONAL TOOLS FOR CODING

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Abstract

Educational Robotics is a specific interdisciplinary field that improves learning experience and develops student skills and competences through robotic-based activities. Constructing of robot models provide hands-on experiences for children while programming the built model teach basic coding knowledge for them. Instead of use text-based programming languages coding can be learned by a Scratch-based language in an age-appropriate way. Educational robots are excellent tools of introducing and teaching programming at all levels of education, though most of them aim at pupils in primary and secondary schools. LEGO Education's products also stand out among the educational robots thanks to their high quality and the very wide range of projects and teaching materials. The recently released Lego robot, SPIKE Prime, can also be programmed in Python, providing a playful way to learn the basics of object-oriented programming even in higher education.

Keywords: Educational Robotics, Scratch programming language, LEGO Education, LEGO SPIKE Prime

1. Introduction

In today's digital world, a worker with IT skills and coding ability has a good chance of getting the job that meets their expectations. The Z-generation youngsters are often assumed to have universal abilities in any field of informatics. There is no doubt that members of the net generation spend a lot of time in the world of digital tools and are good at managing them, but most of them remain at the level of users. As Mitch Resnik, the creator of the Scratch programming language and head of the Lifelong Kindergarten group at the MIT (Massachusetts Institute of Technology) Media Lab, reported in a TEDx talk: „while today's students are technically competent, they are consumers of technology rather than creators. It's as if they can only read and not write” (Biggs, 2013). Relatively few young people are interested in gaining deeper knowledge in programming and developing their own applications. This is also reflected in the decreasing number of students applying to technical and IT courses. In Hungarian secondary education, programming is not part of the compulsory curriculum, and only students studying informatics at advanced level are exposed to coding. Therefore, many students entering technical higher education only encounter elements of programming during their university studies. A significant proportion of these students have difficulty passing programming exams or drop out after unsuccessful attempts. In fact, professional programming language environments do not really meet the needs of

beginners. The complex structure and syntax of the language, the difficulties involved in program development and debugging can easily discourage students new to programming. That's why we think it's very important to get students interested in programming and develop the skills of talented children from primary school onwards. The first encounter with programming should be motivating and inspiring, and this can be achieved by solving practical and exciting problems in a playful environment, using age-appropriate tools and methods.

Again, we quote Mitch Resnick, who, based on his research at the MIT Media Lab, summarised in four guiding principles how to introduce coding (Resnick and Siegel, 2015):

- **Projects:** Provide children with opportunities to work on meaningful projects (not just puzzle-solving activities) so they experience the process of turning an initial idea into a creation that can be shared with others.
- **Peers:** Encourage collaboration and sharing, and help children learn to build on the work of others. Coding shouldn't be a solitary activity.
- **Passion:** Allow children to work on projects connected to their interests. They'll work longer and harder - and learn more in the process.
- **Play:** Encourage children to experiment playfully - try new things, take risks, test the boundaries, learn from failures.

These principles are also echoed in LEGO Education's project-based learning approach, and it is no coincidence that a long and fruitful collaboration between LEGO Company and MIT Media Lab has developed in the field of Educational Robotics.

2. LEGO robots as educational tools

For over forty years, LEGO has recognised the potential of teaching and learning with robots. LEGO Education, part of the LEGO brand, was launched in 1981 with the aim of bringing the experience of learning through play to primary and secondary school children. From the beginning, LEGO Education focused on STEM (Science, Technology, Engineering and Mathematics) learning, before this acronym was common. STEM is an educational approach that encompasses science, technology, engineering and maths, which later expanded to include the arts, and LEGO is also one of the pioneers of STEAM-based learning (Science, Technology, Engineering, Art and Mathematics) (Ruiz et al., 2019). Lego Education products provide learning through action, teamwork and the exploration of new ideas to solve different projects. This concept was then combined with robotics to create several generations of Lego robot kits for different age groups.

The collaboration with MIT has played a crucial role in the development of LEGO's robotics products. In 1987, the LEGO Group introduced LEGO Technic Control 0, a product that can be programmed with a special version of Logo, the first programming language for children. Logo was developed by Seymour Papert, the father of constructivist learning and a founding professor at the MIT Media Lab. Lego owner Kjeld Kirk Kristiansen was greatly influenced by Papert's theory of education, as they both shared the same values and views about learning through play. In 1998, when LEGO's educational flagship Mindstorms was launched, he said (Hocker, 2020): „*For many years we in the LEGO Group have had a dream: that we could combine the creative qualities of the LEGO bricks and the basic LEGO values with the strength and potential of the computer. Today - after more than 10 years of creative research and development work - we can present a new generation of intelligent construction toys and learning tools to children.... New we are able to combine the LEGO Universe with the computer - and put a computer into a LEGO brick.*”

In the new millennium various generations of LEGO robotics products were released: Mindstorms NXT in 2006, NXT 2.0 in 2009, and Mindstorms EV3 in 2013. To reach even younger children, LEGO launched a simple coding platform called WeDo in 2009 which was followed by WeDo 2.0 in 2016. The most recent product in the evolution of LEGO robots, SPIKE Prime, was released in 2020 and is already very popular. One reason for this is probably that the robot can be programmed in several ways and one option is the Scratch programming language. As a continuation of the Logo language, Scratch was developed by Mitchel Resnick at the MIT Media Lab. and today has grown into the world's largest coding community for kids. Scratch is a visual, block-based coding language with a drag-and-drop interface which makes programming easy and enjoyable for the children. Figure 1 shows a screenshot of the Scratch user interface. The blocks of a Scratch program fit together like the pieces of a simple puzzle and create something like a story line for what will happen in your program when you press start (Burns, 2020).

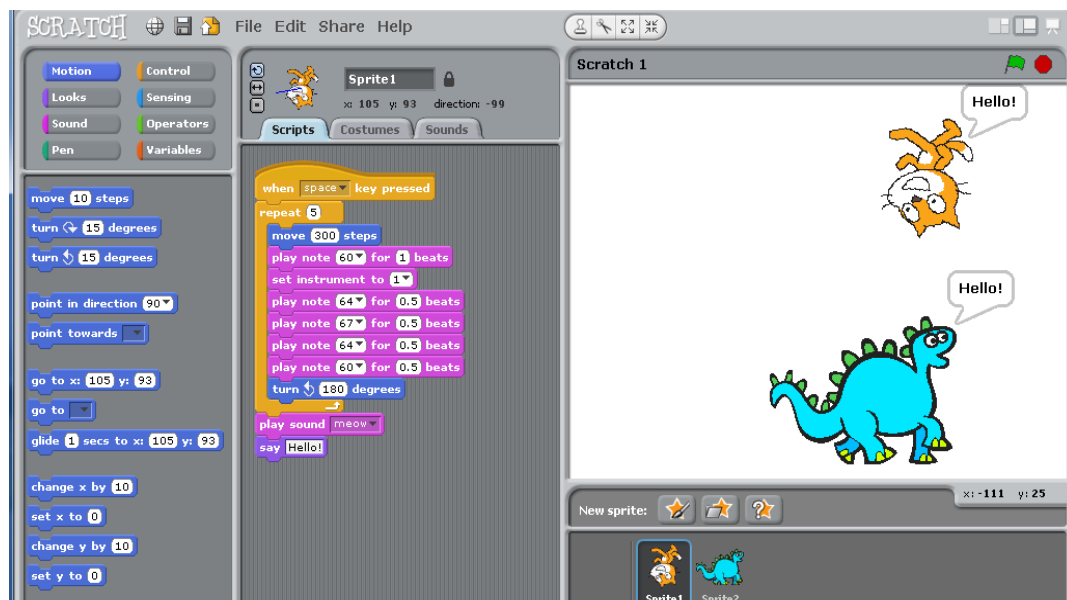


Figure 1. Scratch programming environment.

LEGO Education SPIKE Prime is more complex than WeDo 2.0 and can be considered a competitor of EV3. The set includes a programmable hub with built-in gyroscope, 3 motors, 3 different sensors, and a collection of colourful LEGO Technic bricks (Fig.2.). Recommended for children aged 10 and up, but also offers challenges for students. As for the software, the SPIKE Prime app is free to download, compatible with both computers and mobile systems, and designed for classroom use. When starting a new project, there are three different coding modes to choose from, two different Scratch-based languages (Icon Blocks and Word Blocks) and the high-level, general-purpose Python programming language. The software includes building instructions for several models, as well a number of theme-based STEAM learning unit plans helping teachers in integrating SPIKE Prime into a variety of classes from science and math to social studies.



Figure 2. LEGO Education SPIKE Prime Set.

Source: <https://www.lego.com/hu-hu/product/lego-education-SPIKE-prime-set-45678>

3. Using LEGO robots at different levels of education

LEGO robots are popular and widely used tools in Educational Robotics (ER). The most quoted definition of ER that it is an interdisciplinary learning environment based on the use of robots and electronic accessories for the purpose of improving learning outcomes and developing students' skills and competencies (Papadakis and Kalogiannakis, 2021). The work with programmable robot constructs enhances collaboration and communication among students developing their creativity, problem-solving skills, mathematical and computational thinking. Learning through hands-on activities with robots is becoming increasingly available worldwide and international experience is being collected and evaluated (Eguchi, 2010; Uslu et al., 2022; Ospennikova et al., 2015; Afari and Khine, 2017; Anwar et al., 2019). Researchers agree that robotics activities stimulate students' interest in solving mathematical, programming and engineering problems. National and international robotics competitions are also a great motivation for interested students. The basic skills acquired in robotics courses can be further developed through self-learning, with inspiring ideas and tutorials uploaded online by enthusiastic robot builders and programmers.

The vast majority of research focuses on the use of robotics and its impact on learning performance in primary and secondary schools, as the available educational robots are mainly targeted at this age group. The literature on the use of robots in higher education is much narrower, with researchers seeing this approach as most applicable to engineering education (He and Liang, 2019; Chraith and Kelly, 2010; Danahy et al., 2014; Aslam, 2021). Engineering applications of ER mostly focus on the design side, as a suitable robot module can be useful for modelling vehicles and machines and understanding their operation. However, engineering students also need a basic knowledge of programming, as the software they use in their work often requires more knowledge than the average user has. For example,

when working with Matlab, it is essential to be familiar with conditional statements and loops, and to be able to define and use different functions. But these basic programming concepts are easy to learn when working with robots, so the skills students gain as a child will be useful both at university and in the workplace.

Ideally, the school has robots, and, in some subjects, students use these tools in STEAM projects. The robots built from the SPIKE Prime set, and in particular the programming environment, allow for differentiated projects, i.e. the same project can be implemented with different levels of detail and depth of content. As an illustrative example we present three versions of the same programming problem with levels of difficulty adapted to the knowledge of students of different age groups. The three solutions differ in the used programming platforms offered by the software and the different levels of difficulty, in the third case in a way that is challenging even for university students. The basic task is the same in all three cases: determine the binary expansion of a given decimal number and display the result on the hub's light matrix. The representation of the output is imagined as follows. We identify a region of the light matrix for showing the digits, for example the middle row, in which a five-digit binary number can be represented. If a digit equals one, then the corresponding pixel should be lighted up, otherwise not.

Beyond the programming language used there are several ways to adjust the difficulty level of the task. You can choose the maximum value of the input data. Since the hub's light matrix is 5x5 it can display a binary number of up to 25 digits, the maximum number to be converted is $2^{25}-1=33554431$. The input number can be previously given, randomly generated, or even read from a file. We can also produce the binary expansion of the input number in various ways.

3.1. Basic level

After learning about the different numeral systems, primary school pupils can solve a basic version of the problem. The teacher tells the class an integer between 1 and 32 to convert to binary, and the task is to display the binary code in the middle row of the hub by lighting the pixels corresponding to ones. Pupils calculate the binary digits manually using the descending powers of two. They need to draw a table of power of 2 including 16,8,4,2 and 1. Then they take the given number and subtract from it the maximum possible power of 2 that does not return negative difference and put 1 into that box of this power in the table. Repeat the process for the difference till it remains 0. Finally put a 0 in all other empty boxes and take the output which will be equivalent binary number of the given decimal number. For example, if the given number is 10, digit 1 have to be written in the boxes indicated by 8 and 2, so the binary code of 10 is 01010 in a five-digit system as shown in Table 1.

Table 1. Finding the binary code of 10 using the descending powers of two

Decimal	$2^4 = 16$	$2^3 = 8$	$2^2 = 4$	$2^1 = 2$	$2^0 = 1$
Binary	0	1	0	1	0

After calculating the binary number, pupils program the hub by icon blocks to display the result, as Fig. 3 shows. Then all pupils show their lighted hub, and the results can then be visually checked by the teacher using the displayed patterns on the hubs.

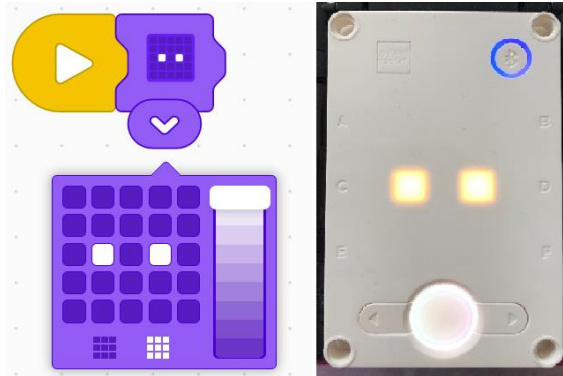


Figure 3. Icon blocks program for displaying the binary code of 10 and the result on Lego SPIKE Prime hub.

3.2. Intermediate level

For secondary school students, it is recommended to convert a larger number, which can be displayed in two rows of the light matrix. For a ten-digit binary number the decimal input should be chosen between 1 and 1023. The conversion process can be carried out by the remainder method which has the following steps:

- Divide the given decimal number by 2 and note the remainder.
- Divide the quotient obtained by 2 and note the remainder.
- Repeat the same process till you get 0 as the quotient.
- Write the values of all the remainders starting from the end to the start.

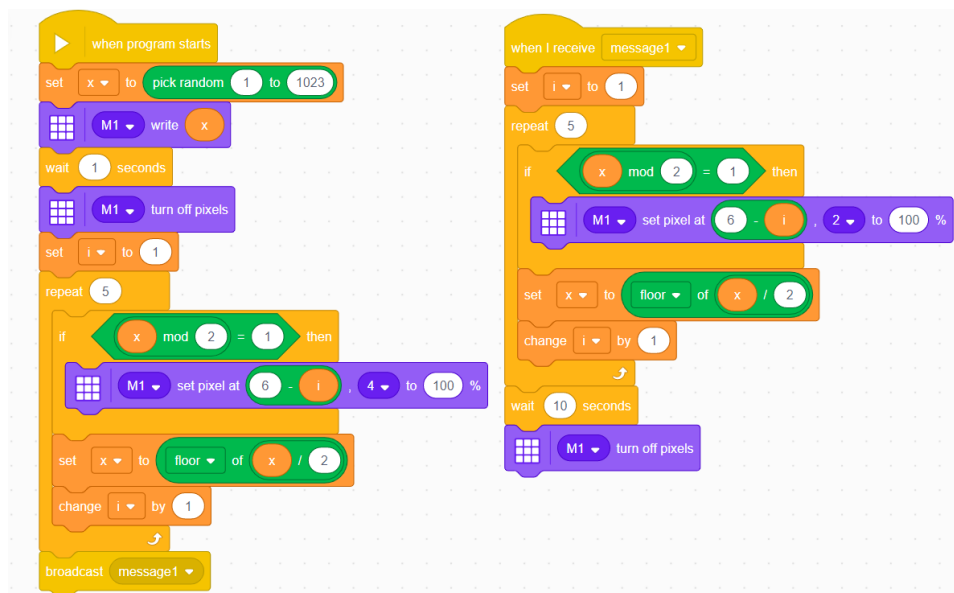


Figure 4. Word Blocks program for binary conversion.

Fig. 4 shows a possible Word Blocks program for solving the task. The randomly generated decimal number is stored in variable x , which is presented on the display for 1 second. The binary code for x is calculated in two loops, because the last five and the first five digits are displayed in two separate rows on the hub. For the remainder method students need to apply the modulo and a rounding operator and to light pixels in the right positions. The two loops are separated by a broadcast command, but this is just to make better use of the space in Fig. 4.

3.3. Advanced level

The binary conversion task can be discussed at a higher level with the Python programming option. In this case, it's a good idea to make full use of the LED matrix and assign each pixel of the hub to a binary digit. This allows us to represent a binary number of up to 25 digits, which can be read sequentially from the LED matrix. For a change, we read the decimal from a text file, convert the scanned string to an integer x , and display x on the hub. The binary digits are obtained by the remainder method and stored in a list L .

```
from SPIKE import PrimeHub, LightMatrix, Button, StatusLight, ForceSensor, MotionSensor, Speaker, ColorSensor, App, DistanceSensor, Motor, MotorPair
from SPIKE.control import wait_for_seconds, wait_until, Timer
from math import *
hub = PrimeHub()
f=open("convert.txt", "r")
x=f.read()
x=int(x)
hub.light_matrix.write(x)
L=[]
for i in range(0,25):
    L.append(x%2)
    x=x//2
print(L)
for i in range(0,5):
    for j in range(0,5):
        if L[24-j-5*i]:
            hub.light_matrix.set_pixel(j, i, brightness=100)
```

Figure 5. Python program for binary conversion.

The pixels of the light matrix are traversed in a nested loop. The elements of the list L are examined starting from the end, and if a non-zero digit is found, the corresponding pixel of the LED matrix is lighted using the `hub.light_matrix.set_pixel()` function (Fig. 5).

4. Conclusion

A big advantage of the Scratch programming environment is that since version 1.1, it can be used with commands in Hungarian. You don't need to install any add-ons to set the Hungarian language, because it is included with the other translations. The completed programs can be uploaded to the international site (<https://scratch.mit.edu/>), where you can learn from others, evaluate others' work, make and receive

suggestions. Everyone can view the uploaded code in their own language - if there is a suitable translation -, so that the people who make the code and the people who view it do not necessarily need to understand each other's language (Bernát, 2015). When teaching introductory programming in primary schools, a teacher can choose from several main areas depending on the interests and abilities of the students. One of these is the creation of animations, for which the Scratch language has been widely used in Hungary for many years (Bernát, 2020). The LEGO SPIKE Prime set is a didactic tool that significantly extends the possibilities of using Scratch programming.

In our article, we highlighted the potential of teaching with robots from primary school to university. Robotics activities can get children interested in careers in IT and technology from an early age. The elements of programming are also easier to learn in a playful environment, in a way that is appropriate for the age of the child. Launched by LEGO Education in 2020, SPIKE Prime is a set for school projects that focus on STEAM learning principles. The kit allows children to build various models that can be programmed in Scratch-based languages and Python as well. We have presented an example of programming the SPIKE Prime light matrix. The task was solved at three different levels, in the most complex version using Python code. This example illustrates that working with robots can be useful even in universities, as students' motivation can be increased by learning the basic elements of the Python language through robot programming.

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