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Alternatives to replace LEGO EV3: using the next-generation Mindstorms and Stem:Bit kits in education

GAÁL Bence, SOLYMOS Dóra

Abstract. Anyone who has dealt with robotics education has evidently encountered the LEGO Mindstorms EV3 model, which has played a crucial role in this field since 2013. However, the production of these robots has officially ceased, and their support will end in the near future. In our article, in addition to introducing the new generation LEGO Mindstorms Robot Inventor, we also aim to present a cheaper alternative in the form of Stem:Bit, which we recommend as a replacement for the EV3. A vital aspect of comparing these devices is to examine what functions they provide compared to the EV3, and what advantages and disadvantages each has in robotics education.

Keywords: robotics, programming, Mindstorms EV3, Robot Inventor, Stem:Bit

1. Introduction

In September 2020, the new National Core Curriculum (NAT) was introduced in Hungary, which includes the basics of robotics as early as the third grade of primary school. [1] In the lower grades, children typically start learning robotics with popular floor robots. However, upon advancing to the upper grades, they can get to know more severe robots with greater knowledge and more programming possibilities. This group includes the LEGO Mindstorms EV3 developed by LEGO Education, which was phased out of the market coinciding with the introduction of the new National Core Curriculum. There are numerous articles about the educational role and usability of the device [2][3][4]; however, if someone wants to acquire it now, they will unfortunately have to look for an alternative, as it is no longer available in stores.

We aim to provide assistance by introducing two devices. The first device is the successor to the EV3, officially named the LEGO Mindstorms Robot Inventor, known in Hungarian as the "Robot Feltaláló" but seldom referred to as the EV4. The other device is the Stem:Bit, a robot controlled by a BBC Micro:bit, containing LEGO-compatible elements.

In our article, we present the changes and the modifications needed for the use of tasks. Based on our experience, both devices can be used in education, and the examined tasks can be solved with minor modifications, making the materials prepared for the previous version usable.

2. Introduction of the LEGO Mindstorms Robot Inventor (51515)

The latest LEGO Mindstorms device, the Robot Inventor (51515), was launched in 2020, replacing its predecessor, the EV3. The new device arrived in a cardboard box, as seen in Figure 1. The dimensions of the box are 47,5 cm wide, 37 cm high, and 6,7 cm thick. Upon opening, a large number of LEGO pieces, a little sticker sheet, and a booklet with the part list are visible. Opening the box has been simplified compared to the EV3 home edition (31313), as the parts can be nested together like a shoebox, though the educational version (45544) of the EV3 had a better solution with an internal organizer, which is missing from this version.

Recommended age group	from age 10
Type of programming language	block-based/Python
Number of building elements	949
Number of motors	4
Type of sensors	distance sensor, light and color sensor, compass, gyroscope
Other accessories	-
Current price	359,99 €/package[1]

Table 1: General overview of the LEGO Mindstorms Robot Inventor 51515



Figure 1: The box of the LEGO Mindstorms Robot Inventor (51515) set[2].

The box contains a total of 949 pieces, which, when compared, is nearly 1,5 times the number of pieces in the home version and twice as many as in the educational version. Among these pieces, a significant portion of the elements found in the EV3 sets are present. A notable addition, however, is the inclusion of several larger-sized elements in the box, among them a board-like element that is suitable for attaching sensors, motors, and other elements. (The best comparison for this new LEGO board would be with the BBC Micro:bit test panels.) The metal ball found in the EV3 set has been removed from this kit, which could potentially causing issues for vehicle-like builds. The appearance of the elements has been modernized and made more colorful, making it more akin to the LEGO Education SPIKE™ Prime (45678) set.

2.1. Models

The developers designed five models for the kit, whose building instructions can be found in the application used for programming. (We will write more about this later.) The models can also be seen on the left side of Figure 1. Their names, from left to right, are: M.V.P, GELO, BLAST,

[1] Source: https://www.brickeconomy.com/set/51515-1/lego-mindstorms-robot-inventor

[2] Source: https://www.lego.com/hu-hu/product/robot-inventor-51515

CHARLIE and TRICKY. Most of the models come with the option for modifications, which also includes building instructions. For example, the base model of TRICKY can be rebuilt to play basketball (with a lifting arm to move the ball), play soccer (with leg-like arms to kick a ball), go bowling (shooting a ball by spinning it), or draw (with a raisable pen stand that can be attached).

To evaluate the device, we tried out several models, but the TRICKY configuration, as suggested by the developers, seemed the most practical for educational use. (Figure 2) We slightly altered the model, choosing not to add the decorative elements to facilitate potential future modifications, which proved to be a wise decision in the long run. According to the instructions, only the distance sensor is initially incorporated into the base model. However, we wanted to test as many sensors as possible, so we attached the color sensor and then the pressure sensor to the back of the robot. (Figure 3)

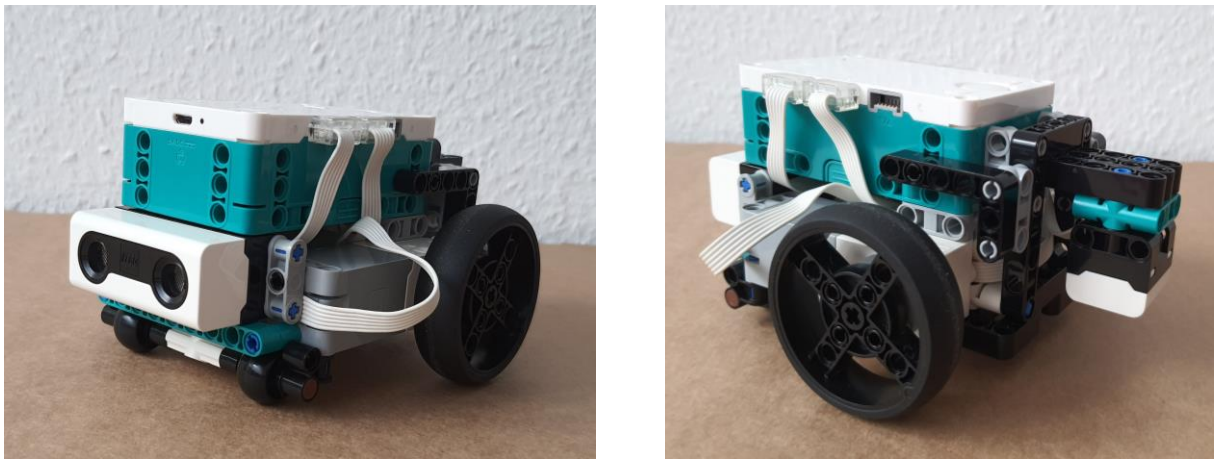


Figure 2: The model named TRICKY is shown in the image, equipped with an additional color sensor.[3]

2.2. Motors and sensors

There has been an increase in the quantity of motors; instead of the two large and one medium that were previously provided, we have four large motors of the same size. Additionally, they became much smaller and have more connecting surfaces than the previous Mindstorms motors. This appearance and functionality were previously encountered in the SPIKE set but in a different color. The motor system has also been changed; occasionally, the program alerts users to the need for an update due to a new version that has appeared.

The appearance of the sensors has undergone significant changes; they now resemble the elements found in the SPIKE set, just like the motors. Within the package, there's an ultrasonic distance sensor like the one found in the educational version of the EV3, but it has a reduced operational range, effectively detecting objects only up to 200 cm away. This change in the sensors marks an improvement in terms of design, aligning them more closely with the newer SPIKE technology. Additionally, an enhancement has been made by including four lamps around the sensor, which can be programmed individually, adding more versatility and interaction possibilities to the device's use. Based on our experiences, an improvement in the device's accuracy has been noted, indicating a positive advancement in sensor technology within this kit.

[3] Source: Dóra Solymos

The light and color sensor can distinguish eight colors and the neutral color. The previous list was adjusted by removing brown and adding pink, as well as enhancing the set with the set's specific shade of cyan blue. Therefore, the device can detect the following colors: black, pink, blue, cyan blue, green, lemon yellow, red, white, and neutral. The reflection of light known from the EV3 is also usable here, and both its versions (reflected light and ambient light) are available on the programming interface. Moreover, the sensor can measure the extent to which the color it sees contains red, blue, or green. Thus, we could query an RGB code of a color, which could be used for tasks involving color sensing. This way, we could print a track or color tracking stripes that the device is more likely to detect than its previous version. However, the color sensor remains a weak point of the device as it does not always recognize green, blue, and the new cyan blue from its own LEGO elements, which were also problematic colors in the EV3. At certain angles and heights, the chances of successfully detecting these colors increase, yet, for reliability, it's advisable to stick with black, white, red, and yellow colors.

The compass and gyroscope have been integrated into the controller named Hub. This integration allows for functionalities such as displaying a smiley face on the Hub with a firm touch or setting up different functions for various directional movements, similar to those found with the BBC Micro:bit.

Compared to the EV3, there might be a sense of something missing regarding sensors since the set lacks a pressure sensor. However, there is one available in the SPIKE set, which is compatible with this set, meaning if we can acquire it, we can use it easily. If we wish to substitute something for it, we can use our creativity with the existing pieces to build something that could serve as an acceptable pressure sensor. Online,[4] most people create pressure sensors using motors; we were inspired by this and created the sensor shown in Figure 3, which was placed above the color sensor on the test vehicle. This setup is operational and can substitute for a pressure sensor, but its accuracy is limited.

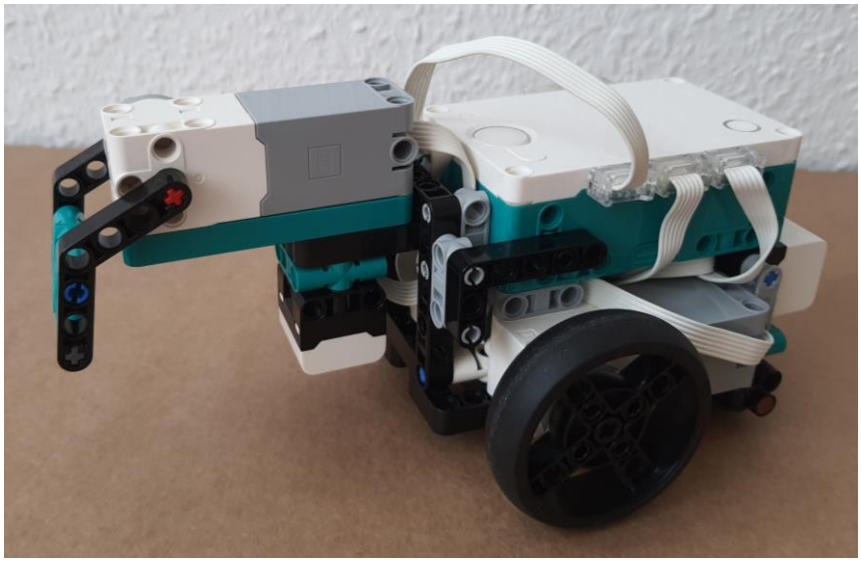


Figure 3: The test car variant equipped with a pressure sensor[5]

[4] https://www.eurobricks.com/forum/index.php?/forums/topic/183443-fix-no-force-sensortouch-sensor-in-51515-robot-inventor/

[5] Source: Dóra Solymos

2.3. The Hub

A significant change can be observed in its appearance compared to its predecessor. The disappearance of the display found on the EV3 means that many familiar functions are either inaccessible or must be accessed elsewhere. The Hub features a large power button, two smaller programmable buttons, and a Bluetooth button. The LED light surrounding the power button is programmable, similar to its predecessor, but the colors have changed, and their number has increased. The display, as a drawing surface, has been simplified in some ways and has become programmable similar to the LEDs on the Micro:bit, meaning we can control them by coordinates and adjust their brightness. Additionally, it can display animations and texts longer than the screen. It is also capable of playing sounds.

The controller features six ports that are evenly distributed along the length of the device, identified by letters A to F. There's no distinction between the ports; both motors and sensors can be connected to any of them. Additionally, there's a micro USB connection available on the Hub. This allows for connection to a computer using the included micro USB to USB cable, which is suitable not only for charging but also for data transfer.

2.4. Introduction of the programming interface

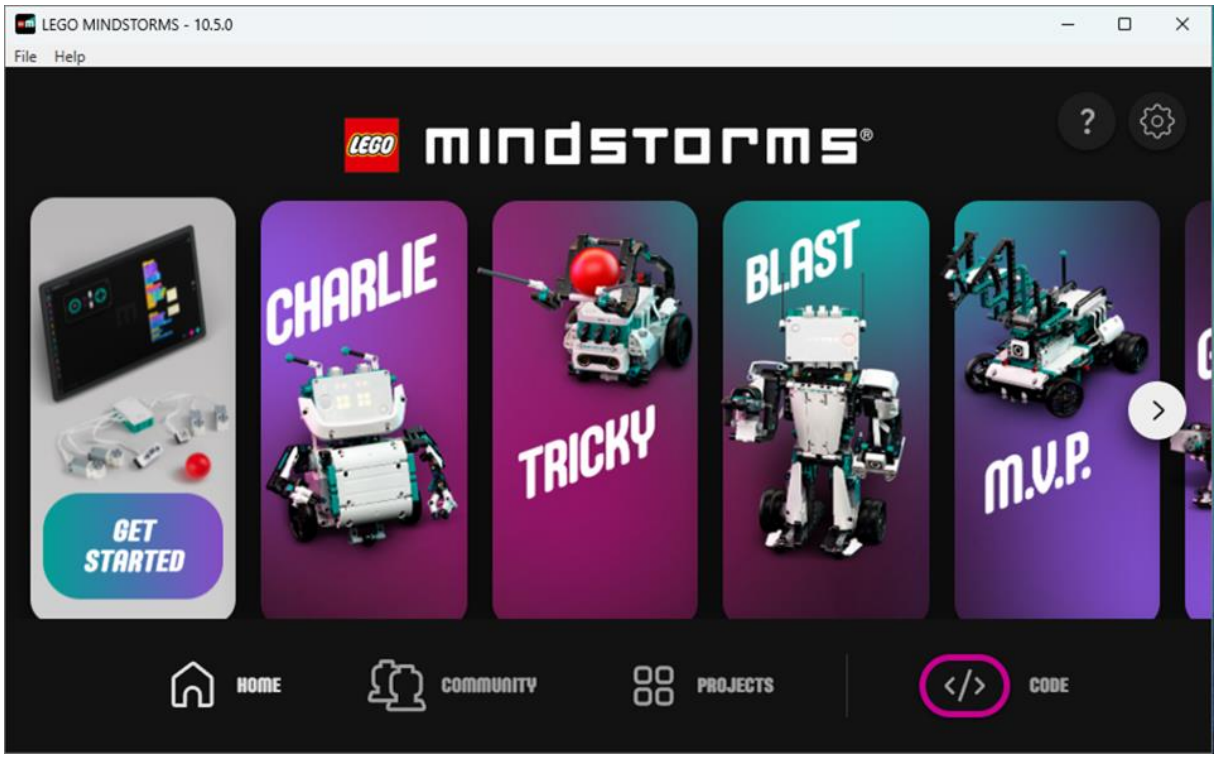


Figure 4: The Interface of the LEGO® MINDSTORMS® Robot Inventor app [6].

To program the Robot Inventor, we need to download an application available on the Microsoft Store, Play Store, and App Store. The application is called LEGO® MINDSTORMS® "Feltaláló" in Hungarian and LEGO® MINDSTORMS® Robot Inventor in English. We can choose from

[6] Source: Dóra Solymos

several languages, but the app will initially start in the default language of the installed device. Upon opening the app, we will see the interface shown in Figure 4, which is the homepage of the app. Choosing the *Get started* option provides assistance with using the device, starting from the basics. Clicking on the pictures of the models grants access to the building instructions, and after building, we receive a code to test out our constructed robot. Clicking on the *Community* tab takes us to building instructions created by users. A drawback of the interface is that we can only view any instructions if we download all of them. The third option in the main menu is *Projects*, where we can find our previous codes, including both block-based and Python-written codes. The last option on the homepage is *Code*, which takes us to the actual programming interface.

In the official software for the EV3, we could program using icon-based blocks, which had to be placed horizontally next to each other. Later, programming was also possible in MicroPython. Nevertheless, we could program using text-based blocks on the Makecode platform, where the blocks had to be inserted into each other vertically, and a simulator was also available. On the new Mindstorms block-based interface, we can use text-based blocks that need to be inserted into each other vertically. The environment itself is based on Scratch, so the appearance and some blocks may be familiar. Additionally, the device can also be programmed in Python using MicroPython. For this, a documentation has been created, which is available in English here: https://lego.github.io/MINDSTORMS-Robot-Inventor-hub-API/index.html

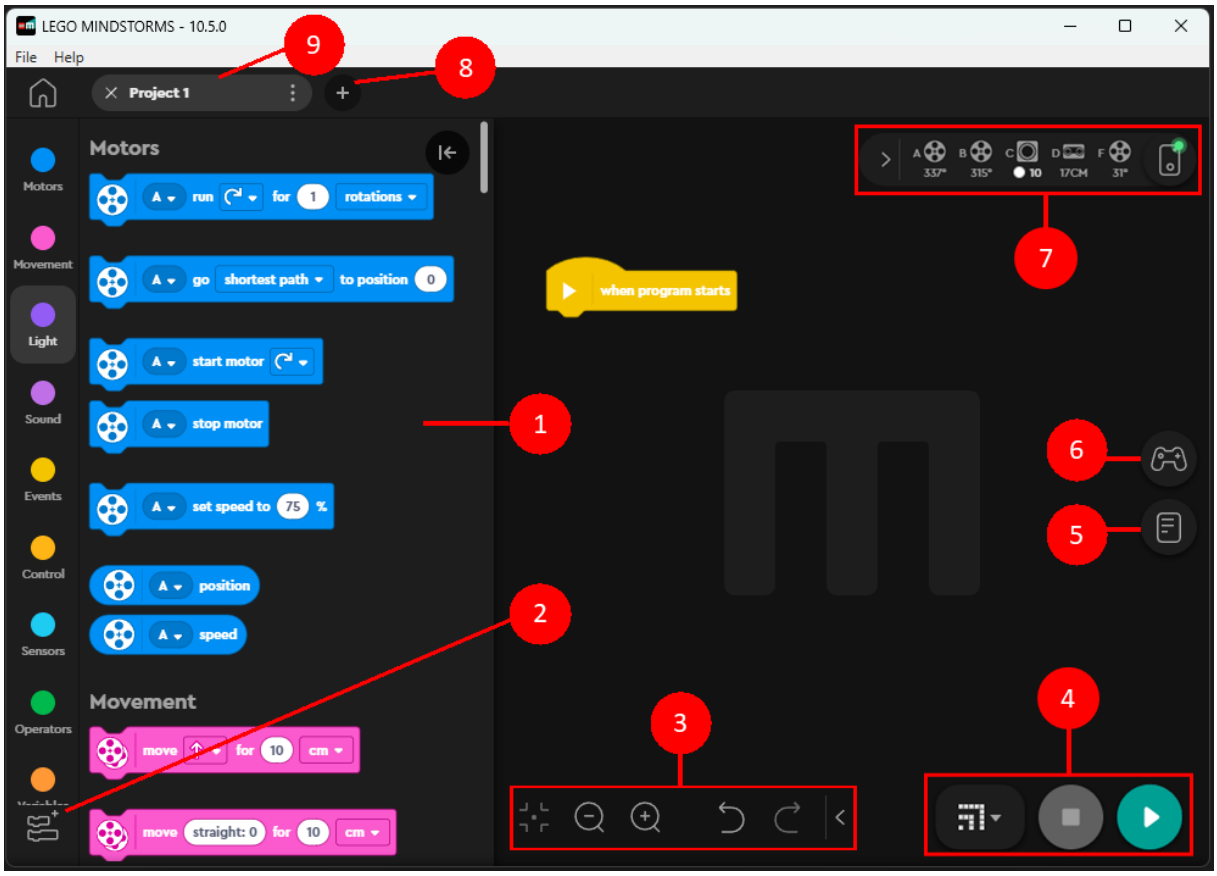


Figure 5: The homepage of the interface used for block programming.[7]

[7] Source: Dóra Solymos

The programming interface (illustrated in Figure 5) is streamlined, featuring only the buttons necessary for programming. However, some of these can be hidden if they are not needed. The interface includes the following parts:

1. Block palette
2. Adding extensions
3. Zoom, undo, and redo
4. Play modes (download/streaming), stop and play
5. Help and monitor
6. Remote control
7. Hub Connection
8. New project
9. Current project

The interface allows hiding the block palette (1), the zoom, undo, and redo functions (3), and the Hub connection (7).

Clicking on the "Add Extensions" button pops up a window where we can choose from a variety of extensions, including model blocks, multiple motors, multiple movements, music, weather, LEGO powered up, and additional sensors. Furthermore, although in experimental status, the following extensions can be tested: machine learning, XBOX ONE controller, DUALSHOCK 4 controller, and Hub-Hub communication.

On Figure 5, marked with the number 4, we have the option to download the program or run it via Bluetooth connection. The second mode can be accessed by selecting Streaming mode, which allows us to run our program immediately without downloading. The download mode has changed from the previous version in that the number of downloadable programs has been maximized to 19, and before downloading, we can select which slot we want to download the program to. After downloading, the Hub immediately runs the program; however, if we want to start it from the device, we need to find its number on the Hub using the left-right buttons and start it with the power button.
In the EV3, we could assign names to our programs, and we had to locate the file we wanted from all the downloaded files based on that name. Managing files on the EV3 was cumbersome, as files had to be deleted individually. However, this process has been greatly simplified here. The new application makes it simple to remove unnecessary files with a single button click.
The two modes available on the Robot Inventor can be distinguished on the device by the different patterns in which the lights activate: during downloading, the sequence number of the download location is indicated, while in stream mode, a Wi-Fi icon is displayed.
The interface includes a mode selection button alongside stop and play buttons (shown in Figure 5, button group number 4). These may not seem so important when creating the first programs; however, after a few more attempts, they become indispensable. Due to the fact that there is no button on the device to stop the currently running program. (On the EV3, we had a grey button for this function that was situated in the bottom left corner of the screen.) After executing the blocks, the program does not exit as its predecessor did but continues running even if there is nothing left to do. At this point, by clicking the play button, we can restart the program, while the stop button allows us to end the execution. Another way to exit from the program is by inserting a "stop and exit program" block (from the orange Control Blocks category) at the end of the code. Then, there is no need to use the stop button to finish running the program.

With the controller-shaped button labelled number 6 in Figure 5, we can bring up a small panel (see Figure 6) where we can place various buttons related to control, sliders, and sensors. Then, we

can format, name and program these elements. During execution, we can use this interface as a remote control. This feature allows us to create a program similar to the application available for the EV3, which enabled the device to be controlled from a phone or tablet.

The help feature on the interface serves as a sort of knowledge base, providing not just descriptions of the blocks but also videos, guides, and snippets of code for using the various functions. However, the help feature is not always understandable on the Hungarian interface because the translation is sometimes meaningless or does not convey the same as its English version.

By clicking on the Hub Connection button (labelled number 7 on Figure 5), we can connect to the device. After connection, we can change the device's name, manage programs on the Hub, modify the modes of motors and sensors, and update the motors. Additionally, we can check the current values of the built-in sensors. During programming, next to the Hub icon, a small bar shows which device is connected to which port, and it even displays the current value of the sensors. (For motors, it can show the current rotation angle or speed.)

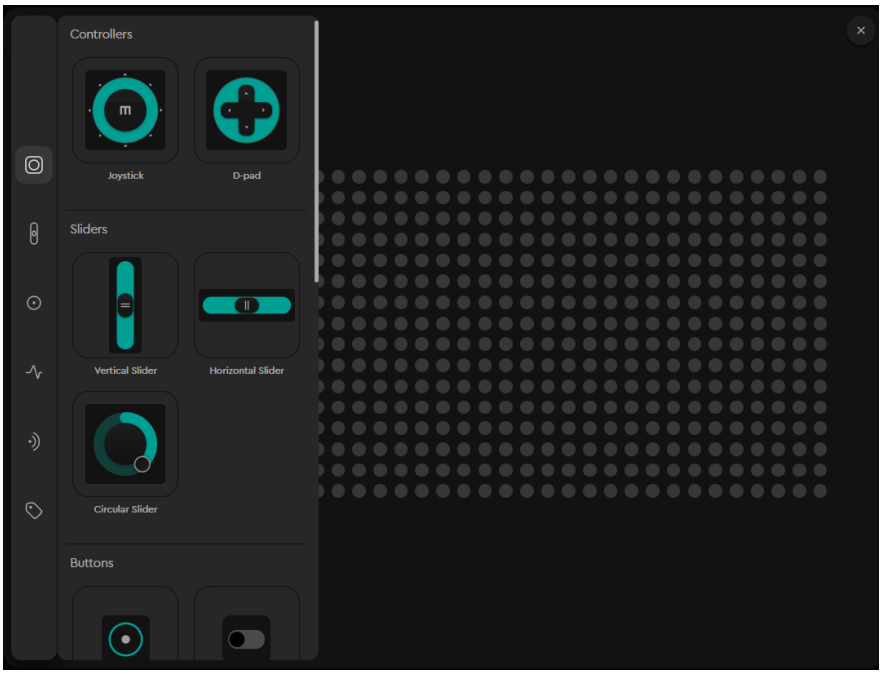


Figure 6: The interface for creating a remote control.[8]

2.4.1. Introduction of the block groups

The interface itself is user-friendly, especially if we already have experience in a block-based environment. However, compared to the EV3, some tasks must be approached differently. For instance, settings that were previously consolidated into a single block for motors, such as names, speed, and control mode (degree, rotation, seconds), are now distributed across separate blocks. In the *Motors* (blue) category, each block allows us to select the desired motor, but we must specify the speed, direction, and duration of movement in different blocks. The mode previously known as "rotation" has been translated to "forgás" in Hungarian, which may be confusing because it is

[8] Source: Dóra Solymos

situated directly above the degree (in Hungarian: "fok") mode, potentially leading to mix-ups among children.

If we want to set both the duration and speed of motor movement within a single block, we need to activate the *More Motors* extension from the available extensions. At the very bottom of the block groups, we will find the blocks suitable for this purpose. These include blocks that let us set the motor's speed or power output at startup. Both blocks look the same, differing only in the last expression, but there aren't any differences in their operation. This phenomenon is also present in the *Multiple Movements* extension.

Among the *Movement* blocks, we find blocks similar to those previously used for operating two motors simultaneously. However, here we only see blocks similar to the *Move Steering* block known from the EV3, which works with direction determination. In order to start our two motors at various speeds, we need to turn on the *More Movement* extension. We can discover some rather complex blocks in this section since one block can change two to three variables.

In the *Light* (purple) blocks section, we find blocks that use the Hub's "screen". A new feature is the ability to play animations, for which there is a library available containing animations created for the models. However, we can also create our own animations. Additionally, we can display individual images on the screen, but there isn't a library available for this. Furthermore, texts are not constrained by the screen size and are shown on the device like an advertising tape. This function resembles the text display feature known from the BBC Micro:bit, as does the display of points by coordinates. We can achieve this with the *set pixel at 1, 1 to 100%* block. A new block for modifying the lights surrounding the distance sensor and a block for programming the LEDs surrounding the power button is also included in this group. Moreover, two blocks for setting the device's orientation are also located here.

In the *Sound* block group, we encounter blocks familiar from the EV3. However, the capability to play sounds on both the programming device and the Hub has been added as a new feature. Consequently, the playable sounds are divided into two groups. The *Sounds on the Hub* section contains sounds that can be played on the Hub, while the "Library" section includes those that can be played on the programming device. A new functionality allows us to edit sounds from the library, and making sound recordings has also been simplified. The names of the blocks for playing piano sounds have changed; they start with *play beep*. In the EV3, this was done by selecting the *Play Note* mode.

In the *Events* group, we can find trigger blocks that allow us to start our program based on the response of a sensor, movement of the Hub, or a button press. Additionally, we find blocks known from Scratch that initiate program execution.

In the *Sensors* group of blocks, you can find blocks necessary for color detection as well as for detecting reflected light. However, in this section, we only have access to blocks that work in the previously known reflected light mode. If we want to use the ambient light mode, activating the "More Sensors" group allows us to do so with the *set mode to ambient*, *ambient light < 50%* and *ambient light* blocks. Among the sensors, new functionalities such as gesture detection and orientation have been introduced, functioning similarly to the Micro:bit. In the *More Sensors* section, we find a block for the raw reflected light value for red, blue, and green colors. (The color value is a number between 0 and 255.) Additionally, this section includes blocks for the pressure sensor found in the Spike set.

2.4.2. What tasks can be solved with the Robot Inventor?

For the Robot Inventor, a few English-language publications have been released, however there are currently no Hungarian instructional resources. Therefore, we selected some tasks from the ones listed in [5] that were originally designed for the EV3 and attempted to solve them within the Robot Inventor block-based environment. During our testing, we were able to solve a significant portion of the tasks with this tool, however in certain cases, we could only achieve this by rephrasing the tasks.

While using the colored LEDs, we encountered an issue where the LEDs could not be turned off, nor did the block have a flashing function, demanding modifications to the related tasks. We resolved the issue of turning off the LEDs by setting them to black color and achieved flashing through a combination of loop and wait blocks.

Due to the absence of a touch sensor, we had to solve related tasks using a motor. This substitution required a complete rephrasing of the tasks and the omission of some. Considering that testing the pressed, released, and bumped functions became meaningless since we don't have a button but an arm that is very sensitive to minor changes, however, to rotate it, we have to turn it by hand. Our tests showed that if the robot approaches an object too quickly, its pressure-sensing motor does not turn, and the device tips over. If the robot moves slowly, it can be used as a touch sensor, but even minimal movement is enough for detection. This can be seen in the code shown in Figure 7.



Figure 7: The code for the following task is shown in the image: when the motor functioning as a touch sensor is "pressed," a smiling face appears on the display[9].

The tasks related to creating parallel programs in the teaching material ([5] page 27, tasks 1-4) can also be solved in this environment, but they will not be parallel programs, only single-threaded ones. Additionally, the task related to drawing a house ([5] page 45, task 5) cannot be solved or can only be solved with significant simplification of the task due to the 5x5 pixel size of the display severely limiting the images that can be displayed. Moreover, the line-following task ([5] page 33, task 3) can only be solved by providing a mathematical formula due to the inaccuracy of the color

[9] Source: Dóra Solymos

and light sensors. More information about the formula and how it works can be found in this video: https://youtu.be/Z8Cv60f75LI.

The names of colors are not included among the sounds. However, since creating sound recordings has become quite simple, and the device can even be programmed from a phone, children can record the names of colors in Hungarian directly in the app using their phones. These recordings can then be used to solve the task. This way, they can also learn a bit about sound editing, and test the operation of the "Hangos színek" task ([5] page 36, task 3) in their language, which could be an advantage for children learning German as their first foreign language.

For tasks not specifically mentioned, we encountered no significant problems; we were able to solve them using the blocks available to us.

3. Introduction of the Stem:Bit [6][7]

Recommended age group	from age 10
Type of programming language:	block-based/python/ Javascript/scratch
Number of building blocks	302
Number of motors	2
Type of sensors	obstacle sensor, line tracker, ultrasound connection option
Other accessories	vibrating motor, 2 x 10mm RGB LEDs, 3x small RGB LEDs, infrared receiver unit, remote control
Current price (micro:bit included)	117,95€/package

Table 2: General description of Stem:Bit[10]



Figure 8: The Stem:Bit package[10]

The Stem:Bit package is divided into two main parts, one is the building blocks and the other is the expansion board itself. To this expansion board we can connect the micro:bit, which will

[10] Source: https://shop.sb-components.co.uk/products/stem-bit-the-programmable-blocks-kit-for-micro-bit?variant=31064155455571

control our robot. Other accessories and sensors shown in the table (Table 2) are all integrated into this board, which may limit creativity during the building process. The bricks in this pack are fully compatible with LEGO products. In terms of learning materials, the balance is tilted in EV3's favor, as unfortunately there is no developed learning material available for Stem:Bit, and while the EV3 package only includes five official building options compared to the nine models of Stem:Bit, for the EV3 we could find certified user guides.

Micro:bit control allows Stem:Bit to be a device that can be used across a wide age spectrum. For this reason, the tool also has all the advantages of micro:bit, such as cost-effectiveness, widespread application and success, and a sufficiently high volume of extensibility. [8] There are many descriptions and articles about the micro:bit available, so we have not specifically addressed it as a control unit in this article.

3.1. Models

Nine official models from the package can be built, and the manual provides instructions for these. We did not encounter any difficulties in building these models. It is important to note that there are models that are not capable of movement. The model most capable of solving EV3 tasks is the IR Car (Figure 9[10]). When it comes to line tracking and object avoidance, the two robots are similar, but it's important to consider that we can't build a robot with one Stem:Bit that moves and can move objects at the same time, so this can be a big disadvantage. Both robots perform similarly to line tracking when it comes to detecting and avoiding obstacles. Due to the rules of the WRO competition, this package is not suitable for racing, as it can only be participated with LEGO robots.

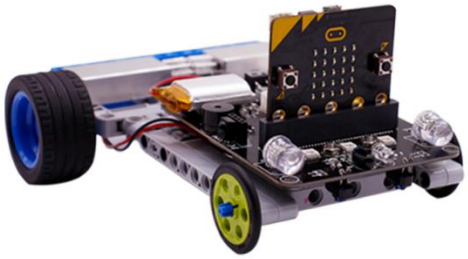


Figure 9: Model of the IR Car

However, we also have the opportunity to make two tracked vehicles, which can be a good basis for making field measuring vehicles, which we can also operate with remote control. The complex sensor package provided by the micro:bit provides an opportunity to take the tool into account more seriously in science education in addition to digital culture classes.

In addition to the tools mentioned above, the package includes a crane, a slingshot, a tuk-tuk cart, a six-legged robot that can climb off-road, a so-called robot car (not suitable for line tracking), and a device for grabbing objects.

3.2. Motors and sensors

In the Stem:Bit package, we get a total of two motors. Not only is the quality of the package inferior to the EV3 in terms of the number of units, but also in terms of the type of motors, as here we do not get servo motors. For this reason, it can be difficult to implement turtle graphics on the floor, as we can only specify the time and speed of operation of the motors, the latter of which will be greatly influenced by the battery charge. However, in terms of extendability, we get three places for servo motors, so we can connect a maximum of 5 motors to the extension board.

When it comes to sensors, we can talk about an extremely diverse device. One of the reasons for this is that we can also use the set of sensors provided by the micro:bit in the course of our work, so we get: accelerometer, compass, light sensor, thermometer, microphone and touch sensor (the latter two only for v2 micro:bit). In addition, the board is equipped with an infrared obstacle sensor and a line tracking sensor, and it is also possible to connect an ultrasound sensor. The obstacle avoider and line tracker made relatively few mistakes during the tests, it can be said that the sensors work properly.

Due to the lack of a color sensor, we will also not be able to perform all tasks performed by the EV3, such as the ability to distinguish colors. In addition, there is an infrared receiver on the device, which allows us to control the robot using the remote control that comes with the package. In terms of extensibility, we get a much more complex device if we look at sensors. The package is inferior to LEGO products in terms of the number of bricks, but due to compatibility, expansion is possible.

What else is worth mentioning and can be useful for children in such a session is the output peripherals. Here we get a vibrating motor, as well as 3 small RGB LEDs that we can program, as well as two more 10mm LEDs located on the front of the board, as if it were the headlight of a car. If we are using micro:bit v2, a speaker will be added to the output devices.

2.7. Introduction of the programming interface

Block-based language can be perfect for using the tool at any age to introduce programming or motivate students more. Block programming appears in Hungary already in the third grade [1], but there is also international research that proves that block programming has many advantages even in high school [9], as it is an easy-to-read, simple programming solution, so it provides a great opportunity to make people love programming and increase motivation.

The tool and micro:bit can be a good option for introducing python in addition to the block-based programming approach. An important consideration when choosing a programming language may be the simplicity of the language and support for object-oriented programming. Based on these aspects, the Python language can be an ideal choice, especially for novice programmers. [10] One of the main advantages of language is the obligation to code readably, beautifully, which allows students to structure their code properly and create code that is easy to maintain. In addition, the Python language is also very popular in the industry and is used by many large companies such as Google, Instagram, and Spotify. Due to the widespread use of Python, learning Python can be a good choice when starting a programming career, especially nowadays.

The current role of Python in the world is well reflected in the fact that, according to the latest TIOBE Index developer survey, Python is the most popular programming language in the world. [11] According to Stack Overflow's 2023 report, for those learning to code, Python rank third among languages chosen for this purpose, after HTML/CSS and JavaScript. Participants who

learned its programming were more likely to indicate that they were using Python compared to the developers' responses (Python: 56% vs. 45%, C++: 31% vs. 20% and C#: 20% vs. 29%). In addition to the increase in popularity, there is also evidence that students are more willing and easier to learn Python than programming languages they have already learned, and based on student feedback, they also found Python more fun. [12] Python is therefore not only perfect as a starting language, but also as the basis for many new, emerging workspaces for students. Such areas include machine learning, data analysis and manipulation, forecasting and the development of artificial intelligence, which are priority and extremely developing areas of today's digital world. For comparison, however, in this article we will only dwell on the block interface in more depth.

Due to the spread of the micro:bit, instead of presenting the official interface in detail, we would like to focus on the new blocks related to the given device and their integration on the Makecode interface.

The blocks responsible for managing the board are not only available for use, but we can also edit them, since the code and resources for the Stem:Bit are available in a GitHub repository[11]. The names of the blocks are clear and with minimal knowledge of English it is easy to understand what we will be able to use each block for.

New blocks can be accessed by clicking on extensions. Here it is necessary to insert the link to the repository, after which we can already select the tool. (Figure 10)

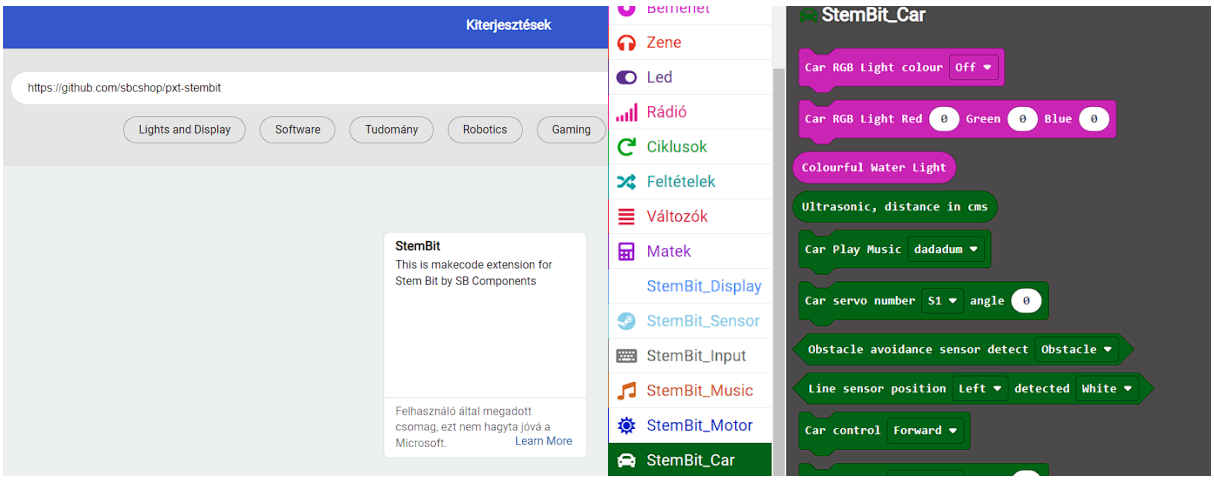


Figure 10: Attaching the extension and the new blocks[12]

After adding the extension, we get the codes that are in English, so for young children this can be difficult and may require a teacher's explanation. The structure of the blocks does not differ from the usual micro:bit environment, so it can be positive that children who have already programmed micro:bits or used block languages will find themselves facing a familiar environment.

A brief description of the interface can be found in the manual that comes with the package, in addition to the nine building instructions mentioned earlier, as well as 1-1 picture of the necessary line of code to make the device work, and at the beginning of the instructions a list of blocks that will be used.

[11] https://github.com/sbcshop/pxt-stembit

[12] Source: Bence Gaál's own picture

We also need the extension for the previously mentioned remote control and, as with Inventor, we have to program the various functions ourselves. This will be discussed in more detail in the next chapter.

3.3.1. Introduction to block groups[13]

In this subchapter we will focus mainly on those blocks that do not require any other accessories and we can control the devices in the package with them. Such block groups for remote control and "car" control blocks.

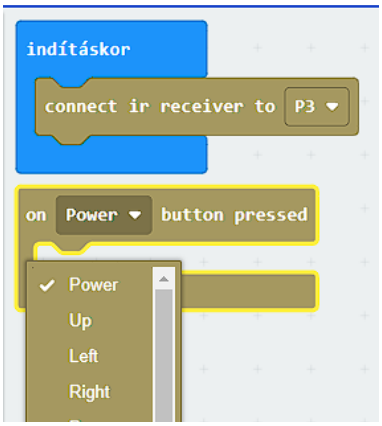


Figure 11: The remote controller related blocks

The first block group we want to introduce is related to the remote control. There are only two new blocks, one of which effectively activates the receiver. We need to know that the receiver unit is connected to P3 pin, so we have to configure it during programming. And in the other block we have the option to specify what happens when pressing which button. The principle of operation is similar to that of buttons on the micro:bit, so when a button is pressed, the code inside the block will run (Figure 11).

The StemBit_Car block group is already made up of many more elements, which can be divided into three subgroups. The first is intended to control the headlights of our imaginary car, which are marked in crimson. With these, we can display preset or created colors of our choice (by rgb code) on the two large leds of the device. The second group includes sensors, as here we can query whether there is an object in front of the obstacle detection sensor, whether the line tracker detects a white/black line or not, and the value of the ultrasonic rangefinder in centimetres. With the third unit, we can control the rotation of the motors, even separately, so we have the opportunity to turning. There is also a block playing pre-built music, and it is also possible to set how many degrees the servo motors should turn, which, like the ultrasonic sensor, must be connected externally to the device (Figure 12).

In *the StemBit_Music* block we can turn on the vibrating motor, while with the *help of the StemBit_Motor* blocks we can adjust the speed of externally connected servo motors and their degree of rotation. The *input* blocks are suitable for the management of externally connected devices, while the *sensor* block group is suitable for the treatment of microphone and ultrasound sensor in addition to the infrared located on the device. With *the help of neopixel* blocks we can make the 3 LEDs on the board work. This and the control of larger LEDs can also be done using display blocks. We do not necessarily recommend using these blocks in the classroom when introducing programming. One of the reasons for this is that these blocks are not necessarily recommended for beginners due to their complexity, and instead of turning the device on and off, we can control the Pins to make different settings.

[13] Image sources: Bence Gaál's own pictures

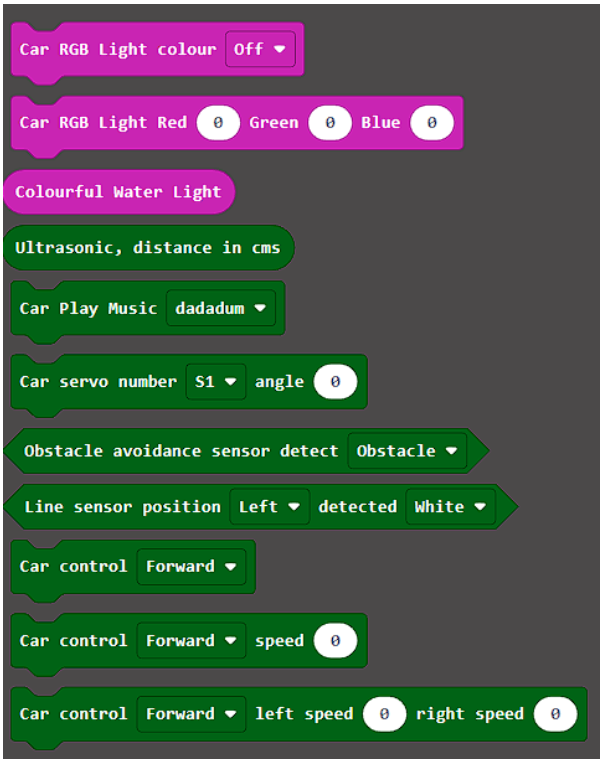


Figure 12: Engine control and sensor blocks

3.3.2. What tasks can we solve with Stem:Bit?

Line tracking tasks can basically be implemented with the tool, even problems related to avoiding objects can be solved with it. Parallel programs can be solved in this environment similarly to Inventor. In the implementation of tasks, the types of sensors and types of motors limit the device, as explained in previous chapters. The size of the display is also mentioned here, so drawing tasks are used to simplify it, since the micro:bit only has a 5x5 led panel.

When used in a competitive environment, it cannot be compared to either the previously discussed Inventor or the EV3 robot, as LEGO products can only be used by participants in WRO Robo Mission and Robo Sports competitions [14].

For its main use, we recommend classroom lessons, where the tool can really stand its ground in making programming more interesting and expanding the micro:bit. Thanks to the block environment, it can be used even in elementary school age, just as we utilized this feature during testing, in fourth grade we used it as a tool to attract attention and strengthen motivation, while in fifth grade it played a role in science subjects in addition to computer science classes as a modeling tool.

It can be used to realize many interesting projects that are not limited to digital culture in class. For example, because of the tracks-based models, it can be effective for modeling a research robot that takes measurements and then transmits data to another device. With the help of micro:bits we can even build vehicles that can be controlled by another micro:bit via the radio connection built-in the micro:bits.

The complexity of the expandability of the device can be beneficial for older age groups, since sensor connections and their control with pins can also strengthen skills related to electronics and

electricity. The disadvantage of this may be that expanding process is more time-consuming than in the case of a modular robot.

4. Summary

Due to the phasing out of the EV3, it is necessary to look for alternatives. Obviously, the structure and price of each robot kit will greatly influence our choice, but we may want to consider other aspects of which one we want to use. Looking at the specifications of the two robot packages discussed above, it could be a good option to replace the EV3, but neither can completely replace it, so consider other factors as well (Table 3).

	Robot Inventor (51515)	**Stem:Bit**	**EV3 Home (31313)**	**EV3 Education (45544)**
Number of motors	4	2	2+1	2+1
Number of motor connection options (ports)	6	2+3 servo	4	4
Number of sensors	2 (built-in) + 2 (modular)	6(built-in)	3 (modular)	5 (modular)
Sensor connectivity	6	beépített+4	4	4
Control unit	Hub	micro:bit	Brick	Brick
Power supply	Li-ion battery	Li-ion battery	6pcs AA battery	Li-ion battery
Total number of items	949	307	601	541
Price	Last known price: ~470 €	101,95 €	Last known price: ~570 €	Last known price: ~745 €

Table 3 Comparison of specifications

We wanted to offer a lesser-known, cheaper alternative to the well-known and established LEGO brand. The use of both devices in education largely depends on the purpose for which they are brought into the classroom. Although LEGO Robot Inventor provides a more expensive option, it is definitely a better supported device, and we get a high-quality device according to the brand. The downside is that the implementations do not necessarily reflect that this device is a successor to the EV3. There is a strong sense that the Spike product line had a big influence on the device during the design process, which will take over fully in the LEGO educational robot assortment in the near future and the manufacturer will focus only on this product.

Despite the Stem:Bit has half as many building blocks, it offers much more freedom in terms of sensory extensibility. Fewer motors and fewer bricks can be a barrier to building more complex robots and, as mentioned earlier, a barrier to creative creation. However, the price of the robot is less than half of the Inventor's price, and this is also a crucial factor in education.

Nevertheless, we believe that we get a particularly good tool for classroom tasks and for introducing and loving programming. They can be used to create interesting, spectacular measuring devices, remote-controlled cars, and can be a good solution for the cost-effective implementation of various interdisciplinary STEM projects.

Overall, both robots are particularly good for educational purposes, but they are targeted in different areas. Inventor is a more widely known tool with greater support and can be used in international competitions, while the cheaper alternative Stem:Bit leverages the versatile micro:bit

to provide a complete experience, while both tools provide the opportunity to cover the robotics education required by the Hungarian National Curriculum.

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Dual Impact of AI on Education: Boosting Personalization, Hindering Computational Thinking

BAYRAMOV Emin

Abstract. The introduction and influence of artificial intelligence into our lives were not the same as any other technological progress, it questioned the fundamental rules of every field it fused and caused a radical change. Various aspects of education field were affected by this trend. In particular, the sharp impact of artificial intelligence on students' approach to assignments, topics, and learning methodology has caused concern in the academic field. In addition to accepting the presence of substantial positive effects, educators are worried about the irreversible negative impact of this integration. The foremost of these is the student's critical thinking ability. Such a dual effect of AI in the education sector, on the one hand, aims to provide easy access to information and personalized assistance, on the other hand, the possibility of hindering their ability to think critically is a profound. Our study aims to address this, to reveal its possible negative effects, lay groundwork for further research, and suggest solutions.

Keywords: Artificial Intelligence, Education, AI Impact on Education, Computational Thinking

1. Introduction

1.1. What is AI?

The term "Artificial Intelligence" (AI) was first mentioned by John McCarthy at the Dartmouth Artificial Intelligence Conference in 1956. Leading researchers from different disciplines converged to develop the concept around “thinking machines”. The most common discussion was not about whether computers could mimic human intelligence, but rather about how and when it would happen. Nowadays, Artificial Intelligence is developing and extending over every part of the world at an alarming rate. [1], [2]

1.2. AI in Education

The introduction of AI into educational contexts may be traced to the 1970s. At that time, researchers were interested in seeing how computers might substitute for one-to-one human tutoring, which is considered to be the most efficacious approach to teaching but is inaccessible to most people. [3] Since those beginnings, the application of AI in education has expanded in multiple directions from student-facing AI (tools designed to support learning and assessment) to also include teacher-facing AI (designed to support teaching) and system-facing AI (designed to support

the management of educational institutions). [4] ‘Intelligent’, ‘adaptive’, and ‘personalized’ learning systems are increasingly being developed by the private sector for deployment in schools and universities around the world, creating a market expected to be worth 6 billion dollar in 2024 according to UNESCO Education Sector. [5] During this study we will focus on student support tools and its impacts on their Computational Thinking (CT) ability.

1.3. Computational Thinking (CT)

Since Jeanette Wing brought the term computational thinking to the forefront of the educational research field, there has been a dramatic expansion in studies examining the0 concept of computational thinking. [6] Wing outlined the basic definition of CT as a way of "solving problems, designing systems, and understanding human behavior by drawing on the concepts of computer science". On the other hand, according to the International Society for Technology in Education (ISTE) and Computer Science Teacher Association (CSTA), [7] CT is a problem-solving process that includes (but is not limited to) the following characteristics:

- Logically organizing and analyzing data
- Representing data through abstractions
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem-solving process to a wide variety of problems

1.4. CT: A Critical Competency for Success in the Modern World

The report "Charting a Course for Success: America's Strategy for STEM Education", released by the White House in December 2018, included CT when laying out the vision for the United States to succeed in STEM education. [8] This recognition extends beyond America. "The Digital Competence Framework for Citizens" report by the European Commission's science and knowledge service has identified CT Competency as crucial and necessary in the modern era, especially in the context of Media literacy skills. [9]

With the key concepts of AI, its role in education, and critical thinking established, we will explore how AI specifically impacts educational practices. The upcoming section will review existing research on this topic, laying the groundwork for a more in-depth analysis of how AI tools influence students' behavior. The primary goal of this study is to provide insights to support future research and promote effective use of AI in education, while also preserving and enhancing students' Computational Thinking abilities.

2. Methodology

The authors operated cautiously to investigate how AI contributes to education. We pursued a structured procedure proposed by the well-known review methodology called Preferred Reporting Items for Systematic Reviews and Meta-Analyses. [10] The review process in the current study consisted of multiple stages. The following sections detail how each step was conducted for this study.

We utilized a combination of key terms including "AI," "Generative AI," "ChatGPT," and "intelligent systems," combined with "education" and "science." This search strategy was formulated to discover and evaluate a wide variety of relevant works centered on AI in teaching and education.

2.1. Search Strategy

We focused on prestigious digital repositories for relevant literature, particularly IEEE Xplore, Springer, ERIC (U.S. Dept. of Education), and the European Commission's science and knowledge service. In addition, we conducted searches on Google Scholar and Google for the most current surveys or studies.

2.2. Eligibility Criteria

Defining explicit eligibility standards helps specify the boundaries of the review. Inclusion of studies meeting essential prerequisites and exclusion of those not aligning with research goals are vital.

- The study must have utilized empirical methods (quantitative, qualitative, data collection, and analysis.
- A crucial requirement is the incorporation of artificial intelligence in the research.
- Studies that did not explicitly mention AI are not accepted.
- Excluding studies are only available in abstract form.

3. Findings

In this comprehensive literature review, we carefully analyzed 38 empirical studies focusing on the integration of AI in education and listed **Table 1**. Various research methodologies were followed within these studies. More than 10 papers in the year 2024 demonstrated an increasing interest in the topic of "AI in education".

Author(s)	Year	Country	Topic
Aldabe & Maritxalar [11]	2014	Spain	Teacher assistance
Blikstein et al. [12]	2014	USA	Patterns in learning
Figueiredo et al. [13]	2015	Portugal	Teaching-Learning Sequence
Zhu X [14]	2015	USA	ML approach toward optimal education
Satabdi Basu et al. [15]	2016	USA	CT in middle school
Avelino et al. [16]	2017	USA	ChatGPT usage in Physics
Balakrishnan [17]	2018	Malaysia	Personalized learning environment
García-Gorrostieta [18]	2018	Mexico	Automatic assessment

Rokade A et al. [19]	2018	India	Automated grading system using Na
Hossain et al.[20]	2019	USA	Students attitude towards sustainable learning
Lee et al. [21]	2019	USA	Automated scoring
Azcona et al. [22]	2019	Ireland	Automated evaluation
Jalil N et al. [23]	2019	Malaysia	Machines learning trends in education sector
Koć-Januchta et al. [24]	2020	Sweden	Students' interaction with AI
Yannier [25]	2020	USA	AI in education
VanLehn [26]	2020	USA	Tutoring systems
Perrotta [27]	2020	Australia	AI in education
J Kim [28]	2020	USA	Students' perspective on AI
Ferrarelli & Iocchi [29]	2021	Italy	AI usage in Physics
Deveci Topal [30]	2021	Turkey	Chatbot application
Maestrales [31]	2021	USA	Automatic assessment
Ngadiran N et al. [32]	2021	Malaysia	Self-Directed Language Learning
Lee et al. [33]	2022	Taiwan	Impact of AI tools
N Selwyn [34]	2022	Australia	Impact of AI
Dirin A et al.[35]	2022	Finland	ML to predict students' path
Cooper [36]	2023	Australia	ChatGPT usage in education
Elkhodr et al.[37]	2023	Australia	Students' perspective on AI
Bitzenbauer [38]	2023	Germany	ChatGPT in physics
Kieser et al. [39]	2023	Germany	ChatGPT in physics
Nasution [40]	2023	Indonesia	AI in biology class
Daher et al. [41]	2023	Israel	AI in chemistry class

Nja et al. [42]	2023	Nigeria	AI in science class
Cochran et al. [43]	2023	Switzerland	Automated evaluation
Nguyen [44]	2023	Vietnam	AI in biology class
Chiu et al. [45]	2023	USA	Future of AI in education
Chan [46]	2023	China	AI policy for university
Marzuki et al. [47]	2023	Indonesia	The impact of AI writing tools on the content
Ward B et al. [48]	2024	USA	Analyzing the Impact of AI Tools on Student Study Habits

Table 1: Articles included in the comprehensive review

3.1. AI Adoption

The results revealed that AI has been integrated into various subject areas in the field of education, including the physical and natural sciences. The Figure 1 provides a clear visualization of the distribution of research topics, highlighting the prevalence of AI applications across different educational contexts.

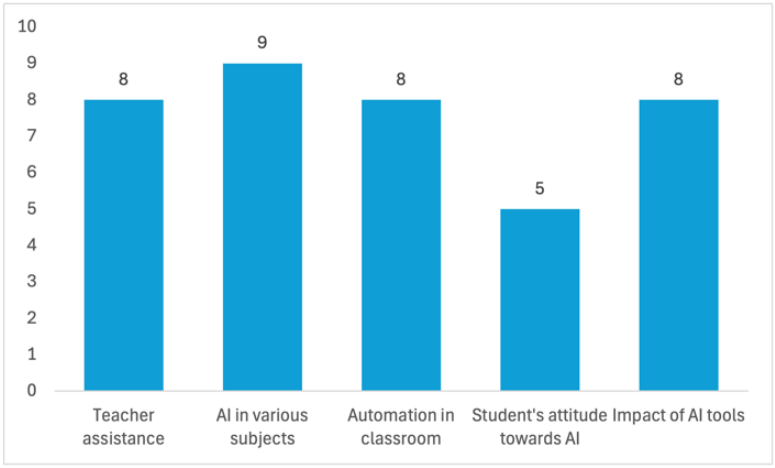


Figure 1: Distribution of topics across 38 reviewed papers, grouped into broader categories. Each bar represents the number of papers addressing a specific category

Some notable Machine Learning (ML) applications include:

- Automated Grading and Feedback Tools – mainly using supervised learning methodologies [18],[21],[31]. There is also study [19] that relies on Natural Language Processing (NLP). Utilization of ML has shown positive increase on straightforwardness and responsibilities in evaluation process.

- Tutoring tools - The human exertion of teachers focuses on organizing exercises, creating rich learning conditions and, above all, building a profound relation with each understudy. Based on these objectives, ML Tutors need to develop in tutoring algorithms [14].
- Prediction of student path - Several organizations have developed programs to predict student success in educational initiatives and reduce the likelihood of dropping out [35]. Based on the understudy dull activities, the projects perceive their shortcomings and inspect whether they can lead to expulsion.
- Matching students and teachers – These ML processing-based platforms (Skooli, TutorMe, Brainly Tutor) matches students with certified teachers based on subject, learning style, and availability. There are also self-directed learning models [32]. System learns from labeled data and predicts the best match.

3.2. Students' attitude towards learning and AI

AI-based tools were shown to have a positive impact on student learning outcomes in certain courses. The experimental group that was exposed to AI integration in their learning environments demonstrated significantly higher scores on their academic tests.[11], [12], [31] Besides, [13] and [29] illustrated how AI helps facilitate improved subject understanding.

Study from Indonesia [47] where research was constructed within a case study design has highlighted AI writing tools such as (Grammarly, QuillBot, Wordtune, and Jenni) have been found to significantly improve students' writing skills.

Another worth to highlight results were derived from lately publicized research by Kent State University [48], research focuses on how AI tools can support personalized learnings where results and analyzes were constructed based on diverse group of 71 university students' detailed feedback.

Figure 2 demonstrates students' perceived academic improvement since they began using AI tools. As we can see from the chart, study [48] reveals a strongly positive trend in the perceived academic impact of AI tools, a substantial majority 48% (34 students) reported some level of academic improvement. This distribution indicates that AI tools are generally having a positive impact on academic performance for most students who use them.

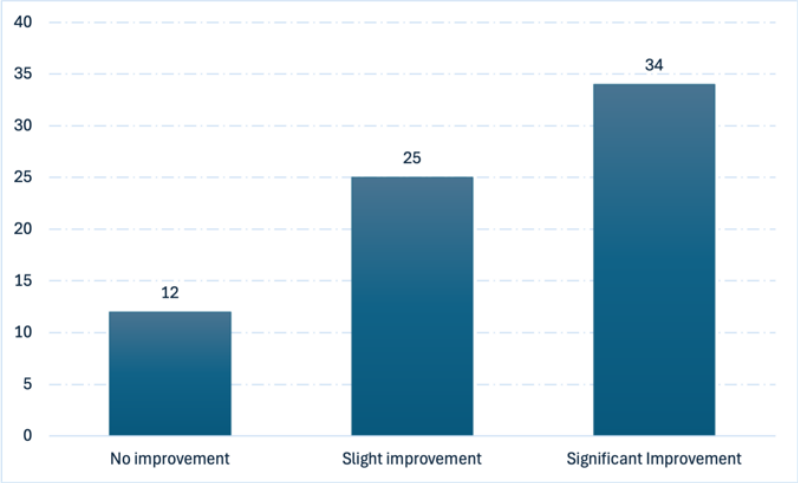


Figure 2: Perceived Academic improvement chart

Even though the study emphasizes AI's promising role in enhancing educational tools, with feedback from students showing substantial support, students also noted the need for flexibility and transparency to ensure AI complements traditional teaching methods.

Other studies supporting there is missing room in state of art approach, Daher [41] and Cooper [36] argued that AI tools require strong evaluation by educators on behalf of their effectiveness in aiding student learning. In addition, Lee [33] contends that AI-based tools, such as chatbots, can facilitate increased cognitive activity among students during the learning process. Correspondingly, Azcona [22] highlights that AI-facilitated personalized learning can reduce the gap between lower and higher-performing students.

Concerns about the impact of AI tools on students' behavior, and cognitive activity extend beyond these studies. A survey conducted by Forbes Advisor in 2023 with 500 practicing educators from around the U.S. revealed further details on how artificial intelligence is affecting education.

3.3. The Most Common AI Tools Used in the Classroom

Teachers use AI-powered educational games more frequently than any other AI tools, but adaptive learning platforms and automated grading and feedback systems [21], [31] are also widely used. The survey results depicted in Figure 3 provide a clear distribution of the types of AI-based tools educators have encountered or interacted with. The results indicate that while AI-powered educational games (51) and adaptive learning platforms (43) are among the most frequently encountered tools, intelligent tutoring systems (29) remain underutilized. This emphasizes the need for increased awareness and targeted training for educators to understand better and incorporate these tools.

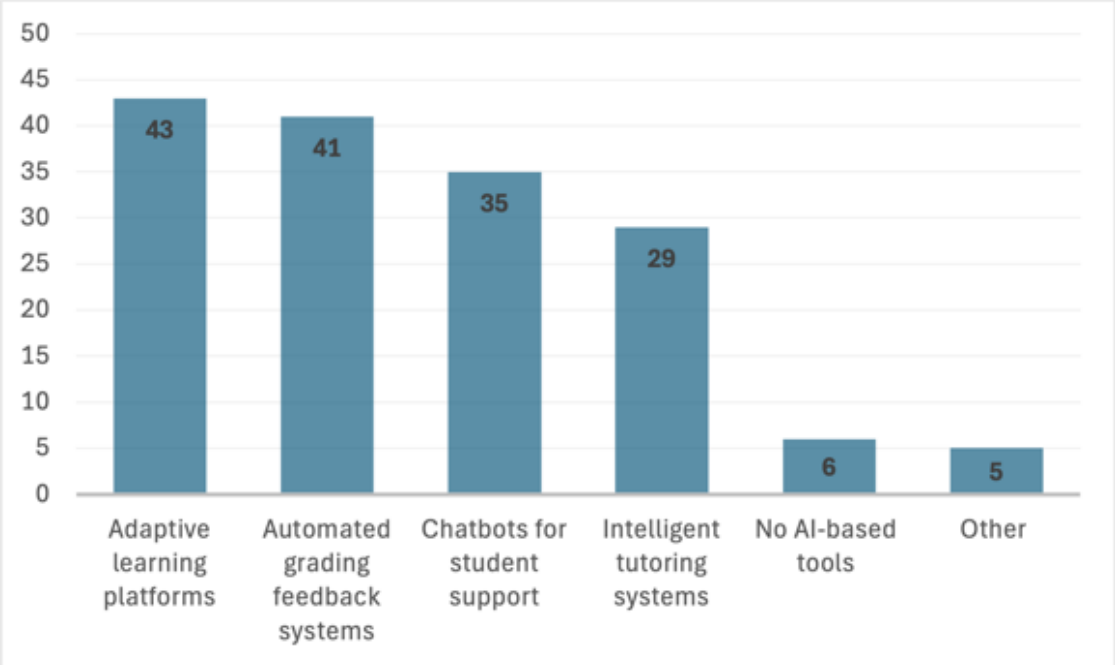


Figure 3: Distribution of AI-based tools or applications encountered in educational settings, based on a survey with US educators

Based on Figure 3 it is obvious that certain tools have gained popularity and are getting wider use. The most common AI tools encountered by educators are outlined in **Table 2**, underlining their functionalities.

AI Tool	Functionality
ChatGPT (OpenAI)	assistant chatbot with NLP that allows you to have human-like conversations to complete various tasks.
Quillbot	provides wide range of advanced, AI-powered writing tools (grammar checker, paraphraser, citation generator, translator)
Grammarly	suggests edits in real time for spelling, grammar, and writing style. It also suggests edits based on types of writing
Magic School AI	provides platform designed specifically for educators, aiming to alleviate burnout and enhance classroom efficiency by offers over 70 AI tools to assist with lesson planning, differentiation, assessment creation
Curipod	allows teachers to develop engaging lessons with interactive elements such as polls, word clouds, and drawing activities, enhancing student participation.
Eduaide.AI	provides AI-driven lesson plan generation, customizable templates, and adaptable lesson plans for unique needs
Khanmigo	provides personalized and interactive tutoring with real-time feedback with a wide range of subjects, and integrations with Khan Academy's curriculum
Gradescope	delivers grading and feedback with student performance analytics, and integrates with learning management systems
PowerPoint Speaker Coach	assists educators in refining their presentation skills. It offers real-time feedback on pacing, use of filler words, and even suggests improvements in tone and clarity.
Brisk Teaching	offers an AI-powered extension for educators that can help when creating curriculum, giving feedback, assessing student writing, adjusting reading levels and translating texts.

Table 2: Overview of the most common AI-based tools used in educational settings, their core functionalities

3.4. Concerns of Educators

AI adoption in the classroom poses a challenge for students, teachers, and schools as they must learn to use these technologies responsibly. As can be seen in Figure 4 which lists down the concerns raised by US educators regarding AI integration into the classroom, survey demonstrates

that educators worry about cheating the most. Only four educators said, "no concerns in particular," implying that the majority view AI integration with some level of skepticism or critical awareness.

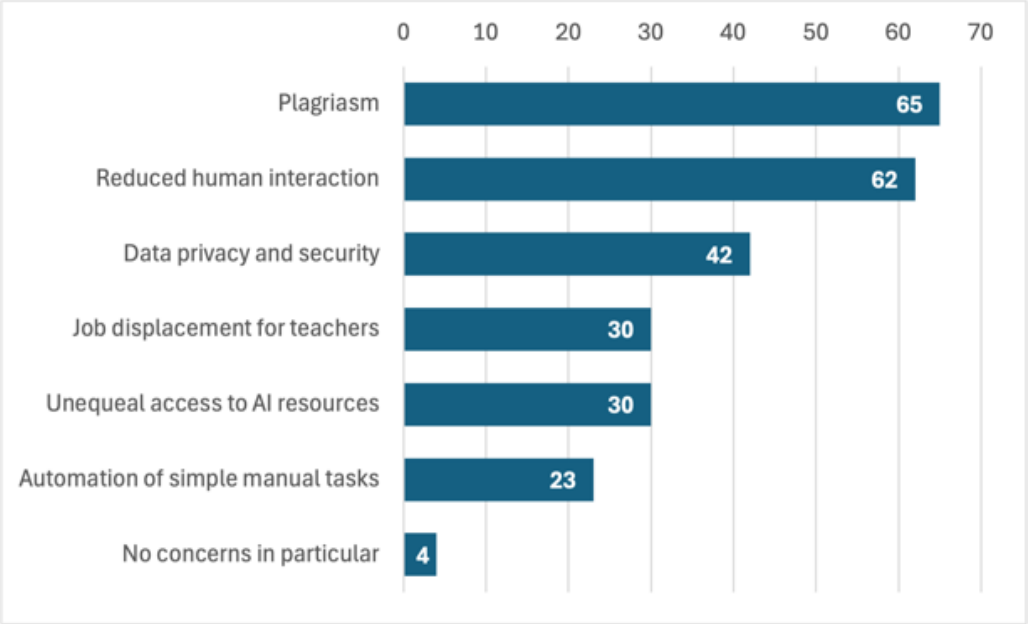


Figure 4: Distribution of concerns about the use of AI in education. based on a survey with US educators

4. Discussion

As highlighted by peers, integration of AI in the learning environment brings numerous benefits, like personalized learning and improved understanding of subjects, but it also raises valid concerns about its impact on the CT Competencies of the learners. Within this section, the authors would like to discuss the potential impacts of integrating AI into education on the core characteristics of students' CT competencies.

4.1. Abstraction

Due to its strong nature AI tools can effortlessly break down a problem into simpler steps or provide a direct solution, students may miss out on the opportunity to practice extracting key concepts and focusing on relevant details. **High dependency on AI** might lead students to become less proficient at identifying and managing abstract concepts independently.

4.2. Pattern Recognition

While AI can promote learning, the sheer volume and presentation of information may cause **Cognitive overload**, potentially hindering students' ability to recognize patterns and underlying trends in tasks and problems.

4.3. Algorithmic Thinking

One of the key drivers for developing algorithmic thinking is when learners are faced with challenging tasks that require a solid foundation in abstract knowledge and the ability to recognize patterns within the problem. However, with **Easy Access to Answers** provided by AI tools, learners may miss out on the opportunity to develop this competency altogether.

4.4. Generalization

AI tool adapts content to a given task automatically which doesn't encourage the application of learned principles to varied contexts, students may not develop the ability to transfer their knowledge to different scenarios. This could cause **Cognitive rigidity** within learners.

5. Conclusion

The anticipation that somewhere around 100 million people will work in the field of artificial intelligence by 2025 and a 50 percent growth in the field of education, and dozens of similar statistical indicators are an indicator that artificial intelligence has caused a revolution and will continue to do so. However, in the current situation, the deadlock has come to a point in the field of education, because many educators and educational institutions do not know how to behave in this matter, due to a lack of expertise, it has led to banning and blocking the use of artificial intelligence among students and taking measures against it.

As we mentioned in the discussion section, the excessive use of artificial intelligence can have a significant impact on their ability to criticize, think analytically, understand the basic factors of a problem, how to behave when faced with similar challenges, and how to solve it when the task becomes more complex.

While our research highlights the transformative potential and challenges associated with artificial intelligence in education, it is essential to acknowledge certain limitations in the scope of our review. Firstly, the rapid evolution of AI technologies and their diverse applications make it difficult to capture the full spectrum of their impact comprehensively.

We see the cause for this in the students' use of AI tools and platforms as a problem solver, an answer device, instead of a database, source of information and assistance, which leads to the side effects mentioned above. It is our view that the best way is to show the capabilities, limitations, and possible impacts of AI and to what level it can be used if it is used correctly. One of the possible paths in the noted topic is the design of an instructive, interactive, innovative curriculum in which various aspects and fields of use of artificial intelligence are discussed and mentioned in this topic and its training in educational institutions. We hope that our research and the results we have revealed will leave a motivating force and influence to look deeply into this topic and work on it in the next research in this field.

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Event-driven kinematic measurements using BBC micro:bits programmed in C++

SOMOGYI Anikó, KELEMEN András, MELLÁR János, MINGESZ Róbert

Abstract In Hungary, according to the Physics curriculum in National Core Curriculum 2020, quantitative description and examination of motions are required. Teachers and students are suggested to use the available computer tools and programs during the measurements and evaluation. We present and recommend microcontroller-driven measurements displaying the physical quantities of the mentioned movements as a function of time. The measurement setup consists of a linear air track, BBC micro:bit, some optical sensors and 3D-printed elements. The event-driven measurement software running on the micro:bit was developed in C++ (CODAL). The microcontroller sends measurement data to the PC through wireless communication (radio or BLE), and the Excel Data Streamer and a self-developed add-in for Excel serves to receive and display real-time data. Linear and non-linear regression analysis of measurement data was performed by built-in Excel functions, Trendlines and the Solver add-in. These measurements can also add interesting extra material to the curriculum in IT classes.

Keywords: BBC micro:bit, event-driven measurement, simple motions, optical sensors, serial communication, Excel Data Streamer

1. Introduction

In the 16th century, the examination of movements with scientific rigour became a natural science based on quantitative measurements. Galileo formulated a precise relationship between time and the displacement during the free fall of an object, also he slowed down the motion using a slope [1]. He also discovered that the period of a simple pendulum is independent of mass [2]. These simple motions form the basis of the topic of high school mechanics, including kinematics, even today [3]. The effect of his research method can be observed even after hundreds of years: The so-called scientific method remains an important part of the National Core Curriculum 2020 of science education in Hungary. One of the most important steps in the process is experimental data collection and analysis, which in the 21st century can be implemented not only with traditional measurement techniques but also with modern tools of technical informatics. The curriculum also recommends the use of available computer tools and programs in measuring and evaluating them [4]. This innovation is to be welcomed because, on the one hand, it provides an opportunity for a kind of interdisciplinary education, i.e. one that treats computer science and science as a whole, and, on the other hand, for student activity.

At the same time, the topic of robotics plays a significant role in the education of digital culture, which, of course, includes sensory measurements [4]. In this way, a kind of fusion of physics and computer science can be realized in education. In digital culture textbooks [5–8], the programming of the BBC micro:bit device, which is very popular and recognized internationally and designed specifically for educational purposes [9–12], plays a prominent role in this topic, one of the probable reasons for which is that a possible temporary shortage of the physical devices can be partially skipped using MakeCode, or the micro:bit Python Editor simulator [13,14]. Many studies can be accessed by interested teachers and students on the website of the program called 'Stumbling of micro:bits' organized by ELTE Faculty of Informatics[15], among which their after-school program curriculum [16] stands out. With the help of these, one can learn the basic use of the built-in sensors of micro:bit V2 (brightness, sound, acceleration, temperature, magnetism sensor), so they can also help those involved in physics education.

The HAS Research Group of Technical Informatics Methodology, in which the authors of this article also participate, among other things aimed to develop methods and tools to support students in learning the basics of engineering thinking through computer-aided measurements and programming easily accessible microcontroller-based devices (Arduino, BBC micro:bit) [17]. In addition to this, several experiments have been developed and published, which can be included in the classroom following the curriculum requirements described above [18–20]. On the website of the research group, both physics and computer science teachers can find aids in Hungarian for the inclusion of technical information technology content in their subjects [21].

In addition to the recording of the measured data, the precise evaluation of the data is of particular importance. The spreadsheet program Microsoft Excel has been among the software recommended by subject pedagogy researchers who wish to modernize the methodology of physics education with the inclusion of computers for a long time. [3,22,23]. Several publications have been published showing how to connect the BBC micro:bit or Arduino with Excel in computer-aided measurement experiments. [24–29].

In this study, we present for the first time an experimental setup based on the BBC micro:bit, containing 3D printed and homemade elements. Next, we describe the measurement algorithm and its software implementation written in C++, running on the micro:bit. and an Excel add-in (Data Streamer) for receiving the measured data on a PC. The evaluation is carried out using Excel's built-in functions and extensions. This hardware-software combination can be suitable for the application of microcontroller-controlled measurements in education, including the computer-aided, quantitative examination of kinematic phenomena prescribed by the framework curriculum.

2. An experimental setup based on the BBC micro:bit

In addition to the built-in sensors of the BBC micro:bit, additional sensors can be connected to the micro:bit. At first, sensors can be connected to wider pins (0, 1, 2) on the edge connector of the micro:bit with alligator clips, but using a panel, a so-called breakout board with a simple row of pins (or possibly with pin holes) is recommended [30], with the help of which circuit elements can be easily and stably connected to all I/O connectors (even the narrow ones), which is not possible with wide alligator clips.

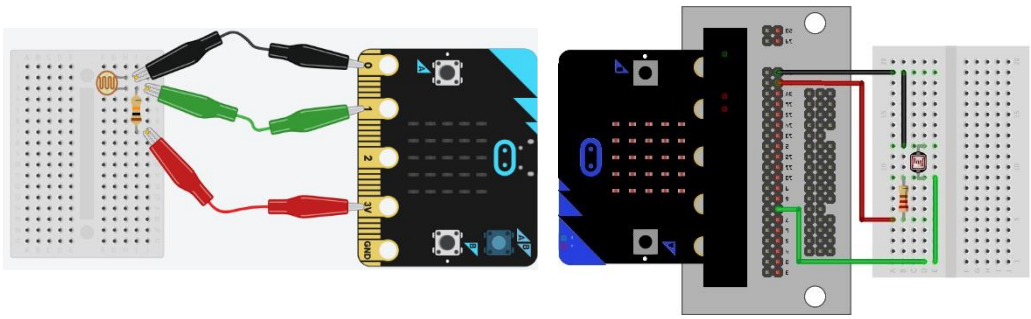


Figure 1. Connecting a photoresistor and resistor in series on a breadboard and wiring them to the edge connector of the BBC micro:bit a) with crocodile clips[1], or b) using a breakout board[2]

[1] The figure was created in the Tinkercad simulator.

[2] The figure was created in the Fritzing application.

2.1. BBC micro:bit supplemented with a reflective photosensor (line tracking sensor)

The continuous detection of the position of a body moving in a straight line can be realized with an experimental setup that works analogously to the quadrature encoder transmitters used to measure angular rotation [31,32]. In the first step, we can stick a self-adhesive encoder tape with alternating black and white (IR absorbing and reflecting) matte surfaces to the path of the movement (in our case, to the bottom of the side wall of a linear air track[3], under the rows of air blower holes), we have attached an A4 printable design for this [34]. A micro:bit and a reflective IR transceiver (e.g. TCRT5000-M line tracking sensor module) connected to one of its digital inputs can be placed on the cart so that the sensor is positioned above the tape during movement. The output signal of the sensor is thus a binary square signal: there are edges in the signal at the borders of the black and white fields (at every 0.785 cm). When these events occur, the position as a function of time can be measured together by recording the time stamp and incrementing the position counter.

If the direction of the movement also changes (so the position counter should be decremented) during the movement, adding another sensor to the setup is advised. When the two sensors are placed at a distance appropriate to produce signals with a phase shift of about a quarter of a period, the so-called quadrature signal appears on their output (Figure 2). Deciding which signal follows the other one, makes it possible to detect movement direction and position. A similar experiment rail equipped with an encoder tape and a small cart equipped with sensors and a controller [35] is available commercially [36], but this assembly can be implemented at a fraction of the cost.

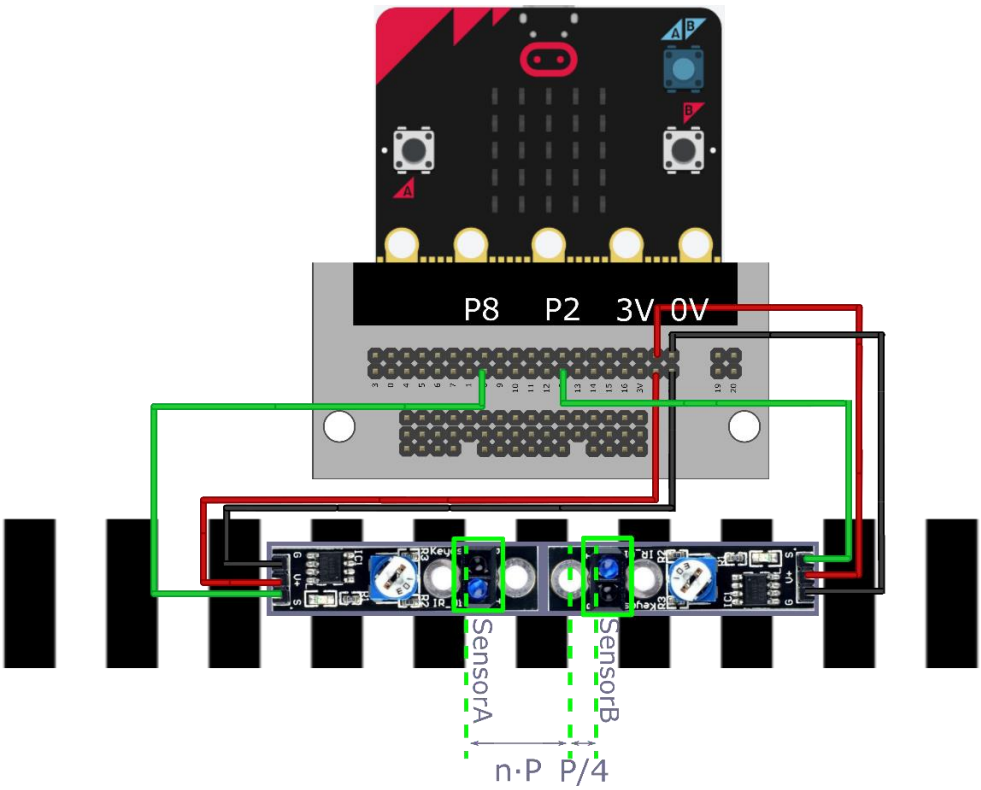


Figure 2: A circuit consisting of the TCRT5000-M modules and the BBC micro:bit. Sensor modules placed above the tape with distance of $n \cdot P + \frac{P}{4}$, where $P = 1.58\ cm, n \in \mathbb{N}$ (and in this figure n=1), produce a square wave signal with a phase difference of a quarter of a period

[3] A low-cost DIY version can be made instead of air tracks available commercially [33]. We tested our experiments at the SzeReTeD student laboratory of the University of Szeged.

2.2. Implementation of wireless data transfer between the micro:bit and the computer

Since we designed a wireless measurement experiment on the air track, there is naturally a need to implement a simple microcontroller system moving with the cart to ensure sending the logged data to the computer. The micro:bit card is controlled by the Nordic Semiconductors brand NRF52833 (BLE) [37], which also enables wireless communication for the device as a built-in radio frequency module.

One possibility is based on radio communication of two micro:bits, the circuit of the moving micro:bit can be mobilized with real-time data transmission [38–40]. The micro:bit placed on the cart serves as a wireless measurement system and also as a radio transmitter of measurement data, while the other device as a radio receiver is connected to the PC via USB.

Another option is to establish a Bluetooth Low Energy connection by pairing the micro:bit with a suitable computer. In this way, the wireless transmitter moving on the rail can send the measured data directly to the computer.

These two ways we can implement wireless data transmission between the measurement device and the computer [41,42].

For experiments on an air track, it is needed to find a power supply that is not too heavy for the air track experiments and can provide the system with the necessary current intensity at 3V operating voltage so that the operation of the sensors and communication would work reliably. Therefore, it is not advisable to power the transmitter with 2 heavy, 1.5V AAA batteries connected in series, though those would provide enough intensity of current. We also dismissed the possibility of using a CR2032 3V coin cell despite its lightweight, since its current output capabilities are too small to be used with the system the low intensity of current. The small, 190 mAh rechargeable Li-Po battery (3.7-4.2 V) would match the two criteria above, however, it cannot be connected directly to the power socket based on the circuit specification. However, the micro USB connector is equipped with a suitable voltage regulator, through which the battery power can be connected, e.g. with the help of a JST-USB adapter obtained by soldering a line of pins to a broken micro USB cable, so we can provide a stable and light-weight power source for the micro:bit that moves with the cart. The block diagram of the setup providing communication and power supply is shown in Figure 3.

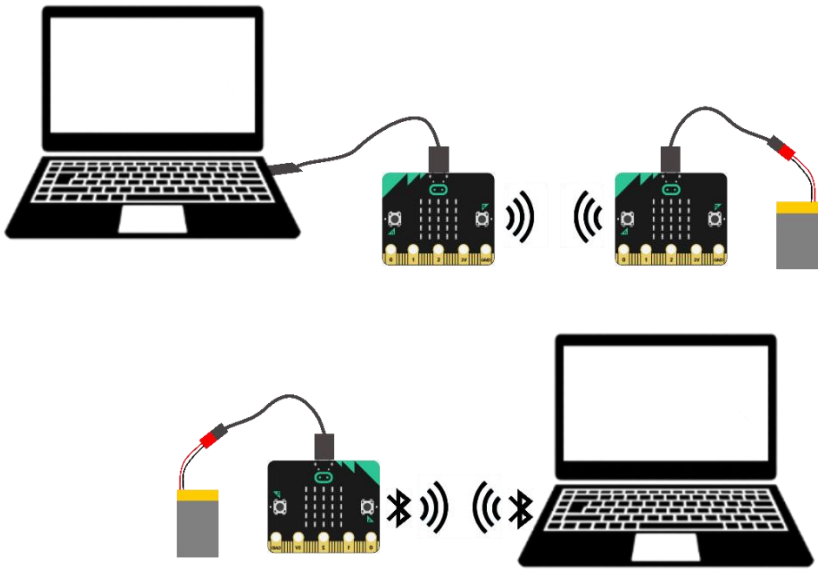


Figure 3: Block diagram of wireless data transmission (radio communication above, BLE communication below)

2.3. A 3D-printed cart moving on a linear air track for the micro:bit and its accessories

3D-printed devices are becoming more and more popular in science education as well, including physics laboratories, which can be enriched with self-designed devices [43]. We can design (e.g. in Tinkercad or Fusion 360) a unique cart that is suitable for the stable carrying of the above circuit, i.e. it provides a suitable place for the micro:bit, its battery and the sensor modules. In the case of the latter, special attention must be paid to the fact that, on the one hand, they are located above the encoder tape, and on the other hand, the sensors must be positioned to produce a quadrature signal.

It is worth considering a few more practical aspects when designing. It is recommended to reduce the air resistance as much as possible, by rounding the edges. The air coming out of the rail must be able to lift the cart away from the wall of the rail, thus one aim is to limit its mass, and on the other hand, the appropriate mass distribution for balance and stability must be ensured. For stability, it is worth designing the side walls hanging from the rail to be long enough. By placing the sensors on the same sidewall, our cart may become unbalanced, which can prevent the airflow on that side, so it is advisable to place internal long cavities in the walls. By throwing small metal balls into these, the object can be balanced. At the inner edge under the spine of the cart, it is also worth making a small longitudinal hole (approx. 1 mm in diameter) to ensure airflow, which can significantly reduce friction. We have attached the 3D design of the cart, designed in Fusion 360 together with our students [34].[4]

The complete experiment setup, with which the position-time dependence of rectilinear movements can be examined, can be seen in Figure 4.

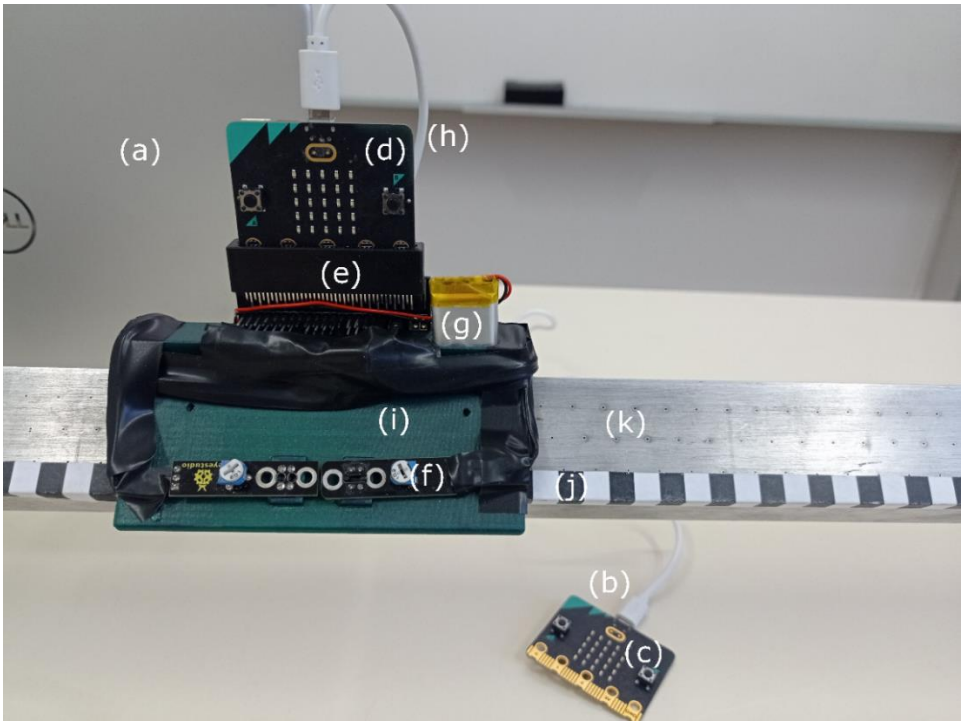


Figure 4: An experimental setup for position-time measurement of movements on an air track:
a) PC, b) micro USB cable, c) wired micro:bit (radio receiver), d) wireless micro:bit (radio/BLE transmitter)
e) breakout board, f) reflective IR transceiver (A TCRT5000-M), g) Li-Po battery
h) micro USB adapter, i) 3D-printed cart j) encoder tape k) linear air track

[4] Since the encoder tape must be glued to the air cushion rail in such a way that the air flow is not disturbed, the length of the side walls and the location of the sensors might be modified when using our model.

3. Software development for the implementation of kinematic experiments based on the BBC micro:bit

We see far fewer examples of measurement experiments with the micro:bit in the literature than with other popular platforms, like Arduino. Therefore, we considered it important to describe the structure of the software tools used for the experiments in detail.

3.1. Programming a micro:bit as a measurement device

In Section 2, we described the structure of the experimental setup, from which it was also revealed that it is necessary to decode square signal(s) to be able to determine time and position. We developed a basic version of the measurement program suitable only for investigating one-directional movement and then a more complicated version for motion with alternating directions. Both versions were created for both radio communication and BLE communication as well. We provide the complete program codes in the supplementary of this paper (both the C++ codes and the .hex machine codes as well) [34].

3.1.1 Programming the micro:bit in different environments

BBC micro:bits can be programmed with block programming on the MakeCode web application [44], or in JavaScript [45] or Python (MicroPython) [14]. It is perhaps less well-known that a wide range of function libraries are also available in the Arduino (C/C++) language [46]. Both MakeCode and MicroPython are based on the DAL/CODAL abstraction layer written in C++, which is based on the NRF5 SDK [47,48]. In general, it can be said that the lower-level language the device can be programmed in, the greater time accuracy can be achieved [49]. For the current experiments, the measurement software was developed in the C++ language using CODAL which supports micro:bit V2 [50].[5]

3.1.2 Handling events and scheduling tasks in C++ language using CODAL

In CODAL's C++ code, the `main()` function we place setting-type commands to be executed once e.g. we initialize the instance of the micro:bit class typically called '`uBit`', we set our digital pin to input by calling once the `getDigitalValue()` function and also set the pull mode of this input to pull-up.

In CODAL, it is possible to implement a kind of multithreading, on the one hand, through its non-preemptive fiber scheduler, which enables the coordinated operation of several concurrent tasks, and on the other hand, through the event management system called message bus, which allows writing reactive code The scheduler is initialized for `uBit` by calling `scheduler_init(uBit.messageBus)` [47].

MessageBus serves on one hand to record an event that occurs in a specific hardware block (e.g. button press or loud sound detection, or the arrival of a radio message), and this event is monitored at runtime. The MessageBus also delivers the occurring events to the program through event handlers. By calling the `listen()`, we attach a callback to a function when a specified event occurs.

[5] Installation instructions and sample codes can be found on Lancester University's GitHub page [51]. The compiled .hex files must be copied to the micro:bit driver.

We applied one of the built-in pushbuttons of the micro:bit as a start button. When the MessageBus sends a notification of the click of the button, the attached event handler is called to change the value of the '`toggle`' Boolean variable.

Similarly, in our experiment unit jump (falling or rising edge) events occur in the digital signal (`MICROBIT_PIN_EVT_FALL` or `MICROBIT_PIN_EVT_RISE`, respectively) on one of the digital inputs (e.g. `MICROBIT_ID_IO_P2`). We note that listening to these events must be enabled on the specified pin by `uBit.io.P2.eventOn(MICROBIT_PIN_EVENT_ON_EDGE)`. The MessageBus informs the program, and the scheduler calls the customizable event handler function (`onEdgeA`). Without setting the scheduler, all events have the same priority, however, after calling the scheduler, we can highlight these time-critical events with the keyword `MESSAGE_BUS_LISTENER_IMMEDIATE`.

The code fragment that implements the monitoring of the event:

```
uBit.messageBus.listen(MICROBIT_ID_IO_P2, MICROBIT_PIN_EVT_FALL,
onEdgeA, MESSAGE_BUS_LISTENER_IMMEDIATE);
```

By calling `create_fiber(sendAvailableData)` once in the `main()` function another fiber is initiated and its previously defined parameter function is called from this fiber by the scheduler. To help concurring fibers, it is advised to use `fiber_sleep(delay_millisec)` function in this non-time-critical fiber to let the scheduler run the time-critical event handlers. The main function also represents a fiber which in our case is released after initializing every component of the program.

3.1.3 Producer and consumer - writing and reading a circular buffer

One possibility to process data in the created fiber would be to check whether the currently available timestamp differs from the one stored when the previous event occurred because then we can know that a new event has occurred [28]. However, when the cycle time of the process is longer than the timespan between consecutive events, timestamps for some events may not be processed. To avoid that, we defined an array of timestamps serving a circular buffer.

The event handler assigned to the rising edge events represents the producer task, storing measurement data at the index called '`writePointer`'. The created fiber for data process and transmission is used as the consumer, reading data from the buffer at the index called '`readPointer`'. To imply a circular boundary condition, we set these indices back to zero when reaching the end of the array. The program also monitors the number of available samples: when an event occurs, its callback function writes a piece of data increasing the variable for the number of available samples, but when the `sendAvailableData()` is called by the fiber scheduler, the same variable is decreased.

The code fragment that implements the event handler (producer):

```
void onEdgeA(MicroBitEvent evt)
{
    if(toggle)
    {
        dataBuffer[writePointer]=evt.timestamp;
        writePointer++;
        if (writePointer == BUFFER_LENGTH)
        {
            writePointer=0;
        }
        if (availableSamples < BUFFER_LENGTH)
        {
```

```
            availableSamples++;
        }
        else
        {
            processingTimeout = true;
        }
    }
}
```

When the elapsed time between two events is less than the process time, the number of available samples increases dynamically. When the buffer is full, i.e. number of available samples equals the buffer size, the timeout is handled by stopping the producer (setting the toggle flag to false), emptying the buffer by the producer, and afterwards freezing the program by an infinite loop [20].

The code fragment that implements the consumer and handles timeout:

```
void sendAvailableData()
{
    while(1)
    {
        if(availableSamples)
        {
            if (processingTimeout)
            {
                uBit.display.scrollAsync("TIMEOUT");
                toggle=false;
                if(availableSamples==0)
                {
                    while(1);
                }
            }
            timeStampData = dataBuffer[readPointer];
            …
            readPointer++;
            if (readPointer == BUFFER_LENGTH)
            {
                readPointer=0;
            }
            availableSamples--;
        }
        fiber_sleep(1);
    }
}
```

3.1.3. Time measurement in the event handler function

Although it is possible to sample the digital signal at equal intervals, only those events provide valuable information about the position of the body as a function of time, when a jump (rising or falling edge) occurs in the digital signal. If at this moment our event handler captures the timestamp (`evt.timestamp`) with microsecond accuracy, we assign a time to a very well-defined moment of the movement: the cart is switching between neighbouring black and white fields of the tape.

Since the event handler function should be executed as quickly as possible (since the scheduler handles it as time-critical), it is advised to keep it as short as possible. Further operations on the measured time data and its transmission to the PC will take place in an infinite loop placed in the fiber of the consumer. The timestamp in CODAL is an unsigned 32-bit integer, so reading data from the buffer is an atomic operation for the 32-bit processor of NRF52833.

3.1.4. Measuring the position of one-way movement by counting events

When processing the signal of the reflective IR transceiver sensor module, in addition to recording the timestamp, we also want to assign a position value to the event. Since the width of the white and black stripes on the encoder tape is the same, it is advisable to record the timestamp for both the rising and falling edge events, and these can be handled alternately with the same event handler routine. In the case of one-way movement, each new edge means an increase of the location coordinate by 0.785 cm, so in the endless loop of the consumer (in addition to processing and sending the timestamp), the position counter variable is also incremented.

3.1.5. Measuring the position of alternating direction movement by decoding quadrature signal

The direction and then the position of the alternating movement can be decoded from the 4 states of the quadrature signal measured by the two sensors, shifted by approximately ¼ period (Table 1).

The logic behind our method of decoding the quadrature signal is as follows. The event handler of one signal (A or B) can derive the information of the edge type, that is falling or rising from the `evt.value` variable, from which we can deduce the binary state of the particular sensor (A or B) right after the edge event. By changing the value of a binary flag respectively, each time, the signal (A or B) can be reproduced.

The code fragment that implements detecting Signal B:

```
void onEdgeB(MicroBitEvent evt)
{
    if(evt.value==MICROBIT_PIN_EVT_FALL)
    {
        stateOfSensorB=0;
    }
    else
    {
        stateOfSensorB=1;
    }
}
```

Ideally, we could ensure with sufficient geometric accuracy that there is exactly a ¼ period shift between the two signals. Then, a timestamp could be recorded in events fired by both types of (rising and falling) edges of the signals of both sensors (A and B), between which the position would change by 0.3925 cm in the positive or negative direction. The inaccuracy of 3D printing and the size of the sensor modules do not allow this level of accuracy. Therefore, as a compromise, we still record a timestamp only at the edges of the signal A, the distance travelled between consecutive events is 0.785 cm. Instead of the one-dimensional array, we applied a two-dimensional one for the circular buffer to store the belonging timestamp, the state of signal A and the state of signal B.

Based on Table 1, it is shown that if the binary state of signals after the edge events is the same, signal A is followed by B, otherwise, the direction of movement is reversed. In the code, we also assign a binary value to the movement direction and record this flag.

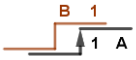
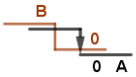
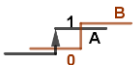
Changes of signal A (Events)	Type of edge	State of signal A after the event	State of signal B after the event	Direction of movement and change of position
	Rising	1	1	A is followed by B↦1
	Falling	0	0	A is followed by B ↦1
	Rising	1	0	B is followed by A ↦0
	Falling	0	1	B is followed by A ↦0

Table 1: Events in the quadrature signal and the logical structure of the decoding

Table 2 illustrates the conditions for incrementing and decrementing the position. The movement direction established in the current event must be compared with the movement direction recorded in the previous event, and if it has changed, the position counter must be increased or decreased.

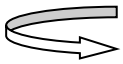
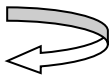
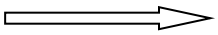
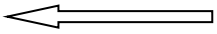
Movement phase	Movement direction at the previous event	Movement direction at the current event	Change of position
	B is followed by A ↦0	A is followed by B ↦1	No change
	A is followed by B ↦1	B is followed by A ↦0	No change
	A is followed by B ↦1	A is followed by B ↦1	Incrementation
	B is followed by A ↦0	B is followed by A ↦0	Decrementation

Table 2: Logical structure of position counting

3.1.6. Radio communication between two micro:bits

In the code of the micro:bit that plays the role of the transmitter, in the first part of the main() function, where we place the commands that are executed once, we enable the radio connection (`uBit.radio.enable()`), and then in the infinite loop, after the type conversion of the timestamp and after changing the position counter properly, the time and position data pair is sent to the receiver as a `ManagedString` type message, separated by commas and provided with a newline character (`uBit.radio.datagram.send(message)`). On the other micro:bit - functioning as a receiver - we also enable the radio connection, and this time the `listen()` function monitors the event of the arrival of the radio message [39,51,52].

3.1.7. Serial communication between a micro:bit and a PC

When data arrives, the data is loaded into a buffer, which is converted into a `ManagedString` type message and then sent to the PC via the serial port (`uBit.serial.send(message)`). Note that the default baud rate of communication, in this case, is 115200 bit/s [53].

3.1.8. Bluetooth communication between a micro:bit and a PC

CODAL's Bluetooth capabilities are currently under development by staff at Lancaster University. As of now, quite a few services are available, e.g. the Event Service, the IOPin Service, the Button Service, Magnetometer Service, etc. For wireless data transmission, we instantiated the UARTService ('`uart`' pointer) [54]. According to its library, it is possible to send ManagedString type messages as well as 8-bit unsigned integer pointers (byte arrays). Another parameter of the `uart->send()` function is the mode, which can be SYNC_SLEEP or ASYNC. If we use the previous one, the function will perform a cooperative blocking wait until all given characters have been received by the connected device, thereby slowing down the fiber. For a multi-task fiber, one should choose the ASYNC option, which will copy as many characters as it can into the buffer when called and then return control so further commands can be run immediately, while ASYNC task runs in the background. If the data transmission is not possible for some reason (the buffer is full or the reading is delayed), the send function returns a negative error code, otherwise with the number of successfully sent bytes [55]. To ensure that each character is sent sooner or later, we iterated the send command using a for loop:

The code fragment that implements sending a string message in asynchronous mode:

```
int uartSendAsync(ManagedString string)
{
    int length = string.length();
    int sent = 0;

    while ( sent < length)
    {
        int bytes = uart->send( string.substring( sent, length - sent), ASYNC);
        if ( bytes >= 0)
        {
            sent += bytes;
        }
        fiber_sleep(1);
    }
    return sent;
}
```

In both versions of our measurement program (adequate for one-directional or two-directional motions) a timestamp and a position value with a separator character and a newline character are sent to the PC. Since timestamps in microseconds are 8-9 or even more characters long, these messages turned out to be too long and the Bluetooth transfer rate slowed down. Messages can be shortened by sending both pieces of information as whole numbers (4 bytes) without extra characters. Conversion of an integer is implemented by bitwise operations as seen below [56]:

The code fragment to convert integer to byte array:

```
int uartSendAsyncByteArray(int32_t num)
{
    uint8_t numByteArray[4];

    numByteArray[0]=(num>>24)&0xFF;
    numByteArray[1]=(num>>16)&0xFF;
    numByteArray[2]=(num>>8)&0xFF;
    numByteArray[3]=(num>>0)&0xFF;
      …
}
```

3.2. Receiving data on PC

During the kinematic measurements, the micro:bit sends time-position data to the computer as it was described previously. In the radio communication version the receiver micro:bit sends data via USB to the computer through Serial COM Port. When data is sent through BLE, the micro:bit serves as a GATT Server and our self-developed add-in serves as a GATT Client to receive wireless data.

3.2.3. Serial data reception with the Excel Data Streamer add-in

There are several ways to receive serial data on a computer, the simplest of which is to use the serial monitor of a development environment (e.g. Arduino IDE, Visual Studio Code). Another solution is to use free add-ins for Excel, like PLX-DAQ and our choice, Microsoft Data Streamer for Excel, which is an optional and free COM add-in available for Excel users that becomes more popular in STEM projects because it makes it possible to evaluate the received serial data immediately, locally [24,29,57].

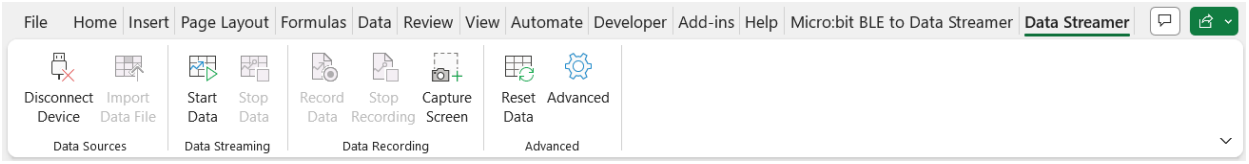


Figure 5: Microsoft Data Streamer for Excel add-in on the ribbon menu

The settings of the measurement software and the data-receiving add-in must be coordinated. In addition to adjusting the previously mentioned Baud Rate (in our case 115200 bit/s), we can specify how many pieces of data separated by commas (time and position values, so Channels number is 2) are received per line. In the current version of the program, the number of lines to be stored can be increased up to one million (the default number is 15).

3.2.3. Data reception with the Micro:bit BLE to Data Streamer add-in

One can find very few available software solutions for wireless data transfer from the micro:bit to a computer. In most applications, it is understandable that developers rather concentrate on data receiver applications on Android or iOS platforms, since for student experiments or IoT projects these are more adequate. However, these experiments on the air track are demonstration experiments, and the aim is to show measurement results frontal to a class. We decided to develop an MS Excel add-in as a supplementary application for Excel Data Streamer.

Microsoft provides several options for developers to create an Excel add-in. One of the most common and oldest options is macro development in the Visual Basic language. Visual Studio Tools for Office (VSTO) provides the opportunity to develop offline extensions based on the Windows operating system in the Visual Studio environment, in the .NET Framework, in both C# and Visual Basic languages. Another possibility is the programming of online, platform-independent Office Add-in extensions in JavaScript/TypeScript.

We developed our data-receiving extension in C# using the VSTO toolbox. [58] The front-end page of the extension is the Ribbon built into Excel, which contains the buttons we specify, dynamic and static menus, drop-down lists (combo boxes), text fields, etc. There is a visual designer to design the Ribbon, but to access advanced functions (e.g. to write the code for dynamically expanding menus based on queries) we used the XML descriptive language. [59]On the backend page, in C# language, in the Ribbon class, we specify the event handler (callback) functions that will be called during the selection of various button presses and menu items (e.g. onAction, onPressed type event handler callback functions). The flexibility of the extension is made possible by the dynamic management of buttons and menus (e.g. getPressed, getLabel, getItemLabel, etc.)[60–62]. The .NET framework allows, for example, to create pop-up windows for more detailed setting options, or to create WinForms dialogs that convey warning or error messages. The user interface of our add-in can be seen in Figure 6.

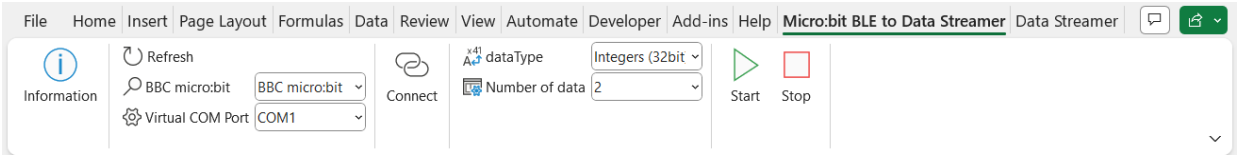


Figure 6: Micro:bit BLE to Data Streamer self-developed add-in on the ribbon menu

To communicate from Excel with the micro:bit, the Bluetooth Low Energy in Universal Windows Platform Apps technology was applied [63]. When the micro:bit is programmed to send data by Bluetooth UARTService, the micro:bit as a GATT Server writes its Transfer GATT Characteristics. The UUIDs of both the service and the characteristics can be found in the Bluetooth Profile of BBC micro:bit [64]. To pair and connect the device, find its UARTService and create a connection to read its TX characteristic, i.e. to create a Bluetooth GATT Client in the backend of our add-in, we followed the official tutorial of Microsoft [65]. When the GATT Characteristic's ValueChanged event is fired, the event handler reads from the transfer characteristic of the micro:bit to an argument buffer, from which a specified number of bytes, integers, strings, etc. can be read by an instance of the Windows.Storage.Streams.DataReader class. Depending on the user settings, received string messages, or four-byte integers converted to string are transferred to Data Streamer. We used a free virtual COM Port software to create a local bridge between the two add-ins [66]. We note that there is a possibility to read Excel cells right from a VSTO add-in, however, Data Streamer is optimized to write collected data to larger cell ranges at the same time with a user-defined rate. The other point of view is that it is advised to keep the ValueChanged event handler as short as possible to speed up Bluetooth communication, in our case received data is sent right after in the serial buffer, and no other data process tasks take place. We provided a downloadable installer for our add-in in the supplementary [34].

The running add-in has an Information window to inform users about connecting their micro:bit. By pressing the Refresh button, a query starts to list all available Bluetooth device paired with the PC, from which the BBC micro:bit can be selected. Similarly, all available COM Ports are listed, among which one-half of the previously created pair of Virtual COM Ports (local bridge) can be selected (while the other half must be selected for Data Streamer). Afterwards, connection can be asked, when the state of the Bluetooth device in Device Manager turns from Paired to Connected and the chosen

Virtual COM Port is opened. Users can choose which type of ValueChanged event handler is preferred according to the message format of the programmed micro:bit (ManagedString or integers). Also, the program needs a clue as to how much data is to be expected per line (in harmony with the Data Channels setting in Data Streamer). Afterwards, the press of the Start button results in reading TX characteristics by subscribing to notifications of its Indicate property and by starting the ValueChanged event handler.

3.4. Evaluation of the results of kinematic experiments in Excel

The measurement experiments were carried out on an air track and then evaluated in Excel. Our results show good agreement with the theoretical position-time correlations of the movements listed in the introduction.

3.4.1. Linear regression analysis of the measurement data of the experiments in Excel using the Trendline

Position–time data pairs were visualised on XY-point graphs in Excel. The option called Trendline offers the possibility to fit linear, logarithmic, exponential, polynomial, and power function curves on data or apply moving averages. In addition, equations of these curves and statistical R^2 values can be visualised on the graph. Among the examined movements on the air track, the space-time dependence of the uniform motion in a straight line and uniformly accelerated straight-line motion can be analysed using the Trendline.

3.4.2. Linear regression analysis of measurement data using Excel's built-in statistical functions

The features characterizing simple straight-line motions needed to be determined, applying the well-known equations for the position-time dependence of these motions. Though the coefficients can be derived from the equations of the Trendlines, one cannot change the accuracy of those values. Based on the least-squares method, Excel provides several functions of which output values can be used to determine those coefficients, thus features of motions like the initial position (x_0) and the velocity (v) of the uniform straight-line motion, or the initial position (x_0), the initial velocity (v_0)and the acceleration (a) of the uniformly accelerated motion (Table 3) [67,68].

Before beginning the evaluation, data ranges are advised to be named dynamically [69] e.g. Named Ranges **x** and **t** are for position and timestamp values, respectively. Afterwards, these ranges can be referenced in Excel formulas as can be seen in Table 3 [70].

Type of motion	Equation	Parameters evaluated in Excel	
uniform motion in a straight line	$\boldsymbol{x} = v\boldsymbol{t} + x_0$	v	SLOPE(**x**,**t**)
		x_0	INTERCEPT(**x**,**t**)
uniformly accelerated straight-line motion	$\boldsymbol{x} = \frac{1}{2}a\boldsymbol{t}^2 + v_0\boldsymbol{t} + x_0$	a	2*INDEX(LINEST(**x**,**t**^{1,2}),1,1)
		v_0	INDEX(LINEST(**x**,**t**^{1,2}),1,2)
		x_0	INDEX(LINEST(**x**,**t**^{1,2}),1,3)

Table 3: Parameters, equations and formulas to analyse position-time data for straight-line motions. Bold letters refer to Named Ranges

In Figure 7, the linear position-time dependence of uniform motion in a straight line can be seen. To gain parameters of the fitted linear function, simply SLOPE() and INTERCEPT() functions can be used to evaluate the velocity and initial position, respectively.

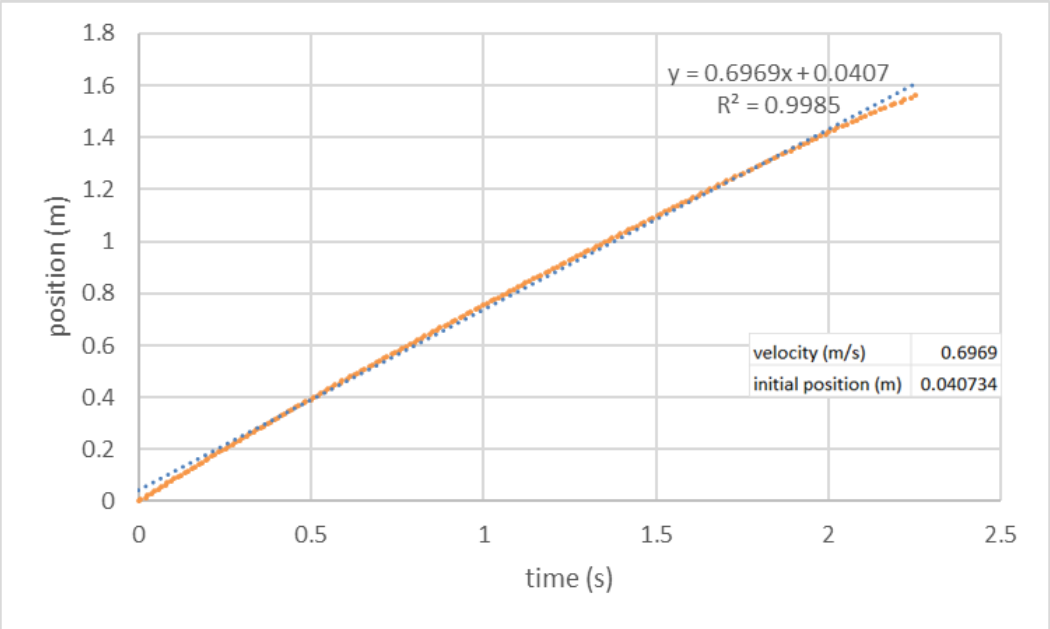


Figure 7: The position of the cart on an air track as a function of time in case of uniformly accelerated straight-line motion. Measurement data in orange and Trendline in blue are plotted.

While barely noticeable in Figure 7, we note that the time interval spent above a black stripe is not equal to the one above a white stripe. The reason for this is the fact that the analogue sensor signal edges are not quite sharp. A comparator on the module converts the signal to binary using signal cross-level detection, so it possibly happens that the edges in the signal emerge not exactly above the edges of the encoder tape. For more adequate position sensing one can choose to monitor events only on either falling or rising edges and compute position with a distance of 1.57 cm. Another solution can be to apply a moving average with a window size of 2.

We raised one end of the hover rail compared to the other end, so we got a slope with a small angle of inclination. Figure 8 illustrates that, as expected, a quadratic function describes the position as a function of time. The LINEST() Excel function can be used to extract the parameters of the quadratic function, which generates a table containing all the parameters and statistical characteristics of the regression. Using the INDEX() Excel function, we can select the coefficients of the members of the appropriate order of the fitted quadratic polynomial function from this data set [67].

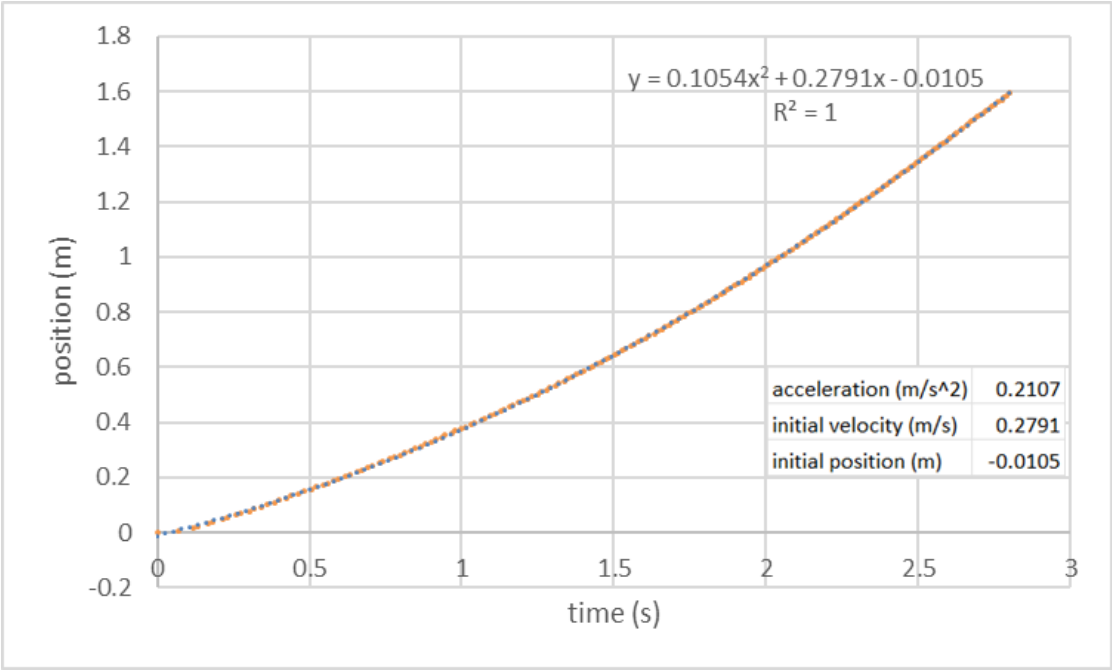


Figure 8: The position of the cart on an air track as a function of time in case of uniformly accelerated straight-line motion. Measurement data in orange and Trendline in blue are plotted.

3.6. Non-linear regression analysis by using Solver for least-squares optimization in Excel

In our modified experiment setup, the cart was attached between two relatively loose spiral springs. When we moved the object out of its equilibrium position, a damped vibration was created. When harmonic oscillation is damped by a force proportional to speed, the time dependence of the position can be estimated in the form of $y(t)=a\cdot e^{-bt}\cdot\sin\left(\frac{2\pi}{T}\cdot t+\varphi_0\right)+y_0$ [25]. It is not possible to fit a non-linear function like that using the previously used Trendline or the LINEST() built-in function. In recent years, step-by-step guides were published on how least-squares regressions can be applied to fit non-linear curves [71].

First, a, b, T, φ_0 and y_0 parameters were guessed as close to real as possible using the measurement data. Parameters a and b determine the exponential envelope, T means the period time of the oscillation, φ_0 is the initial phase, and y_0 is the offset of the damped sinusoidal function, i.e. the position of the equilibrium. We note that this estimation process might be very useful for the students helping them understand the meaning of each parameter. Second, with those parameters, the estimated y_{est} values, as well as the residuals ($y - y_{est}$) were counted. Then the sum of the squared residuals was determined and minimized by the Solver resulting in optimized values of the parameters. Using these parameters, a curve fit like the Trendline can be realized with the y(t) formula on a uniform, densely spaced time series as shown in Figure 8. We note that this more generalized method is suitable for the other types of motion, too.

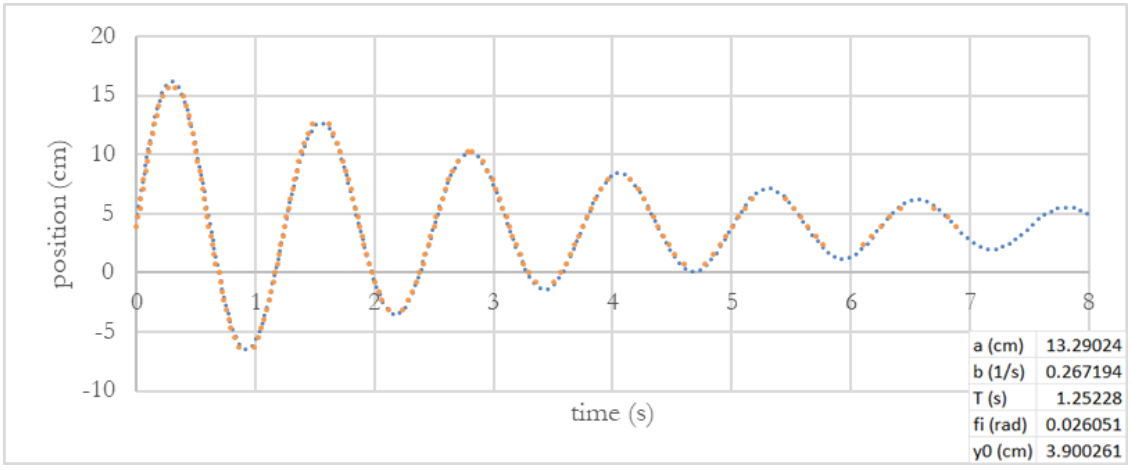


Figure 9: The position of the cart on an air track as a function of time in case of damped oscillation. Measurement data in orange and Trendline in blue are plotted.

4. Summary

In the study, we presented a hardware and software assembly that, based on the BBC micro:bit teaching tool, can function as a complex measurement system for physics education. 3D printing played an important role in the experiment setup. During the presentation of the structure of the measurement software, we highlighted some of the possibilities inherent in the CODAL (C++) environment, regarding the potential inherent in event-driven programming. When evaluating the data, we used popular Excel extensions (Data Streamer, Solver) and functions (e.g. LINEST()). Our experimental results show a very good agreement with the theoretical description of the movements.

We believe that the tools and solutions presented above can also be useful for IT teachers: it is important to build relationships between subjects since education in these scientific fields can contribute to students choosing a career in the area of STEAM.

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