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Application and impact of electronic solutions in teaching programming

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Abstract. The market trends that are determining the electronics industry today point to a sharp increase in the use of IoT devices, sensors are collecting data around us, using wireless data transmission technologies to transmit the measured values to cloud-based databases, which are processed with various software. Low-power microcontrollers developed for battery power, which are widely used today, provide sensor data collection and data transfer control.

In this article, we present a literature search on the technical IT teaching tools in use today, some of which are inherently educational and popular with students and teachers. We pay attention to the educational principles of technical IT methods.

We show with examples how technical IT solutions can provide an appropriate experiential learning opportunity and background in programming education. We focus on teaching methods that use microcontrollers and various sensors to develop programming skills and acquire programming knowledge. By developing both computational and algorithmic thinking, we aim to develop both skills.

Keywords: Robots, microcontrollers, teaching methods

AMS Subject Classification: 94-06

1. Introduction

Today, most of the devices around us are based on electronic solutions which contain a processor and are controlled by a software. With sensors, they are able to convert the physical, chemical and biological signals of the outside world into electronic quantities and then information, which can thus be processed with the help of software. The electronics used allow battery-powered devices that can handle

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more and more signals to run operating systems and various applications. These electronic tools can be used effectively to improve the quality of secondary and university programming education [12]. In particular, it has a major impact on the development of technical and computer-minded thinking, without which students have difficulty in today's labor market [10].

The aim of this article is to underline the importance of using robots, microcontrollers and IoT (Internet of Thinks) devices in secondary and university education. Using robots, microcontrollers and IoT in education can improve students' algorithmic thinking and familiarize them with programming techniques. The acquisition of tools using real and scientific examples supports the complex development of STEM.

2. Methodology

In the article, we conducted a short literature search, where we focused on technical IT methods, including the project solution method. We determined which electronic devices are used most in education. We will then conduct a research to support our hypothesis according to which the use of robots, microcontrollers and IoT devices in education can improve students' algorithmic thinking and familiarize them with programming techniques.

The contribution of robotics to education to clarify new disciplines is remarkable. In fact, there is a need for experimental examples that facilitate the acquisition of students 'professional knowledge and thus meet the potential of the actual systems used in various modern disciplines. In [6], the authors discuss laboratory experience in implementing an automatic airflow control system for remote configuration and monitoring of convincing size and role. An example is a non-traditional robot. Built-in electromechanical equipment from old farms are being exploited and revived using modern, widely available microcontrollers, smartphones, tablets, network transceivers, motor drives and some low-cost and custom sensors.

Teachers of Technical University of Košice in their article describes the implementation of IoT technology in the teaching of microprocessor technology. The method presented in this article combines the reality and virtualization of a microprocessor technology laboratory. A built-in IoT monitoring device monitors students 'microcontroller needles and sends the data through the control application to the server to which the teacher is connected. The teacher has the opportunity to monitor the development of the program tasks and student code, where the functionality of these tasks can be checked. Thanks to the remote laboratory implementation of IoT, students' lesson tasks have improved [5].

Programming using microcontrollers is becoming increasingly popular in teaching to help learners gain a deeper understanding of programming principles. Using sensors, motors, and various electronic components with microcontrollers, we can create impressive results in teaching programming, such as movement, flashing, etc. It engages students and gets them interested in programming [15]. We can design applications visually with the help of visual programming, a new trend within coding. The use of visual programming is growing in popularity today. TinkerCad is an excellent tool for visual programming. Using TinkerCad, we can assemble the circuit, write the software code and simulate the results. This application displays the result of each step. An application such as this can be used well during a time of pandemic, when students are being educated online. TinkerCad supports a variety of predefined components, such as Arduino, Raspberry PI, Micro:Bit, and more [4, 11, 13, 14]. The authors of this article describe a method for visualizing programming instructions using the TinkerCad online application.

In [8], the authors detail the development of an approach that provides students with an integrated coursework and laboratory experience. The increased performance and functionality of modern microcontrollers is both an opportunity and a challenge for educators. Increased complexity, the need to integrate hands-on laboratory experience, and declining pressures on curriculum hours require a significant investment of time to modernize microcontroller instruction that few instructors can afford. However, a successful microcontroller course offers a unique opportunity to prepare students for large, complex systems.

In his article, Cubero describes how to direct students to become their own best teachers, able to test their newly acquired skills without receiving minimal or no help from an instructor. They describe "closed-loop" student-centred learning and problem-based learning approaches that include weekly lectures and hands-on laboratory activities that maintain students 'curiosity, motivation, and participation in self-regulated learning. Students must design and test their own original circuits and software code by modifying, extending, or expanding the sample circuits and sample codes described in the lecture notes in order to meet and demonstrate the specific objectives or requirements of each weekly laboratory session. These "closed-loop" student-centred learning labs ensure that all teams of students reach a general or minimum acceptable level of practical skills that appropriately prepares them for the competition of "design and construction". This learning style also contributes to the development of general lifelong learning skills such as problem research and identification (problem definition and analysis), independent research and experimentation, decision making, communication and teamwork. Even without prior hands-on experience in electronic circuit design, programming, and microcontrollers, all student teams were able to apply and demonstrate new knowledge and skills, design and test original circuit and software designs unsupervised; solve and correct complex problems successfully and confidently; build a workable remote-controlled electric vehicle or mobile robot for the ultimate race. Some went even further and built sensor-controlled, fully autonomous mobile robots [3].

In most articles, the authors suggest using the project method or the problem-solving method in teaching. In their article, Mendoza and his colleagues present the content, teaching, and assessment methods of a mandatory course in the design of microprocessor-based real-time embedded systems in the final years of undergraduate telecommunications engineering. The method used was project-based learning and assessment was based on the skills learned. Finally, the article reflects on how well the course has achieved its objectives using a project-oriented approach [7].

Amiel describes a six-year experiment with his peers based on a project-oriented learning approach to teaching the basics of electronics. The proposed teaching framework has a dynamic structure as it adapts and modifies the conditions for annual assessment to help motivate and interest students. The authors present the effectiveness and value of this approach in terms of student motivation [1].

According to Sari et al., Taking advantage of the benefits of information technology in the digital age of the twenty-first century is increasing in every economy to overcome problems and difficulties and find the solutions you want. So the development of algorithmic thinking is important as a skill that requires the application of knowledge from different disciplines, especially the natural sciences, technology, engineering and mathematics, and improves the solution of real problems. Therefore, practical studies are needed on how to develop algorithmic thinking and what activities and learning contents can be used in classrooms. The impact of STEM-centric physical computing activities with Arduino on teacher candidates 'algorithmic thinking skills and STEM awareness was investigated using mixed-method research. In addition, the student-teacher roles in the activities and the pros and cons of the activities were discussed, taking into account the views of the future teachers. The results showed that STEM-centric physical computing activities improve the algorithmic thinking skills of prospective teachers. Therefore, it can be said that the activities raised the awareness of future teachers about STEM [9].

Angeli describes in his article that those working in science, technology, engineering, and mathematics play a significant role in the sustainable growth and stability of the global economy and thus play a key role in the prosperity of all countries in the world. In this context, computer thinking is an important skill that allows workers to develop creative solutions to complex problems. However, all economies in the world need more workers who are able to think computationally about problems, challenges, and solutions. Therefore, integrating the teaching of computer thinking into secondary and university education is extremely important in order to reduce the skills gap between education and the workplace. An important and crucial question arises as to whether teachers have the knowledge and skills that will teach students to think computationally. Existing research shows that teacher-education classes do not currently have the knowledge to facilitate computer thinking in their programs. This study focuses on two aspects of computational thinking, such as algorithmic thinking and debugging skills, using scaffolding programming scripts in an undergraduate training in educational technology. The results show a statistically significant improvement in learning in the algorithmic thinking and debugging skills of preparatory teachers in the context of LEGO WeDo robot programming activities[2].

3. Results

The use of robots, microcontrollers and IoT (Internet of Thinks) in education can improve students' algorithmic thinking and familiarize them with programming techniques. And the acquisition of tools through the use of real life and science examples supports the complex development of STEM. In the following we will show some of the robots and microcontrollers used in education.

Then, with the results of our research, we confirm that students achieve better results on average when learning programming using visual tools (microcontrollers, TinkerCAD). It can be seen that not all tasks had significant results, but we supported our claims based on these. From the analysis of the results of the 4 task groups, we can conclude that the students achieved significantly better results in the case of the conditional branching (if..else) and the do..while conditional loop instruction task groups. While in the case of the counting loop instruction (for loop instruction) and the while..do conditional loop instruction task groups, there were no significantly better results, although on average the students taught with the help of visual tools performed better here as well.

3.1. LEGO robots

LEGO robots are very useful in education: programming with their help, measurement of various signals (use of sensors), communication between devices, construction of software-controlled mechanical systems (robots) can be learned and taught in a playful and experiential way. However, in addition to the many benefits, it is also important to point out that the transparency of the components is rather low, and due to the integrity, no details are revealed. The goal of the developers of LEGO robots was to make the devices as compact as possible, even without background knowledge.

3.2. Single board computers – microcontrollers

The Raspberry Pi single-sheet computer, originally developed specifically for education, and the Arduino circuit, which is indispensable for most hobbyists, including students and teachers, are also extremely popular. The Arduino is actually a card that has the contacts of a microcontroller used in the industry connected to more easily accessible connectors. For hobbyists and students, the simple development environment and the extremely rich information available on the Internet, as well as the wide range of additional circuits available cheaply, make it very convenient and easy to use.

These devices are already much closer to the technical systems used in practice, the user needs to know more about digital signals, interfaces, electronic solutions, because they encounter them more directly. In many cases, they are quite simple to use and provide very good transparency, which is especially important for education.

In the educational application of Raspberry Pi and Arduino circuits, there are elaborate solutions for almost every task that, while instructive, often encourage more than just copying. Unfortunately, the vast majority of the available knowledge (which can be considered as a curriculum in the case of educational use) was

Figure 1. Arduino Uno microcontroller.

produced by professionals with in-depth technical knowledge and attitudes, as well as professional and didactic reliability.

Figure 2. Rasberry PI microcontroller.

3.3. PIC controller

PIC stands for Peripheral Interface Controller. The PIC microcontroller is the smallest microcontroller in the world and is programmed to perform a large number of operations. These were originally designed to support PDP (Programmed Data Processing) computers to control peripheral devices. It is based on RISC architecture.

3.4. Micro:Bit

The BBC Micro:Bit is a small, programmable panel with built-in sensors (compass, accelerometer, light sensor), LED matrix display, I/O connectors, Bluetooth technology. The tool can also be programmed using an easy-to-use graphical block language, similar to the Scratch environment.

There are other educational tools on the market that can be considered robots, which are especially useful in kindergartens and elementary schools to develop algorithmic thinking in education. Such robots, resp. bots include Code&Go, Ozobot, Bee-Bot, etc.

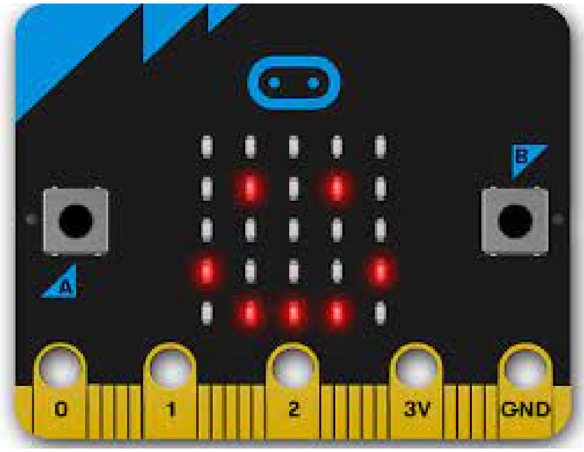

Figure 3. Micro:Bit microcontroller.

3.5. Characteristics of technical IT methods

Practice orientation

The real operation of technical IT teaching tools, the handling of real signals and the creation of effects ensure a practice-orientation. Easy and inexpensive tools help with experimental education, whether it's a teacher demonstration or school or home student experiments. This can improve the retention of interest and provide an opportunity to work together.

Task orientation

With the help of electronic-electrical sensors, teachers can create projects and tasks where students can learn how to use the tools and operating principles of the tools needed to solve the task.

Professionally correct application

Nowadays, technical (electronic) IT tools are used by many people, many people also share application suggestions and educational materials on the Internet, which from a pedagogical point of view may not be suitable for achieving the goal. There are plenty of imaginative and varied solutions to specific problems on the Internet. We must strive to develop critical thinking, the ability to override, the right attitude and demandingness. This requires the acquisition of certain basic professional knowledge, an appropriate level of confidence, and knowledge of the most important operating principles.

Multidisciplinarity

Technical IT methods can be used in almost all science lessons: in addition to IT education, physics class (distance, time, acceleration, pressure, speed measurement, ...), chemistry class (CO, CO2 measurement, ...) and biology class (blood pressure, heart rate, ...).

Transparency

From a pedagogical point of view, it is necessary for the students to understand the structure of the tools and the operating principles as much as possible. This is ensured by the transparency feature. It is usually difficult to find a balance, both superficially and in detail, between problem presentation and solution. This is well influenced by teachers' experience in using the tools directly.

Scalability

The tasks in the lessons should be such that everyone can have a sense of success, everyone can develop, as the skills of the students participating in the lessons in the field of IT can be especially diverse. Most of the time, their interest in the subject is not the same. In the case of technical IT methods, this is quite feasible; the student can solve the given task on many levels, with different additions.

Visual programming is a new trend within programming that allows us to develop applications. Nowadays, visual programming is becoming very popular. TinkerCad online application is very suitable for visual programming. Using the TinkerCad online application, we can assemble our circuit and then simulate the results after writing the program. In fact, the app visualizes the steps taken. The app can also be used during a pandemic period when students are being educated online. TinkerCad can use a lot of predefined tools (parts, sensors) for visualization on different platforms, such as Arduino, Raspberry PI, Micro: Bit,... [1, 2]. Here are some projects to visualize your programming education using the TinkerCad online application:

- Password-protected access
- Distance measurement
- Digital clock
- Temperature monitoring – measurement
- Engine control
- Remote control – Bluetooth, Wifi
- Brightness measurement
- Motion detection
- Line tracking
- Moisture measurement

- Moving lights using LEDs
- Digital sandstone
- Parking system
- RFID identification
- Qcode, barcode reading
- Using the display
- Maze problem

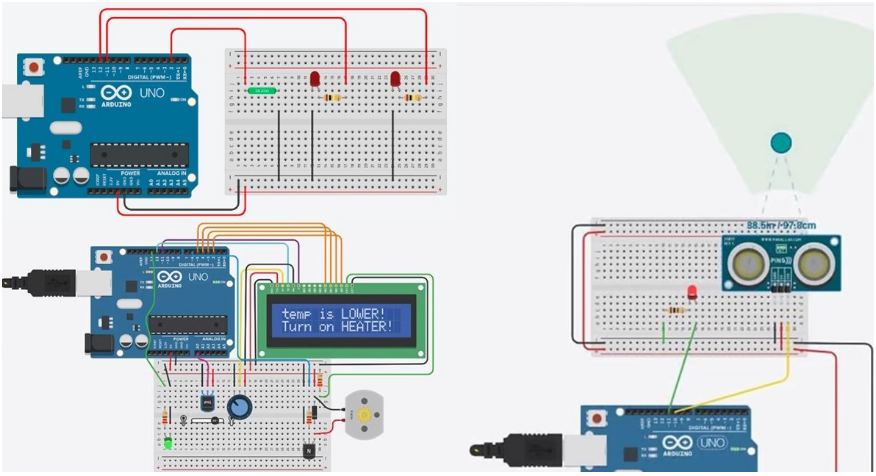

Figure 4. Circuits with Arduino Uno microcontroller created in TinkerCAD.

3.6. Research

We conducted our research in the second year of a secondary school in Slovakia (which is not IT oriented). According to the curriculum, we had 15 hours for teaching programming. The research was carried out in two classes, where only a minimal difference can be observed between students' knowledge level. This difference does not affect the research results. In this research, the results of a programming basics survey taught by an instructor are investigated. In this way, we rule out the possibility that teaching is influenced by multiple teaching methods and personal factors. We would like to examine the results from several perspectives. We would like to draw the appropriate conclusions from the results that can be used in further teaching work. The studied group is composed of 41 students, 21 students were taught the basics of programming using the classical method (ORIGINAL GROUP), while the other 20 students were taught using microcontrollers and TinkerCAD software (CONTROLL GROUP). The aim of the teaching was to learn and correctly use control structures. For both groups, 4 groups of tasks were evaluated in the assessment, which assessed the knowledge of: conditional branching (if..else), counter loop instructions (for loop instructions), conditional loop instructions (while and do..while loop instructions). In all four cases, the maximum score available in the assessment was 5 and the minimum was 0. In our research, we do not consider gender as it is not relevant in our case.

We examined the answers given by the original and the control group in SPSS with a hypothesis test (Independent Samples Test), based on which, on the one hand, the standard deviations of the two groups are the same, so among the tests offered by SPSS, the results obtained along the same standard deviation should be taken as a basis.

Table 1. The averages of the responses to the different questions vary between the two groups.

Group Statistics

	ROUND	N	Mean	Std. Deviation	Std. Error Mean
Q1	ORIGINAL	21	3,33	1,278	,279
	CONTROLL	20	4,25	1,118	,250
Q2	ORIGINAL	21	3,57	1,599	,349
	CONTROLL	20	4,05	1,146	,256
Q3	ORIGINAL	21	3,24	1,640	,358
	CONTROLL	20	3,30	1,455	,325
Q4	ORIGINAL	21	2,57	1,502	,328
	CONTROLL	20	3,60	1,231	,275

Table 1 shows how the averages of the responses to the different questions vary between the two groups. Based on this the average responses for the original recording are lower compared to the control group.

Table 2. Independent Sample Test of the responses of the two groups.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q1	Equal variances assumed	,450	,506	-2,439	39	,019	-,917	,376	-1,677	-,157
	Equal variances not assumed			-2,447	38,731	,019	-,917	,375	-1,674	-,159
Q2	Equal variances assumed	1,283	,264	-1,097	39	,280	-,479	,436	-1,361	,404
	Equal variances not assumed			-1,105	36,280	,276	-,479	,433	-1,356	,399
Q3	Equal variances assumed	,445	,509	-,128	39	,899	-,062	,485	-1,043	,919
	Equal variances not assumed			-,128	38,811	,899	-,062	,484	-1,040	,917
Q4	Equal variances assumed	,885	,353	-2,391	39	,022	-1,029	,430	-1,899	-,158
	Equal variances not assumed			-2,403	38,171	,021	-1,029	,428	-1,895	-,162

Table 2 (Independent Sample Test) gives an answer to the similarity/difference of the variances of the two groups and the similarity/difference of the responses of the two groups.

Based on this, since Sig > 5% for all questions, the standard deviation of the responses of the two groups can be considered to be the same for all questions, so the first row should be looked at for all questions when testing similarity/dissimilarity. Since the Sig (2-tailed) > 5% for all questions, the hypothesis H0 is accepted, which states that there is no significant difference between the responses of the two groups.

In addition, we have also considered the case where we do not examine the two groups separately for each question, but on the basis of the sum score (SUM value).

Table 3. The averages of the total response value (SUM) between the two groups.

Group Statistics

	ROUND	N	Mean	Std. Deviation	Std. Error Mean
SUM	ORIGINAL	21	12,71	5,081	1,109
	CONTROLL	20	15,20	3,397	,760

Table 3 shows, similar to the first study (when we looked at each question), the control group performed better on average in terms of the total response value (SUM).

Table 4. Independent Sample Test of total response value (SUM).

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
SUM	Equal variances assumed	2,091	,156	-1,832	39	,075	-2,486	1,357	-5,230	,259
	Equal variances not assumed			-1,850	35,050	,073	-2,486	1,344	-5,214	,242

Table 4 shows the responses of both groups (original and controll) which not show significant differences here either (because Sig (2-tailed) > 5%).

These would have been the results if the responses had followed a normal deviation.

However, since the normality condition is not met, it was necessary to continue the tests in a non-parametric direction with a Mann-Whitney test, which does not require a normal deviation of samples.

The main difference between non-parametric and parametric tests (Independent Samples Test) is that they are tested on a median basis instead of a mean basis.

Table 5. Hypothesis Test Summary.

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Q1 is the same across categories of ROUND.	Independent-Samples Mann-Whitney U Test	,006	Reject the null hypothesis.
2	The distribution of Q2 is the same across categories of ROUND.	Independent-Samples Mann-Whitney U Test	,351	Retain the null hypothesis.
3	The distribution of Q3 is the same across categories of ROUND.	Independent-Samples Mann-Whitney U Test	1,000	Retain the null hypothesis.
4	The distribution of Q4 is the same across categories of ROUND.	Independent-Samples Mann-Whitney U Test	,016	Reject the null hypothesis.
5	The distribution of SUM is the same across categories of ROUND.	Independent-Samples Mann-Whitney U Test	,099	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Based on results of Table 5, the only significant difference between the two groups' responses is for the first and fourth questions. For the other questions and SUM value, no significant difference is found at the 5% significance level.

4. Conclusion

Most of the devices around us are based on electronic solutions. The results of our research show that students on average achieve better results when using visual tools (microcontrollers, TinkerCAD) to learn programming. It can be seen that there were not significant results for all tasks, but they also support our claims Electronic tools can be used effectively to raise the standard of secondary and university programming education. It has a major impact on the development of technical and computer thinking, without which it will be difficult for students to succeed in today's job market. The market trends that are determining the electronics industry today point in the direction of a sharp increase in the use of IoT devices. With the help of electronics and technical IT methods, the following skills can be effectively developed: algorithmic thinking, technical and computer thinking, problem solving, project team thinking. We can further increase efficiency with visual programming. TinkerCad online application is very suitable for visual programming.

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