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Digital Transformation for Sustainable Engineering Education

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***Abstract*— The teacher's portfolio presenting the mastery of competencies focused on the student, the educational process and professional development is an important part of a teacher's career growth in Slovakia. The teacher must demonstrate that they are able to innovate learning practices, considering the educational needs of each pupil. Programmable hardware that is easy and fast to use allows teachers to make computer science lessons more attractive to students on the one hand and increase teacher self-confidence on the other. We decided to be the first working group in Slovakia that create a project to implement the innovation at national level education by using physical computing principles to develop student's digital skills. In cooperation with Slovak mobile company, we have realized the project, focused on education with the BBC micro:bit in Slovak schools. Thanks to the project teachers could have not only hardware but also access to information they needed to start teaching with BBC micro:bit. It helped to eliminate the problems with how to start and teachers could focus on the students. After teaching with micro:bit teachers were more motivated and confident. Based on the post-questionnaire, we found that computer science teachers perceive their competencies higher than before the start of the project.**

Keywords— microcontroller, micro:bit, programming, education, competencies

I. INTRODUCTION

How do things work around us? What are the technical principles of the things we commonly use? These are issues that could motivate elementary school students and learners to become more interested in programmable hardware. Practical programming of buttons and various sensors could also make up for the huge differences in the digital skills of pupils and their teachers. Through physical computing, children and teenagers learn basic concepts of embedded systems in a creative and motivating manner. Teachers' expectations towards and first experiences with physical computing help to gain a better understanding of their needs in professional development [1]. In our paper, we describe an educational program for the integration of the BBC (British Broadcasting Corporation) micro:bit into the curriculum in primary and secondary schools, the aim of which was also to increase the professional and pedagogical competencies of teachers. There are varied ways in which teachers can use the BBC micro:bit in an un-instructional styles. The first impressions of teachers and learners are positive [2].

II. PROGRAMMABLE HARDWARE IN EDUCATION

If students have full time access to programmable boards the learning process is improved. The results of some studies in last decade [3][4][5][6] present that using physical computing principles improve the overall learning process and students gain a better knowledge of modern technologies and design methods. Physical computing involves combining software and hardware to build interactive physical systems that sense and respond to the real world [7]. The tiny board BBC micro:bit, developed in 2017 with a goal to use it in schools and in extra-curricular contexts to teach computer science in the United Kingdom [8][9] was spread over the world in a few years [10]. It was developed for educational purpose and the first impressions were that children are going to love it [11]. The benefits of this tiny programmable device were already researched and reported in several countries including United Kingdom [12][13][14], Northern Ireland [15], Finland [16], Hungary [17], Denmark [18], Sweden [19][20], Croatia [21], Kingdom of Saudi Arabia [12] and Slovakia [22].

The BBC micro:bit consists of LEDs, programmable buttons, PINs, buzzer, a sound sensor, an accelerometer and a compass and provided us a different programming methods, from entry-level block-based editors (Scratch and Microsoft Makecode [23][24][25]) aimed towards beginner, to advanced forms of programming in MicroPython and JavaScript Blocks, simplified versions of the popular Python and JavaScript programming languages [26]. Using the BBC micro:bit blocks, students may easy experiment what

programming block represent in terms of real world conditions and in terms of programming concepts [27]. This range of software allows the teacher to set different levels of challenges in relation to the pupils' ability levels [15]. It is inspiring students to develop core computing skills [23] and computational thinking [28] in fun and creative ways. Significant interest in learning about ICT (Information and Communications Technology) even though it is perceived as the difficult area was revealed also among the girls [29][30]. Students' contact with technology is essential to develop adequate skills to study and analyze existing programmable technological solutions and design new ones [31]. By appropriate setting of projects, where students do not only program the project but also describe the progress, create video documentation, or present the project to the audience, we also develop the so-called soft skills [32].

STEM (Science, Technology, Engineering, and Mathematics) subjects have an inevitable role in forming competency-based knowledge and developing of 21st century skills [33][34]. There is a wide range of project type that could be realized through micro:bit, it can be fitted to clothing as wearable electronics [35], it could be used to develop a gaming mini-projects [36], it could be used to build own experiment equipment using the data from sensors to explain the underlying physics phenomena [37], it could relate to socially relevant problems [38], or it could trigger the discussion about the privacy, security and safety [39] in the field of programmable IoT (Internet of Things) [40] and even to engage in educational activities to solve real world problems [41]. Through connection of micro:bit with soil moisture sensor and cloud storage the traditional farming can be transformed into smart farming [42].

In Slovakia the most often used board in education was Arduino but due to the lack of comfortable access to components it is not suitable for lower education. After the BBC micro:bit was released the situation in Slovakia significantly changed and it seems to be the best hardware option among the teaching aids today [30].

III. Competencies of Computer Science Teacher

Computer Science (CS) is a fast-moving field. Paradoxically, it is often taken for granted that teachers who graduated from computer science colleges are qualified to teach the technical content of the subject [12]. In the context of rapid curriculum change, teaching computer science in school requires new skills and knowledge that existing teachers may not have. There are also many teachers with mathematics, business or other backgrounds who teach CS in schools, for these teachers the challenges are much more severe [43]. Teachers need to improve their competencies to teach computer science effectively, adequate development of teachers' competencies during their education is extremely important. Pedagogical content knowledge and teachers' beliefs and motivational orientations play an important role in effective teaching [44]. In modern conditions formal education is unable to meet the various educational needs of educators, especially when it comes to ICTs and computer science, so undergoing corresponding informal adult education is becoming an increasingly urgent mandatory requirement to a modern teacher [45].

A. 21st century competencies when learning programming

New digitally based learning concepts are constantly evolving, and teachers are now expected to not only use these new platforms and software but be able to teach them. As Chardnarumarn et al. [46] identified, the most important skills the teacher must develop in the pupils are (1) cognitive skills and attitudes, (2) language skills, (3) creative problem-solving skills and attitudes and (4) collaborative skills and attitudes. Which competencies are essential for teacher to achieve this difficult task? According to E. Roelofs et al. [47] the most important competencies are interpersonal competence, pedagogic competence, subject matter and didactic competence, organizational competence, competence in cooperating with colleagues, competence in cooperating with the school environment and competence in reflection and development. The authors are from the beginning a part of the project called ENTER with slogan Being smart is cool (chapter IV, ENTER is not an acronym, the name of the project is based on the keyboard key and meaning to enter with the project to better future). We hope that during this one-year program most of the above-mentioned competencies will be increased in a group of attenders. Detailed information about the project is presented in other paper [22]. In this paper we only briefly describe the project.

IV. Project Enter

We decided to be the first working group in Slovakia that create a project to implement the innovation at national level education by using physical computing principles to develop student's digital skills. The ENTER project started in 2020. It was funded by the Slovak Telekom Endowment Fund. Several smaller non-governmental organizations participate as the educational and technical support for teachers from granted schools.

The project offers for involved teachers from Slovakian schools several activities:

- A grant call, the fund up to 1000 € for buying physical kits based on BBC micro:bit technology and extensions. We obtained 388 applications and the committee chose 243 (63%) projects that were supported and together 229 000 € was given to the schools.
- A digital library of methodical and popular materials.
- Courses to present the basic programming concept in different levels. We planned on doing the face-to-face courses throughout Slovakia. Due to COVID-19 pandemic situation we had to make them online in the form of webinars.
- Smaller competitions to motivate participants for continual work.
- Consultants as a support for teachers that are not fully prepared to implement the new technology into the educational process.
- Mini ENTER call to motivate teachers which were not granted in a grant call.
- Online streams with a lot of extra information.

A. Webinars organization

Webinars were organized into 3 levels, we called them Blocks. Each block consisted of a minimum of two online meetings lasting 2 hours (Fig. 1). Each teacher had the opportunity to attend 18 hours of online learning [22].

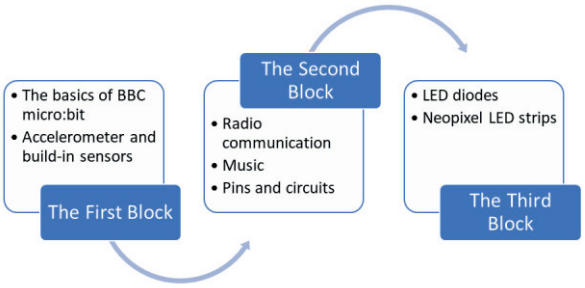

Fig. 1. Enter project realized in three block

Each of seven webinars has theoretical section (the theoretical background mostly about how specific part of hardware works) and the practical section (specific activities supported the theoretical part and presented principles of the things we commonly use such as pedometer, door alarm, electric piano etc.)

The blocks gradually presented the physical computing principles. The content of the basic level course was connection of microcontroller to computer, downloading the program from programming environment into the microcontroller memory, programmable buttons, built-in sensors (acceleration, light intensity, heading and temperature level). The content of the middle-level course was radiocommunication, music modulation, pinout and circuits. The advanced level course contained how to program LEDs in digital and analog mode and how to program neopixel LED strip.

Each of our training module was realized using the micro:bit classroom online management system that allows us to connect 30 teachers at the same time. Using this classroom management, we were able to send the presented block-based code to all teachers at the same time and we were able to see their local solutions. We use the screen sharing and the webcam live streaming of the hardware solution.

Our webinars started after the teacher had their own hardware kits at home, so they were able to try the solutions directly during the webinar and also ask to solve actual problems if occurred.

V. ACTUAL OUTCOMES

During the school year 2020/2021, we collected data on two separate occasions. When applying for the ENTER project in October 2020, it was provided with the pre-questionnaire. After completing the project in July 2021, only the successful solvers of the ENTER project were able to answer the post questionnaire, which was only available to them after they had completed the project. We also gathered teacher identities to be able to compare the shifts in individual teachers between the pre- and post-surveys. Our project was aimed at two educational level, primary school (from 11 to16 age) and high school? Our experiment is not designed to address the competency of the teacher teaching at the primary or high school differently, both groups had the same questions about their self-evaluation. At the conclusion, we obtained 110 answers from computer science teachers from across Slovakia, 85 of whom were women and 25 of whom were males, and most of them were qualified computer science teachers (according to the legislation and rules of the Ministry of Education of the Slovak Republic). In this paper we take data as one group without the demographic information about the respondents.

The ENTER project has also moved teachers to the educational competency (Fig. 2). 76% of teachers stated that they had moved pedagogically, 84% had moved professionally and 2% had not moved anywhere. Thus, most teachers stated that they had moved both pedagogically and professionally.

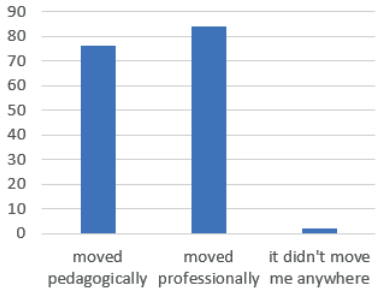

Fig. 2. Did the project move educational or professionall competency? Values on y-axis mean the percentage.

We also asked if the BBC micro:bit made lessons more interesting (Fig. 3). Up to 90% answered certainly yes and 10% yes. There were not no and certainly no answers in any case. 110 teachers when asked:

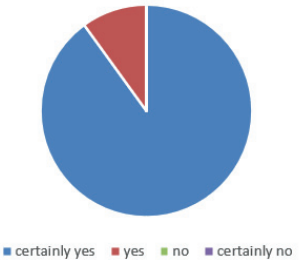

Fig. 3. Did the BBC micro:bit make you lessons more interesting?

How many lessons did you teach with the BBC micro:bit? It was said that they taught them up to 4,384 hours. On average, one teacher taught 43 lessons with a micro:bit.

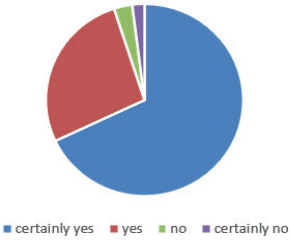

Fig. 4. Did the BBC micro:bit helped you be more confident in teaching computer science?

We also asked teachers if the BBC micro:bit helped them be more confident in teaching computer science (Fig. 4). As many as 68% of teachers said yes, 27% said yes and the remaining 5% said no or certainly not.

We asked them a few questions that focused on professional development.

According to the answers, 95% of teachers agree that the ENTER project helped them educate students how to utilize programming for creative problem solving (Fig. 5).

In the ENTER project, teachers could choose what resources to utilize (Fig. 6). 48% of teachers responded that they use available materials, but also make their own. 44% of

teachers use accessible materials but alter them to their own requirements. 4% of teachers use only their own resources, and another 4% of teachers use the provided materials without change.

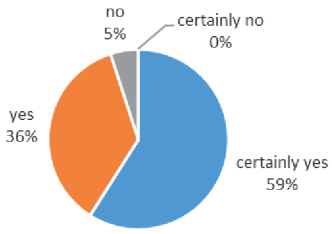

Fig. 5. Did the Enter project help you teach students how to use programming for creative problem solving?

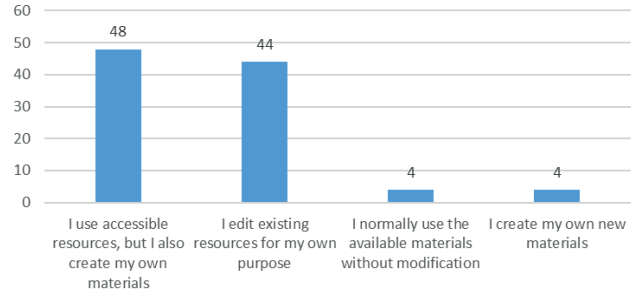

Fig. 6. Where you inspired by the ENTER project to create your own micro:bit materials? Values on y-axis mean the percentage.

BBC micro:bit is a suitable tool for programming in pairs (Fig. 7). Teachers with micro:bits utilized such programming considerably more often during and after the ENTER project. Shift by 13% when answering very often and occasionally by about 3%. On the contrary, the incidence of never and rarely decreased.

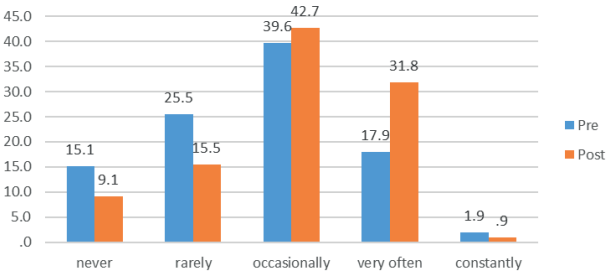

Fig. 7. Did you use the teaching method called pair programming? Values on y-axis mean the percentage.

Teachers recognized the value of debugging in programming and began including debugging into their lessons (Fig. 8). Growth happened primarily in responses that occurred rarely and very often (by 5%).

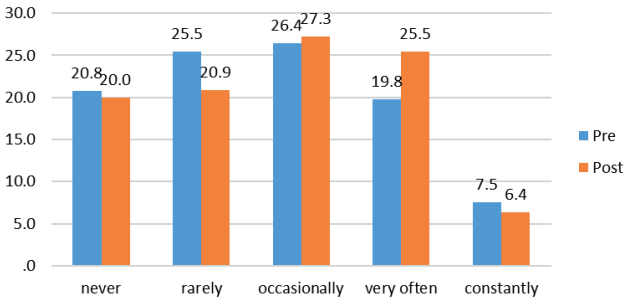

Fig. 8. Did you use the program debugging during the programming lessons? Values on y-axis mean the percentage.

In addition, teachers began to make more frequent use of commentary on individual parts of the program (Fig. 9). We also try to lead them to this in the project courses. They answered very often with the incidence increased by 6%.

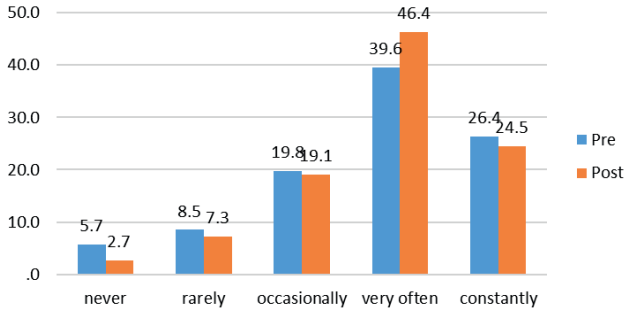

Fig. 9. Did you use the commentary during the programming lessons? Values on y-axis mean the percentage.

When comparing the situation before the ENTER project and after the ENTER project, teachers state that they use Project Creation more often (Fig. 10). On the positive side, none of them said they had never created projects. The most frequent answer was very often in the pre-questionnaire and in the post-questionnaire it increased by 5%. The lecturers focused on this area during the project courses.

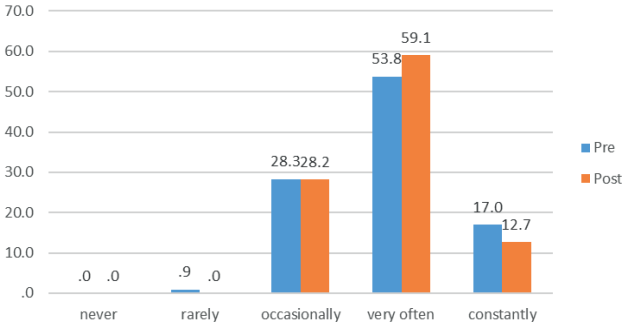

Fig. 10. Did you create the project the programming lessons? Values on y-axis mean the percentage.

Discussions, that are important in programming in process of finding the right solution, are becoming more common (Fig. 11). Discussions increased very often by 6%. It can also be noticed that, as pair programming began to be used, group work also increased, even very often by as much as 18% (Fig. 12).

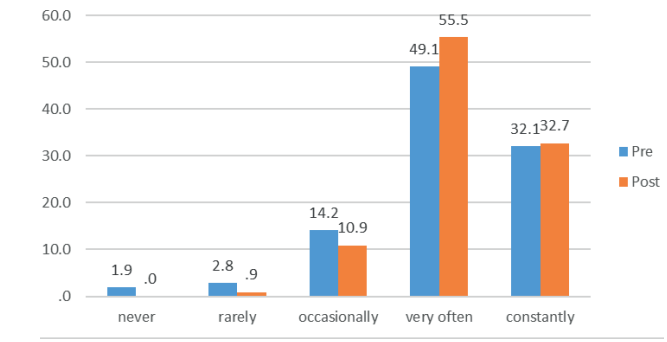

Fig. 11. Did you discuss the problem solving process during the programming lessons? Values on y-axis mean the percentage.

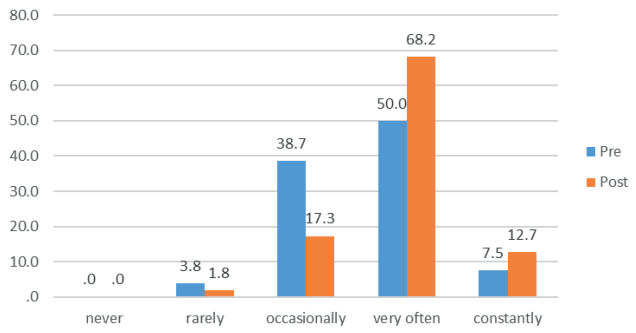

Fig. 12. Did you use the teaching method called collaboration? Values on y-axis mean the percentage.

In cooperative teaching, there was a shift to the answers very often by less than 4%, in the answer constantly by up to 7% (Fig. 13).

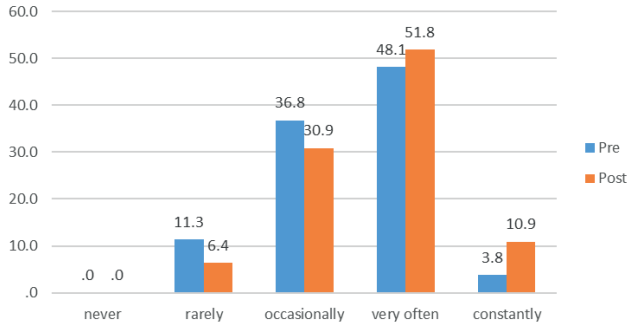

Fig. 13. Did you use the cooperative teaching method? Values on y-axis mean the percentage.

VI. Conclusion

Motivating students to program is not an easy task for teachers. The student must see the result, otherwise the process is abstract for him. However, programming hardware devices with sensors allows the student to focus on creating meaningful projects. Programmable hardware opens space for the teacher to develop student-centered competencies, as he can adapt the activities to the specific needs of the student by choosing appropriate accessories for the device. By preparing follow-up inter-project projects, the teacher learns to plan, cooperate with teachers of other subjects and by documenting the results and writing a report on education promotes the school.

Based on informal discussions and school final reports, we can say that programmable sets will become part of the school curriculum.

In conclusion our project was successful. It should have been just one year project, but it continues. After teaching with micro:bit teachers were more motivated and confident. This article pointed out the possibilities of increasing not only pedagogical but also professional competencies of teachers. Several hundred computer science teachers were involved in the ENTER project, which provided them with funding, education and support. Thanks to the project teachers could have not only hardware but also access to information they needed to start teaching with BBC micro:bit. It helped to eliminate the problems with how to start and teachers could focus on the students.

Based on the post-questionnaire, we found that computer science teachers perceive their competencies higher than before the start of the ENTER project, especially teaching methods like pair programming, discussion of the problem solving, collaboration, cooperation and use debugging, commentaries more often.

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