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THE ROLE OF THE UNIVERSITIES AS ACCELERATORS FOR THE INTEGRATION OF THE STEM LEARNING METHODS IN THE PRIMARY AND SECONDARY SCHOOLS

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Abstract. The digital transformation of the industrial domains and the everyday human life has led to new ways of entertainment, safer working environments, better transport technologies, global connectivity and many other social and economic benefits, but it has also caused some indirect and unexpected consequences for the labour market – the emergence of numerous never-before-seen professions, which are closely related to the information and communication technologies. This has led to a sudden demand for large number of workers with knowledge and experience in the area of the digital technologies – something for which the educational systems of many countries were not adequately prepared and were caught by surprise.

In order to meet the challenges of this digital revolution, numerous plans, programmes and mechanisms were created for the rapid and large-scale digitization of all levels of the educational system. Unfortunately, one of the most vital requirements for the introduction of the innovative teaching methods in the primary and secondary schools was significantly underestimated – the lack of sufficient time and capabilities to train and prepare the teachers. It is exactly here, where the role of the universities stands out, as they can respond appropriately to this need and they can prepare the teachers for the new digital challenges much faster and easier. The universities can also act as mediators between the business sector and the primary or secondary education institutions and can help them easily acquire financial or material support for the introduction of STEM classes in the educational processes.

In this publication, we briefly discuss the STEM educational methods, their main goals and their primary characteristics. The article then presents a methodology for the rapid large-scale integration of these learning methods in the primary and secondary schools with the help and with the involvement of the higher education institutions. The last part of this publication presents in details the pilot initiative of the University of Ruse "Angel Kanchev" for the introduction of classes in robotics and block-based programming in the primary and secondary schools in the Municipality of Ruse.

Keywords: STEM; primary education; secondary education; methodology; block-based programming; robotics; micro:bit; micro:maqueen

1. Introduction

The STEM educational methods are aimed at the development of skills and competences in the students and at providing them with the means, the environment and the guidance to progress, solve problems, make innovations and learn specific topics form the areas of the science, technology, engineering, and mathematics. Numerous studies (Garriott et al. 2016; Brown etal 2019; Van den Hurk et al. 2019; Kayan-Fadlelmula et al. 2022) present the STEM educational methods as the most important teaching method and the most significant educational innovation of the 21st century. Although the acronym STEM (science, technology, engineering and mathematics) was initially introduced in the beginning of this century (Japan Society of STEM education 2018), this teaching and learning approach is the continuation of the constructivist educational approach, which was defined and introduced by Prof. Seymour Papert in the second half of the last century (Papert et al. 1991). The constructionist learning approach is focused on having the students draw their own conclusions through creative experimentation and practical problem-based learning activities and by having the teachers take the role of mediators in educational processes, where they can help the students understand and implement the tasks at hand.

The STEM learning and teaching approach steps on these foundations, but focuses additionally on the establishment of critical thinking skills and on the development of practical learning capabilities, which can prepare the students to enter, live and work in the modern digital world (Han 2016;). The STEM educational approach has numerous advantages, but is also characterised with several disadvantages, which are summarized in the following table (Table 1) (Kayan-Fadlelmula et al. 2022).

Table 1. Main advantages and disadvantages of the STEM learning and teaching approach

Advantages of the STEM learning and teaching approach	Disadvantages of the STEM learning and teaching approach
• STEM teaches the students how to think and learn in new ways, which are closely related or involve the use of the digital technologies from the 21st century (Brown 2012);	• STEM is a very broad concept, which makes it difficult to understand and implement; • STEM is covering wide application areas, which makes its implementation difficult in staff-limited educational institutions;

• STEM develops skills and prepares the student to be professionals and innovators; • STEM provides the means for the in-depth detailed exploration of complex topics in various application and study domains; • STEM builds and develops critical thinking, problem-solving skills and digital competences (Coufal 2022); • STEM can be easily "upgraded" to cover additional topics and to develop competences from the area of the arts (STEAM) and the literature (STREAM) (Lee et al. 2019).	• There are no specific national or European standards for the introduction of the STEM educational approach in the different levels of the educational systems (Wiseman 2016); • The establishment of STEM labs can require significant financial investments, which can exceed the budgets of underfunded schools; • In general STEM excludes subjects like arts and literature (Holmegaard et al. 2014); • The teaching of STEM courses requires more efforts and dedication by the teachers.

2. Methodology for rapid large-scale integration of the STEM teaching and learning approach in the primary and secondary education systems

The STEM educational approach is among the primary focuses of the educational systems in the 21st century (Van Laar et. al. 2017). This approach provides significant advantages and benefits to the students and helps them adapt to the digital world, but the approach is also accompanied by a specific set of issues and problems. The proper implementation of the STEM approach depends on numerous internal and external factors, some of which are within the control of the educational institutions, while others are not. These factors are also the main barriers, which the teachers and the students have to overcome, so that the STEM courses have the positive effect that they are intended to have (Ejiwale 2013). Some of the most important barriers for the STEM education are presented in the Table 2.

Table 2. Main barriers for teachers and students with the STEM educational approach

	Barriers for the STEM teachers	Barriers for the STEM students
Issues outside of our control	• The environment and the structure of the educational institution • Evaluation of the teaching materials • Time • Perspectives for the professional development of the teacher • Funding and materials for the courses	• Lack of experience • Lack of support by the teachers or by the parents • Fear of failure • Lack of understanding about the STEM concepts and the goals of this educational approach
Issues within our control	• The environment and the structure of the educational institution • The goals of the STEM courses • The will for self-improvement	• Motivation to learn new things and to gain knowledge in a modern way • The topics and the scope of the STEM course

Issues within our control	• The development and use of attractive and interesting educational materials	• Interest in the STEM course • Participation in the practical activities

The presented issues and difficulties are not conclusive and are not covering all aspects and processes of the STEM educational approach. Nevertheless, they highlight the need for the development of a unified methodology with a clear set of actions, which will lead to the successful introduction of this educational approach in the schools. The discussed STEM-related problems are evident and detectable in almost every primary and secondary school, not only in Bulgaria, but in other countries, as well. These issues and difficulties and can be categorized as small-scale or institutional problems. However, when we take a more general look at the entire educational system at the level of the primary and secondary schools, a more important large-scale problem becomes clearly evident, namely, the STEM educational approach is suffering from reduced or limited scalability. This means that even if we are able to solve the issues and the difficulties with the introduction of the STEM education in one or in several schools, the possibility to multiply the educational activities using the developed teaching courses to a significant number of other educational organizations is very slim or even sometimes this turns out to be completely impossible.

To overcome this particular large-scale problem, we have designed an innovative methodology for the rapid large-scale integration of the STEM teaching and learning approach in the primary and secondary education systems. The developed methodology is presented in Fig. 1.

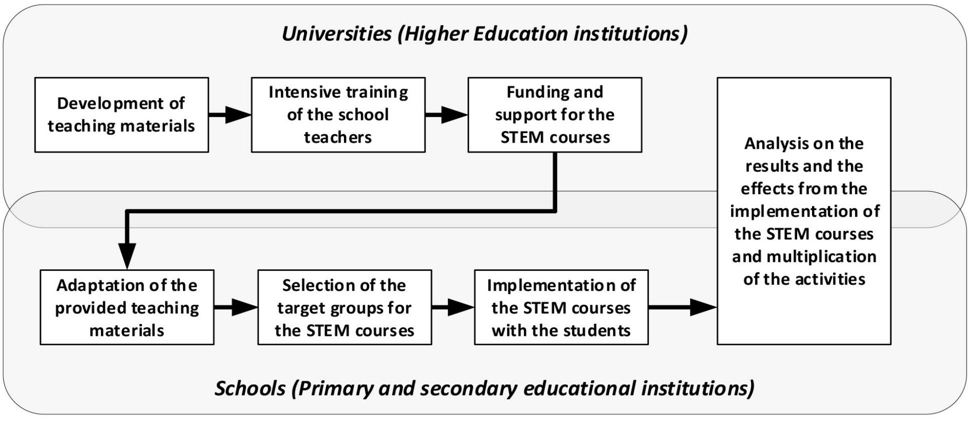

Figure 1. Methodology for rapid large-scale integration of the STEM teaching and learning approach in the primary and secondary education systems

The presented methodology requires and depends on the heavy involvement of the Higher Education Institutions (HEIs) in the processes for integration of the STEM approach in the primary and secondary education systems. The role of the universities in the process is crucial, as they act as central point for the development of unified teaching materials, as environment for the implementation of specialized teaching courses with the school teachers and as mediator for the connection between the schools and the business organizations, which might have interest in providing funding or materials for the introduction of the STEM education in the schools.

The discussed methodology requires from the HEIs to involve in all integration processes their highly experienced and extremely qualified teaching and research staff, as it is up to these lecturers and scientists to evaluate the needs of the students from the individual grades in the schools and to develop the appropriate educational materials, presentations and learning activities, which will be used in the STEM courses.

If the abovementioned requirement is not met, the effect from the involvement of the universities in the STEM integration processes can be inverted and the results can be extremely negative. For example, the developed materials for the educational courses could require the use of mathematical equations, which have not been included in the educational program of the students or are learned in the higher grades. This will make the solving of the tasks and the completion of the planned activities by the students very difficult and will also put extra weight on the teachers, as it will be up to them to teach the new material and to help the students solve the problems.

3. Approbation and evaluation of the developed methodology

The approbation of the effectiveness of the proposed methodology and the evaluation of the obtained results was accomplished following a pilot initiative for integration of a STEM educational course about robotics for the students from the 3^{rd} and 4^{th} grades in the primary and secondary schools of the Municipality of Ruse in Bulgaria. The general idea for this pilot project was to develop and integrate a basic course about robotics, which will present to the students the concepts of the modern microcontrollers, the structure and the components of the educational robots and the principles of the block-based programming. Apart from the actual practical skills and the hands-on experience, it was also planned to develop the course contents and the educational materials in such way, so that they can form additional competences and lead to the development of skills for working in teams, solving individual or group tasks, creative thinking, etc.

As previously mentioned, the main prerequisite for the successful rapid large-scale integration of the STEM courses, according to the presented methodology, requires the involvement of experiences and skilled teachers and researchers from the HEIs. In this case the task for the development of the course contents and the preparation of the educational materials was given to a group of lecturers from the University of Ruse, which had long experience in the STEM educational processes and have also organized numerous courses, seminars, presentations and events. These lecturers were selected, as they are mentors in the student teams for competitive robotics and for innovative transport systems, as they have participated in events, like the Shell Eco-marathon and many national and international competitions for educational and competitive robotics and as they have previously organized many similar events at the University of Ruse. Above all, the selected group of lecturers already had more than 10 years of experience in the area of the STEM technologies, and they have already conducted and implemented small-scale STEM educational courses on topics from the areas of the 3D technologies, the block-based programming of drones, the unmanned aerial vehicles, etc. (Fig. 2).

Figure 2. A moment from previous STEM courses in 3D technologies, robotics and block-based programming of drones, clearly showing the experience of the lecturers

Development of the course contents and the teaching materials

Prior to the development of the contents for the STEM course and the definition of the topics for each of the exercises, an in-depth analysis on the market was made. The goal of this analysis was to compare the microcontrollers, the platforms and the software environments, which are currently used in the area of the educational robotics, and to select the best possible solution amongst them, which is most suitable for students from the 3rd and 4th grade. Platforms, like Lego NXT and Mindstorm[1], Arduino[2], Raspberry Pi[3], micro:bit[4], zumo[5], m3pi[6] and many other were analyzed and compared. Case studies of the use of these solutions were also analyzed and compared. The conducted analysis clearly showed that each of these platforms has specific advantages and disadvantages, but the most suitable for the purpose of the planned pilot rapid large-scale integration of the STEM course is the micro:bit microcontroller[4] in combination with the micro:maqueen[7] robot extension kit (Fig. 3).

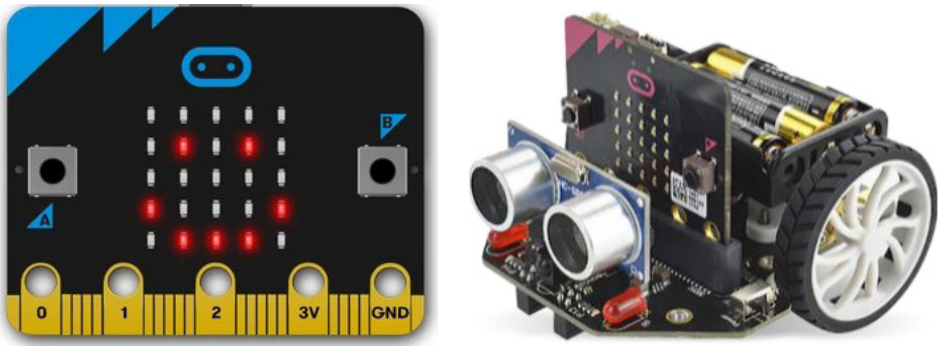

Figure 3. The micro:bit[4] microcontroller (left) and the micro:maqueen[7] robot extension kit (right), which were selected as hardware platforms for the development of the STEM course

The contents of the course were divided into 28 individual topics and included 4 theoretical topics, 20 practical assignments and 4 bonus assignments. The topics are presented in more details in Table 3.

Table 3. Topics of the developed STEM educational course in robotics

	Title	Contents
Topic 1	Introduction to the educational robotics	History of STEM and the educational robotics; Elements, components and functions of the robots; Types of robots; Platforms and software environments for educational robotics;
Topic 2	The micro:bit and the micro:maqueen extension kit	Introduction to micro:bit; Types of micro:bit controllers; Extensions, sensors and additional components for the micro:bit microcontroller; The micro:maqueen robot kit and its components;
Topic 3	Methods for programming the micro:bit	The environments for programming of the micro:bit microcontroller; Online and offline programming of the micro:bit; The MakeCode environment; Components of the programs and main programming blocks;

Topic 4	Assignment 1 – Pulsating hearth	Definition of the assignment; Video demonstration; Step-by-step guide for the development of the block-based program; Implementation of the program in different ways;
Topic 5	Assignment 2 – Name tag/badge	Definition of the assignment; Video demonstration; Step-by-step guide for the development of the block-based program;
Topic 6	Assignment 3 – Dice roller	Introduction to the accelerometer and its functions; Definition of the assignment; Video demonstration; Step-by-step guide for the development of the block-based program; Demonstrations;
Topic 7	Assignment 4 – Button activities	Definition of the assignment; Algorithm for implementation of the program; Video demonstration; Step-by-step guide for the development of the block-based program; Demonstrations;
Topic 8	Assignment 5 – “My Best Friend” game	Definition of the assignment; Algorithm for implementation of the program; Video demonstration; Step-by-step guide for the development of the block-based program; Demonstrations;
Topic 9	Assignment 6 – Walkie-Talkie	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Working in pairs and demonstrations;
Topic 10	Assignment 7 – “7 seconds”	Definition of the assignment; Introduction to the variables and constants; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Individual assignment;
Topic 11	Assignment 8 – “Heads and Tails”	Definition of the assignment; Introduction to conditional operators; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program;
Topic 12	Assignment 9 – “Hot potato”	Definition of the assignment; Introduction to loops; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Individual assignment;
Topic 13	Assignment 10 – “Wristwatch”	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Individual assignment;
Topic 14	Assignment 11 – “Teleport”	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Individual assignment;

Topic 15	Assignment 12 – “Share me a secret”	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Working in pairs; Individual assignment;
Topic 16	Assignment 13 – “Rock, paper scissors V1”	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Working in pairs; Individual assignment;
Topic 17	Assignment 14 – “Rock, paper scissors V2”	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Working in pairs; Individual assignment;
Topic 18	The micro:maqueen robot	Introduction to the micro:maqueen robot and its components and parts; Assembly of the robot; The sensors and the buttons of the robot; Powering and working with the robot;
Topic 19	Assignment 15 – Light following robot	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 20	Assignment 16 – Dancing robot	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 21	Assignment 17 – Police robot	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 22	Assignment 18 – “Park assist”	Introduction to the ultrasonic sensors; Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Additional challenge and discussions;
Topic 23	Assignment 19 – Remote controlled vehicle V1	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 24	Assignment 20 – Remote controlled vehicle V2	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 25	Bonus Assignment 1 – Sound controlled torch	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;

Topic 26	Bonus Assignment 2 – “Chase away the ghost” game	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 27	Bonus Assignment 3 – Clap counter	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations and discussions;
Topic 28	Bonus Assignment 4 – Line following robot	Definition of the assignment; Video demonstration; Algorithm for implementation of the program; Step-by-step guide for the development of the block-based program; Demonstrations; Additional challenge and discussions;

As evident from Table 3, the topics cover all major aspects of a standard programming course, including main concepts, like variables, constants, conditional operators, loops, etc., but the contents are presented as practical assignments with increasing complexity and often have entertaining or game-related orientation. Additional to this, some of the assignments require the work in pairs, which contributes to the development of social skills and responsibilities.

The presented and discussed topics were used for the development of the educational materials for the course. These materials include printed working sheets, PowerPoint presentations and demonstration videos (Fig. 4). The prepared educational materials were also published in an online learning

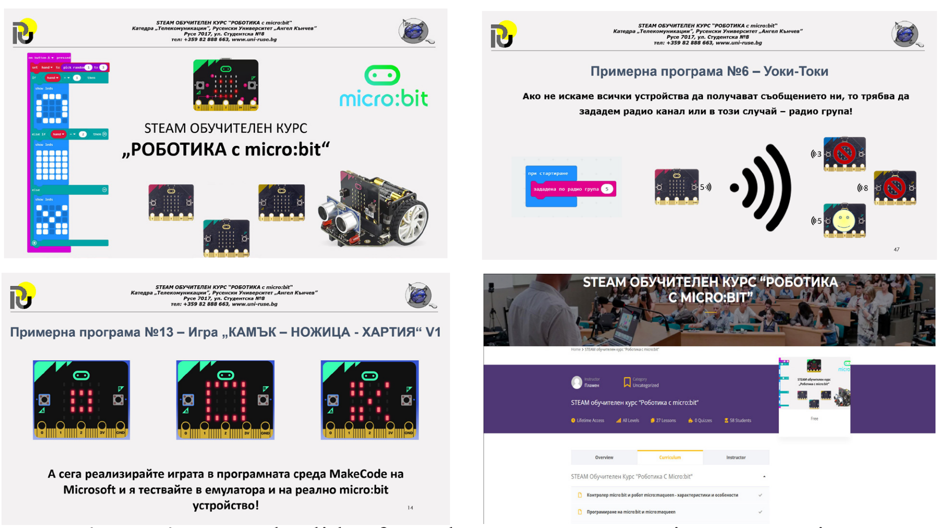

Figure 4. Example slides from the course PowerPoint presentations (top left, top right and bottom left) and the main screen of the online platform where the materials were published (bottom right)

platform (Fig. 4), which made them freely accessible and reachable from all locations and at any time.

Train-the-trainers course with the school teachers

The organization of the training course for the teachers from the primary and secondary schools in the Municipality of Ruse was made following the development of the course materials. The Regional Department of Education in Ruse[8] assisted the university by sending out invitation to all school and their principals and by organizing the attendance of the teachers. The organization of the course was also done in close cooperation with the Center for student, technological and scientific activities in Ruse[9] and the teachers from this institution were also enrolled in the course.

The train-the-trainers course took place between November and December 2021 and more than 30 teachers participated in the activities. The classes were organized only in the weekend days, so that the regular activities of the teachers are not affected and all of them can attend the activities.

Funding and support for the integration of the STEM course in the schools

Apart from the activities related to the development of the course materials and the actual implementation of the train-the-trainers course, the University of Ruse contributed to the rapid large-scale integration of the STEM course by finding funding from the business sector for the purchase of the necessary hardware platforms. Following the end of the train-the-trainers course, all teachers and the principals of their schools were invited to an official ceremony, where a the teachers received certificates for their involvement in the course and the principals received the provided micro:bit microcontrollers and micro:maqueen robot kits (Fig. 6). A total of 300 microcontrollers and 150 robot kits were presented to almost all primary and secondary schools in the municipality.

Adaptation of the course materials and implementation of the STEM courses at the schools

Following the activities presented in the previous parts of this article, the primary and secondary schools in the Municipality of Ruse were completely prepared to integrate the STEM course in the education activities for the students from the 3rd and the 4th grade. For this purpose, the teachers have used the provided training materials and have modified them to suit the needs of the educational processes in the school system – some activities were shortened, while other were divided in several learning hours, etc. The donated platforms and the modified teaching materials allowed the implementation of the STEM course in more than a dozen schools in the municipality, as well as in the Center for student, technological and scientific activities in Ruse. The University of Ruse and the lecturers involved in the preparation of the teaching materials and the implementation of the train-the-trainers course were available during the implementation of the STEM courses in the schools and have provided active support, guidance and help to the teachers.

Evaluation of the effects and the impacts from the implementation of the STEM course

Several weeks prior the end of the academic year for the students in the 3rd and 4th school grades, the University of Ruse contacted the principals of the schools and all teachers that were involved in the STEM course and the pilot initiative and invited them to organize teams of three to four students, which can then participate and compete in the first-of-its-kind event – a Municipal competition in robotics for students from the 3rd and 4th school grades. The competition was organized by the University of Ruse, with the support of the Regional Department of Education in Ruse and the Center for student, technological and scientific activities in Ruse.

The competition was divided in three separate categories – “Light tracing sprint”, “Line following competition” and “Robodance”. The first category required from the students to program their robots to follow the light emitted from their mobile phones and to clear a course track with obstacles, which was specially designed for the event, and which was divided into several stages. The students were also required to pass the light source from one team member to the other, during the different stages of the track. The second category required the unsupervised line following by the robot and the completion of one full lap in a close contour racetrack. Both of these categories required from the teams to complete the activities in the shortest possible time. The last category required from the students to “dance” with their robots and the teams were evaluated and ranked by a jury.

The competition event took place on the 11th June 2022 at the premises of the University of Ruse. Sixteen teams from twelve different institutions participated in the

Figure 5. Moments from the opening of the event and from the competitions in the different categories The event concluded with the presentation of certificates and prizes for all participants in the event, as well as with an official awarding ceremony for the winners in the individual categories.

competition (Fig. 6). The event turned out to be a major success and the competitive spirit, the dedication and the focus of the students generated a massive amount of positive energy and emotions for all organizers, participants and spectators.

4. Conclusions

The STEM educational approach is an attractive and engaging way to deliver new knowledge and build practical skills in the students. The STEM education is no longer just an interesting thing – the approach has gained "critical mass" and is well past the "point of no return", as numerous educational systems are being adapted and transformed to include STEM courses in their syllabuses. The sudden shift to STEM education in the primary and secondary school systems has led to some serious problems, which were presented and discussed in details in this article. The surprise was not only for the teachers, many students experienced the "fear of failure" symptoms following the introduction of this new educational approach.

As presented in the manuscript, the HEIs can play an extremely important role for the rapid large-scale deployment of STEM courses, as they can develop or help with the development of the necessary teaching materials and they can provide the qualified and experiences lecturers to train the school teachers. The universities can also act as mediators for the connection between the schools and the business organizations and can supervise and guide the overall transition of the primary and secondary educational systems to the digital age.

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NOTES

1. https://www.lego.com – official website of LEGO NXT and LEGO Mindstorm.
2. https://www.arduino.cc – official website of Arduino.
3. https://www.raspberrypi.org – official website of the Raspberry Pi Foundation.
4. https://microbit.org – official website of the BBC micro:bit microcontroller.
5. https://www.pololu.com/category/169/zumo-robot-for-arduino – webpage of the Zumo robot at the Pololu Robotics and Electronics website.
6. https://www.pololu.com/product/975 – webpage of the 3pi robot at the Pololu Robotics and Electronics website.

7. https://www.dfrobot.com/product-1783.html – webpage of the micro:maqueen robot extension kit at the DFRobot website.
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