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The effects of robotics programming on secondary school students' problem-solving skills

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Abstract

Robotics programming is a type of coding that combines mechanics and programming. Robotics technology facilitates coding instruction. Coding improves students' problem-solving skills. However, studies from the literature show that some teaching methods do not have a positive effect on coding skills. This study aims to examine the effects of robotics programming training on secondary school students' problem-solving skills. For this purpose, the study was conducted as a pretest-posttest quasi-experimental model without a control group. Hence, 30 6th grade students (12 boys and 18 girls) from three secondary schools have participated in this study. Activities were conducted with the VEX IQ Robot Kit for 9 weeks. Before and after the process, problem-solving inventory and the perception scale of problem-solving skills were applied as pre- and post-test. As the scores obtained from the scales did not show a normal distribution, the difference between the pretest and post-test scale scores was examined by the Wilcoxon signed-rank test. As a result of the analysis, it was revealed that robotics programming helped students to develop problem-solving skills.

Keyword: Problem-solving skill, programming, robotics.

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1. Introduction

Due to technological developments affecting life conditions, the features expected from individuals have changed. According to the World Economic Forum (2016), 65% of children from primary schools will work in new jobs that are not currently available. This situation requires changing the skills available for the workforce (Siper Kabadayi, 2019). Critical thinking, problem-solving, communication, collaboration, creativity and innovation are amongst the common ones of the 21st-century skills in the literature (Partnership for 21st Century Skills, 2011). The reports prepared by the International Society for Technology in Education (ISTE, 2016) indicates that 'Computational thinking' and 'programming skills' are amongst the 21st-century skills that individuals should have. Similarly, 'coding skills' and 'computational thinking' take place in the reports prepared by the European Commission and American Bureau of Labour Statistics (Bidwell, 2013). According to Demirer and Sak (2016), it is necessary to show young generations how they can develop new software rather than consuming the existing software. The production also passes through problem-solving skills. In terms of occupations and individual characteristics, problem-solving skills are also the most important requirement of the 21st century (Siper Kabadayi, 2019).

Problem-solving is the whole of individuals' efforts to reach the goal in the absence of a solution (Schunk, 2012) and is one of the most important types of cognitive processes that frequently occur in the learning process (Cinar, 2019). According to Kneeland (2001), the problem-solving process consists of the following steps: becoming aware of the problem, gathering the necessary information, going to the basis of the problem, searching for solutions, determining the most appropriate solution and solving the problem. Problem-solving skill is the level of an individual's ability to solve a problem by combining the necessary rules to produce a solution (Bilen, 2006). Problem-solving skill is the most important learning skill that one can gain in school life and social life process (Johassen, 2001: as cited in Aksu, 2019). Problem-solving is a skill that requires the use of many thinking skills together (Aksu, 2019). Computational thinking also contributes to the development of problem-solving skills with its basic concepts such as abstraction, fragmentation, analysis, visualisation, problem-solving and algorithmic thinking (Kasalak, 2017). Coding or programme training is given mainly on the development of students' computational thinking skills (Lye & Koh, 2014).

Dalton and Goodrum (1991) suggested that computer programming could contribute to teaching problem-solving skills when used in combination with problem-solving strategies. Aksu (2019) and Ersoy, Madran and Gulbahar (2011) stated that problem-solving skills would be improved with programming training. In the literature, it is frequently encountered in the studies that demonstrate that students develop problem-solving skills through programming learning (Alkan, 2018; Begosso & Silva, 2013; Casey, 1997; Cosar, 2013; Cetin, 2012; Kim, Chung & Yu, 2013). The basis of the programming teaching process starts with coding. Coding is defined as the process of application development using command sets to solve problems, to enable human-computer interaction and to perform a specific task by the computer (Business Dictionary, 2015: as cited in Aksu, 2019). There are also studies demonstrating the development of students' problem-solving skills through coding teaching (Akpinar & Altun, 2014; Karabak & Gunes, 2013; Demirer & Sak, 2016; Ozer Sanal & Erdem, 2017).

Programming is one of the prominent educational activities in K12 (Popat & Starkey, 2019). The programming process requires different high-level thinking skills (Yildiz Durak, Karaoglan Yilmaz, & Yilmaz, 2018). On the other hand, programme training involves difficult tasks for students to perceive (Koorsse, Cilliers & Calitz, 2015). Whilst teaching the programming language, most of the processes and concepts remain abstract for the students, and students have difficulty in embodying the knowledge that they have learned (Armoni, 2012; Ersoy et al., 2011). For this reason, block-based and robotic coding instruction activities, which enable students to participate willingly in the activities and develop students' problem-solving and computational thinking skills, are preferred (Kasalak, 2017). Educational robotic is a powerful and flexible teaching material, where students carry out robot programming activities using special coding tools (Alimisis, 2013).

Particularly, computer-aided robot programming has important roles in the development of abstract learning skills at the primary and secondary schools (Cavas & Cavas, 2005; Ersoy et al., 2011). Robotics technologies, programming with motors and sensors, make abstract and mechanical concepts such as loops and variables concrete and fun (Ucgul, 2017). Abstract concepts can be easily concretised by using robots in programming instruction, and students can improve their problem-solving and computational thinking skills more easily and quickly (Numanoglu & Keser, 2017). Instead of increasing the cognitive load by presenting the whole process to the students at once, dividing the process into meaningful parts, for example first presenting the parts and then presenting the relations of the parts with each other in the whole process will decrease the cognitive load. For example, if a robot that moves without the obstacles is to be programmed, it is possible to implement a holistic programming application that consists of meaningful parts such as moving the motor, receiving data from the sensor, looping and decision structure (Sisman & Kucuk, 2018). Robotics programming contributes to creative design, computational thinking and problem-solving skill development (Bers, 2010; Karim, Lemaignan & Mondada, 2015). Robotics is one of the preferred methods of teaching programming for students to develop positive attitudes and succeed in learning tasks (Mikropoulos & Bellou, 2013). Robotics hardware and block-based programming are easy to use. Therefore, it is suitable for use in primary and secondary schools (Numanoglu & Keser, 2017). Students can actively create original products in educational robotics studies. Thus, learning motivation increases, and the learning process becomes more effective (Karim et al., 2015; Lin, Liu & Huang, 2012; Liu, Lin & Chang, 2010; Liu, Lin, Feng & Hou, 2013). Educational robots are powerful tools that can be used in hands-on training by arousing the interest and curiosity of students in the learning environment by offering funny activities. Students find the robotics activities quite entertaining and state that they are not bored with the process (Kasalak, 2017). Teachers agree with the students about the process (Aksu, 2019).

Robotics technologies encourage students to think about abstract ideas (Burleson et al., 2018). In robotics activities, students design to solve complex problems and test their solutions (Atmatzidou, Demetriadis & Nika, 2018). In this case, students learn how to cope with challenging situations in a real-world context (Yildiz Durak et al., 2018). Thus, students' analytical, creative and systematic thinking and problem-solving skills are developed (Ersoy et al., 2011).

Robots have played an important role in the education process (Ospennikova, Ershov & Iljin, 2015). In many countries, various training activities are organised for teachers to make educational robotics activities widespread in educational institutions (Kim et al., 2015). Programmable and interactive robots provide the opportunity to develop the skills of each student from preschool to university (Bers, Flannery, Kazakoff & Sullivan, 2014; Erdem, 2019; Siper Kabadayi, 2019). Problem-solving skills, which are developed by robotic applications, are seen as very important for this century. If learners develop problem-solving skills, they will move away from the rote-based system and take more responsibility for learning (Cevahir & Ozdemir, 2017). Cakmak and Tertemiz (2002) also noted that individuals with problem-solving skills will develop their assessment skills, learn to take responsibility, realise more permanent learning, increase their motivation, learn in cognitive and affective areas, increase their learning desires, learn to use the scientific method and perform collaborative learning.

Various programmable robots belonging to different companies are used in the teaching process (Oros & Krichmar, 2013). According to the results of the studies in the literature, programmable Lego robots improve students' mathematical thinking skills, cooperative working skills, creativity and problem-solving skills (Cavas, 2009; Ozdogru, 2013; Fidan & Yalcin, 2012). Sullivan and Bers (2016) also used the KIBO robot kit and showed that students' problem-solving skills increased. Robotics activities help the students to gain Science, Technology, Engineering and Mathematics (STEM) skills. Furthermore, robotics encourages teamwork, problem-solving and leadership for students. VEX IQ Robot is appropriate for 5–8th Grade students (VEX IQ, 2019). This study aims to determine the effect of using and coding the VEX IQ robot kit on the problem-solving skills of 6th-grade students.

2. Method

2.1. Study model and participants

This study aims to determine whether robotics programming develops secondary school students' problem-solving skills. For this purpose, a single-group pretest-posttest design was used. This is a type of pre-experimental design. This model is mostly utilised by behavioural researchers to determine the effect of a treatment or intervention on a given sample (Cranmer, 2018). In the single group pretest-posttest model, the dependent variables are measured before and after the experimental process. The difference between the measurement results mostly stems from the experimental process (Karasar, 1999, p.96). Whilst the independent variable of this study is robotics programming instruction, the dependent variable is students' problem-solving skills. Thirty 6th-grade students (twelve boys and eighteen girls) from three different secondary schools have participated in this study.

2.2. Data collection tools

Before and after the training process, problem-solving inventory for children at the level of primary education and problem-solving skills perception scale for secondary students were applied as pre- and post-test. Problem-solving inventory (PSI) for children at the level of primary education was developed by Serin, Bulut Serin and Saygili (2010). A total of 568 pupils consisting of the 4th, 5th, 6th, 7th and 8th graders in eight primary education schools have participated in the development stage of the inventory. It has 24 items about three factors (12 items about self-confidence in their problem-solving ability, 7 items about self-control and 5 items about avoidance). The scale is a 5-point Likert-type scale (score range is 24–120). Cronbach's alpha coefficient of the inventory was found to be 0.80. The perception scale of problem-solving skills (PSPS) for secondary students was developed by Ekici and Balim (2013). The scale is a 5-point Likert-type scale (score range is 24–120). It has two factors with 22 items. The first factor, perceptions of students about problem-solving skills, has accounted for 30.29% of the total variance with 15 items. The second factor of the scale, students' perception of willingness and determination to solve problems, has accounted for 9.976% of the total variances with seven negative items. The reliability of the scale was found as 0.88. High scores in both scales indicate stronger self-perception for problem-solving skill. The relationship between score and perception level is given in Table 1. These levels were calculated for PSI and PSPS ((n-1)/n * number of items).

Table 1. Perception levels for problem-solving skill

Perception Level	5-point Likert-Type Scale	Score Range	
		PSI	PSPS
Very Low	1.0-1.8	24-43.2	22-39.6
Low	1.9-2.6	43.3-62.4	39.7-57.2
Moderate	2.7-3.4	62.5-81.6	57.3-74.8
High	3.5-4.2	81.7-100.8	74.5-92.4
Very High	4.3-5.0	100.9-120	92.5-110

2.3. Analysis of data

The Wilcoxon signed-rank test was used for the analysis of the data. This test was used because the assumptions of t-test analysis were not met for the paired samples. The Wilcoxon signed-rank test uses a z-test statistic (Buyukozturk, 2003, p.157). Reporting of effect size is important for non-parametric tests, especially in the case of statistical significance (Leech & Onwuegbuzie, 2002). Cohen d affected by violations of normality and heterogeneity of variances. Hence, it is not recommended for use with these data. Therefore, only r statistics are used for effect size (Cinar, 2019).

2.4. Training process

The 'VEX IQ' robotics training set was used in the training. VEX Robotics (2019) claims that they provide the tools to inspire the problem solvers of tomorrow. They produce different robotic kits. VEX IQ is for elementary and middle schools. It is the most effective for 4-8 grades. The VEX IQ Robot Brain features a backlit LCD screen and 12 Smart Ports (configurable as either motors or sensors) for additional versatility in robot design. VEX IQ Controller is a remote-control system. The parts of robots are shown in Figure 1, and the robot types are shown in Figure 2.

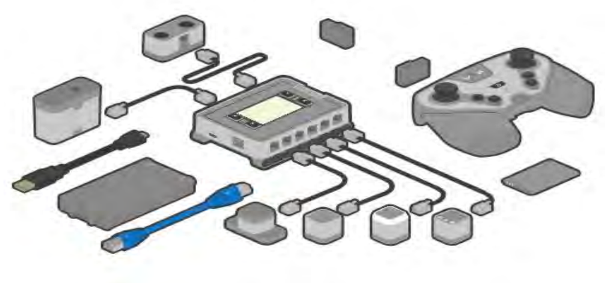

Figure 1. Parts of VEX IQ robot kit

Figure 2. Robot types of VEX IQ

With the parts coming out of the box, students have the opportunity to design robots according to their expectations (Figure 2). After the robots are completed, students can run their robots autonomously with a controller or coding if they want. Two different platforms are provided with students to code. MODKIT VEX (Figures 3 and 4) is a fully graphical drag and drop programming platform. ROBOTC (Figure 5) provides a graphical interface and allows programming in the C language (Aksu, 2019).

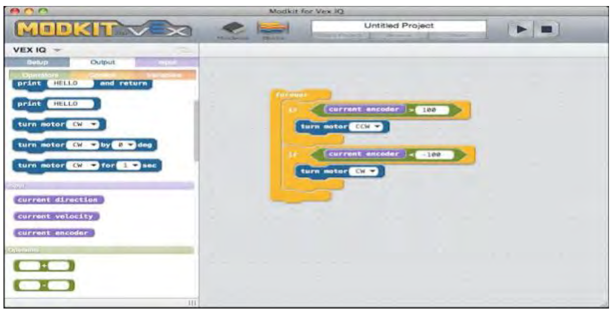

Figure 3. MODKIT for VEX Editor 1

Figure 4. MODKIT for VEX Editor 2

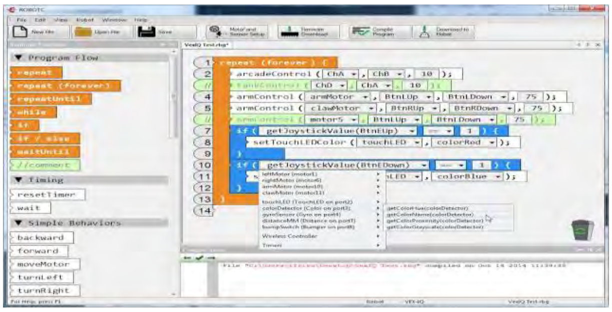

Figure 5. ROBOTC interface

Within the scope of the study, 6th-grade students carried out over 10 robotic activities using MODKIT for 9 weeks. Activities were an introduction to the VEX robot and the MODKIT program required to operate the VEX robot, Drivetrain, Touch LED, Distance, Broadcast, Colour Sensor, Controller, Rotator and Rotator 2. After the introduction of the VEX robot and the MODKIT software, students started to perform some tasks. The tasks were to create the required code block that prints his/her name in the robot's brain one time and four times in each line and moves the robot around the frame; the robot comes back 15 cm, changes direction and continues to progress when it hits the obstacle and the robot stops and sounds the alarm tone when hit the obstacle, stops with red light and goes with the green light.

2.4.1. Week 1:

The students were informed about the VEX robot and parts. The use of MODKIT software which is required to operate VEX robot was taught. The necessary port outputs for connecting VEX robot to MODKIT and the contents of the Brain part of the VEX robot were explained.

Figure 6. Introduction to the necessary code blocks for the brain

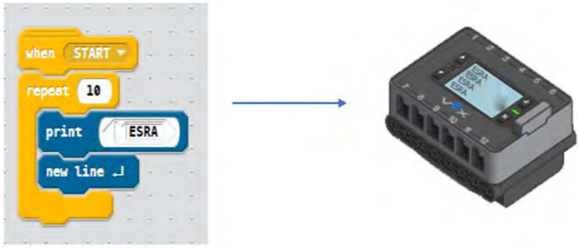

Figure 7. Code block activity that prints his/her name on the robot's brain four times with each name on each line

2.4.2. Week 2

The students were informed about the movement and the programming of the drivetrain. All of the students were involved in various competitions. The loop logic is given in practice, and the benefits of using the loop are discussed. Students were able to observe the benefit of using the loop. The students were given general information about sensors. Then, Touch LED from sensors in VEX was explained, and the applications related to Touch LED were made.

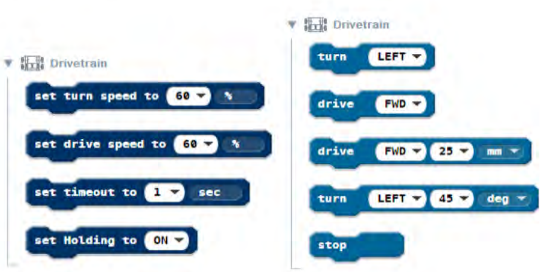

Figure 8. Drivetrain code blocks

Figure 9. Touch LED code blocks

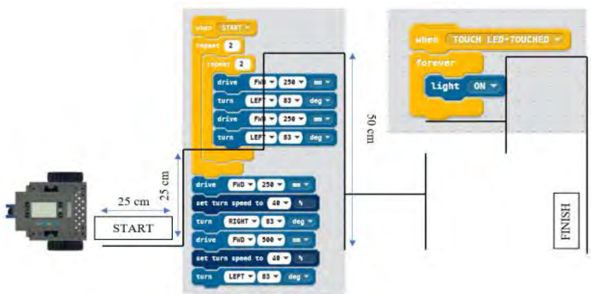

Figure 10. The activity that allows the robot to move around the figure above and the Touch LED to light during movement

2.4.3. Week 3

The contents of the distance section of Vex robot were explained. Subprogram and broadcasting were taught.

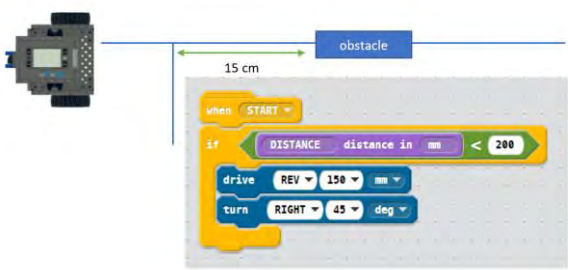

Figure 11. Robot activity that goes back 15 cm when it hits the obstacle, changes direction, and continues to move

Figure 12. Robot activity that stops and sounds the alarm when it hits an obstacle

2.4.4. Week 4

Colour sensor was explained. Drivetrain movement with a colour sensor was taught. A Colour printing activity was done.

2.4.5. Week 5

The contents of the controller part of the VEX robot were explained. The controller button and moving the robot with the controller activities were done.

2.4.6. Week 6

The control of motors was explained to the students. The right and left motor control and control applications were used together. The students were asked to assemble all parts of the robot and build the robot.

2.4.7. Week 7

The control of motors was explained to the students. Writing the codes to move VEX Robot's arms was taught. The right and left motor control and control applications were used together. The contents of the Rotator and Rotator 2 sections of the VEX Robot were explained.

2.4.8. Week 8 and 9

The students were made circuits using sensors with VEX motor. A robotic coding activity which leaves the objects of the specified colours at the specified distance to the designated places was performed. During these weeks, students were asked to create original products.

Figure 13. Students' robotics activities

3. Results

Students' PSPS and PSI scores and descriptive statistics are shown in Table 2. As the scores obtained from the scales did not show a normal distribution, the difference between the pretest and post-test scale scores was examined by the Wilcoxon signed-rank test (Table 3).

Table 2. Descriptive statistics

Measurement	Instrument	N	$\bar{X}$	Std. Dev.	Min	Max
Pretest	PSPS	30	88.83	15.89	43.00	109.00
	PSI	30	96.83	12.31	66.00	118.00
Post-test	PSPS	30	94.70	17.65	29.00	110.00
	PSI	30	101.77	13.46	62.00	120.00

As shown in Table 2, PSPS and PSI post-test mean scores ($\bar{X}_{PSPS} = 94.70$, $SD_{PSPS} = 17.65$; $\bar{X}_{PSI} = 101.77$, $SD_{PSI} = 13.46$) are higher than the pretest mean scores ($\bar{X}_{PSPS} = 88.83$, $SD_{PSPS} = 15.89$; $\bar{X}_{PSI} = 96.83$, $SD_{PSI} = 12.31$). While students' perception of problem-solving was at high level, it reached very high level after the experimental process.

Table 3. Wilcoxon signed-rank test analyse results

Instrument	Posttest-Pretest	N	Mean Rank	Sum of Ranks	Z	p	r
PSPS	Negative ranks	10	13.70	137.00	-1.965^{a}	0.049^{*}	–0.18
	Positive ranks	20	16.40	328.00			
	Ties	0					
PSI	Negative ranks	7	17.36	121.50	-2.079^{a}	0.038^{*}	–0.16
	Positive ranks	22	14.25	313.50			
	Ties	1					

* $p < 0.05$

^{a} Based on negative ranks.

According to test results, whilst students' PSPS pretest mean score was 88.83, the post-test mean score was 94.70. Twenty students' scores were positive ranks, and ten students' scores were negative ranks. The number of students increasing the post-test score was higher than the number of students reducing it. There was a significant difference between pre- and post-test scores for students' problem-solving skills ($z = -1.965$, $p < 0.05$). At the same time, students' PSI pretest mean score was 96.83, and post-test mean score was 101.77. Twenty-two students' scores were positive ranks, seven students' scores were negative ranks and one student's score was a tie for problem-solving skills' perception. The number of students increasing the post-test score was higher than the number of students reducing it. For these scale analyses, there was a significant difference between pre- and post-test scores for students' problem-solving skill perceptions ($z = -2.079$, $p < 0.05$).

As a result of the analysis, it was revealed that robotics programming developed the students' problem-solving skills and perceptions. It was found that there was a low effect size ($r_{PSPS} = -0.18$; $r_{PSI} = -0.16$).

4. Discussion

This study aimed to examine the effects of robotics programming training on secondary school students' problem-solving skills. Problem-solving inventory and problem-solving skills' perception scale were used to find the effect size of robotics programming. It was revealed that robotics programming helped students to develop problem-solving skills. Similarly, Sisman, Kucuk and Yaman (2020) stated that robotics programming activities improve problem-solving skills.

Educational robots have been used extensively to develop students' cognitive and social skills at the K12 level (Alimisis, 2013; Ludi, 2012). Educational robotics is funny and creative activities that contribute to the development of problem-solving skills (Atmatzidou & Demetriadis, 2016). When the studies interested in robot programming in the literature are examined, it is seen that the students increase their motivation towards the lesson with their usage levels of technology and decrease the negative psychology created by technology (Koc & Boyuk, 2013). Resinovic (2015) found that the use of robots is very useful in teaching programming skills. Saleiro, Carmo, Rodrigues and du Buf (2013) concluded that educational robots are effective in problem-based learning activities. Different robotic kits such as Arduino, mBot, Vex IQ, Vex EDR, Lego Mindstorms EV3, Lego We Do 2.0 and Makey Makey are used in the teaching process (Aksu, 2019). Marulcu (2010) found that 5th-grade students working with Lego sets were more successful in solving daily life problems. Bers et al. (2014) and Buitrago Florez et al. (2017) stated that Lego educational robots provide an effective learning environment in the development of problem-solving skills. Sullivan and Bers (2016) also found that students using the KIBO robot kit improved their problem-solving skills. In this study, it was found that the problem-solving skills of middle school students increased significantly by coding VEX IQ robots.

In the study of Ozer (2019), the scores obtained from the problem-solving inventory of the group working with robots were higher, and this difference was statistically significant. Kirkan (2018), working with gifted students, found that project-based basic robotics training contributes to problem-solving skills. In the studies conducted by Silik (2016), Dizman (2018) and Pakman (2018), it was observed that there was an increase in problem-solving skill scores of students.

5. Conclusion and Future Research

The findings of the study revealed that robotics programming helped students to develop problem-solving skills. While students' perception of problem-solving was at high level, it reached very high level after the experimental process. Results indicated that the problem-solving skills of middle school students increased significantly by coding VEX IQ robots. When we look at the results of the studies conducted in the literature, it is seen that both block-based programming environments and robotic activities contribute positively to problem-solving skills (Cankaya, Durak, & Yunkul, 2017; Shin & Park, 2014). However, some studies in the literature show that robotic or block-based programming causes not a significant difference (Cinar, 2019; Kalelioglu, 2015; Kalelioglu & Gulbahar, 2014). At this point, different variables affecting the process can be examined. This study conducted in pre-experimental design. It can be seen as a limitation since a lack of validity. Therefore, more experimental studies can be designed. Besides, a module can be developed which includes the activities for problem-solving skills for robotics programming. The process can be examined by repeating activities with different levels and robotics kits.

Notes

Preliminary results of this research were presented at 10th World Conference on Learning, Teaching and Educational Leadership (WCLTA-2019) which took place on November 1st–3rd, 2019, in Athens, Greece.

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