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Effects of STEM-focused Arduino practical activities on problem-solving and entrepreneurship skills

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In this study, the effects of science, technology, engineering and mathematics (STEM) focused Arduino practical activities on problem-solving and entrepreneurship skills were analysed using qualitative and quantitative methods. Also, the contribution of these activities to teacher candidates and their effects on the learning-teaching process were discussed by evaluating their views. The study group consisted of 31 final-year teacher candidates studying in the science teaching department of a university in Turkey. The quantitative findings reveal that STEM-focused Arduino practical activities have a positive effect on improving the problem-solving and entrepreneurship skills of teacher candidates. Their opinions also support these results. The teacher candidates stated that the practical activities contribute to their professional development, support the development of 21st-century skills such as problem-solving and creativity and positively affect the learning-teaching process. As a result, STEM-focused Arduino practical activities are of significance in terms of adopting an interdisciplinary approach to education following the requirements of the century and developing problem-solving, entrepreneurial and productive individuals.

Implications for practice or policy:
- STEM educators should integrate Arduino into STEM education to increase STEM learning outcomes.
- STEM educators should attach importance to STEM-focused Arduino activities to develop students' reflective thinking and entrepreneurial skills.
- Educators and researchers who want to use coding in STEM education may need to consider this article for example activities and implementation steps.

Keywords: STEM education, Arduino practical activities, physical computing, problem-solving skill, entrepreneurship

Introduction

Being successful in a knowledge-based and technology-literate society makes it essential to develop individuals who have the skills required by the digital age and who can meet the expectations of the 21st-century business world. In this context, many countries, especially the United States of America and EU countries, have developed new educational reforms and projects in their education systems. One of them is science, technology, engineering and mathematics (STEM) education, which aims to develop individuals with 21st-century skills and contributes to economic and social developments. STEM education is considered to find solutions to real-life problems by interdisciplinary approaches (Stohlmann et al., 2011). This process allows students to explore and develop technology in a meaningful learning process with a real-life context (Johnson et al., 2016). STEM education establishes the connections between school, workplace, society and the global economy (Bybee, 2010). Therefore, emphasis should be placed on STEM education to develop a highly equipped and educated workforce that will provide competitive power on a global scale (Breiner et al., 2012). Cognitive, personal and interpersonal skills and abilities, which form the basis of 21st-century skills, not only enable students to learn more effectively but also help them transfer their previous knowledge to real situations in their daily lives (Osman et al., 2009). Thinking skills are essential for analysing problems, making predictions, identifying patterns and representing results (Gómez-Barreto et al., 2020). Problem-solving emerges as one of the essential skills that an individual should have. Reflective thinking is an act of inquiry, and it is an advanced search for solutions and decision-making. Therefore, these two thinking processes should be evaluated together in the teaching process. Reflective thinking is a kind of upper-level thinking defined as a way of thinking that aims to determine the factors affecting the learning level and problem-solving methods by students (Barton & Ryan, 2014). In this context, we considered that reflective thinking would contribute to the problem-solving process.

Innovation and entrepreneurship skills are also regarded as important in today's educational approach for achieving the goals of STEM education in real life (Fayolle & Gailly, 2015). Besides, research questions the learning status of students by taking into account their individual differences. (Aljohani, 2015). The main outputs of entrepreneurship education are to create an environment for sensitivity, knowledge, and understanding about the concept and application of entrepreneurship, to develop personal entrepreneurial skills and attitudes, to build personal assurance and self-efficacy and to have an understanding of using entrepreneurial tools correctly (Hannon et al., 2006). While evaluating the programs on entrepreneurship education, Garavan and O'Cinneide (1994) pointed out that there is still too much emphasis on knowledge but little emphasis on gaining competence. Similarly, Solomon et al. (2002) stated that the most common teaching methods used in entrepreneurship education are lectures by well-known professors, case studies, and supervised reading programs. Studies have pointed out that it does not seem possible to teach 21st-century skills to children with a traditional understanding of education (Garavan & O'Cinneide, 1994), and STEM education is an effective tool in applying these skills (Cooper & Heaverlo, 2013). Davis et al. (2020) developed links between STEM education and entrepreneurship and provided evidence that entrepreneurial characteristics can be improved with STEM education. Moreover, recent developments in entrepreneurship education have emphasised the need to focus on technology entrepreneurship education, which regards information technology as an important part of utilising entrepreneurial opportunities (Kang & Lee, 2020; Snihur et al., 2018). Information technology has a significant impact on understanding the concepts and mechanisms of different technologies. Therefore, different business models can be produced, and a new value can be created with the use of information technology. Physical computing as information technology has attracted attention in recent years as it allows students to use their creativity to design their own devices and develop original systems (Juškevičienė et al., 2021). Especially when evaluated in terms of production and innovation, physical computing in STEM learning environments can provide important opportunities for entrepreneurship. STEM-focused physical computing can contribute to students' developing entrepreneurial thinking and producing the necessary tools for national development and industrialisation in their future careers. In this regard, physical computing activities with Arduino in STEM education can lead to meaningful results in terms of entrepreneurship in students. Although there is some evidence about the contributions of physical computing to entrepreneurship education, research is still minimal (Kang & Lee, 2020), and applied studies are needed. In this context, the present study will contribute to the literature.

Programming and robotics have become an efficient pedagogical approach in STEM education in recent years (Mcdonald, 2016). Programming has taken on a new meaning with STEM education and involves different fields such as science, mathematics, engineering and technology (Junior et al., 2013). Thus, with programming, students are expected not only to acquire concepts and processes of a programming language but also to gain skills such as problem-solving, creative thinking and product-oriented work, which are the requirements of the 21st century (Fessakis et al., 2013). Although there are different approaches to gaining these skills, physical computing is often preferred. It is a method that aims to design smart physical systems that use this information by getting information from the physical outside world through various hardware, such as physical programming and sensors (Kuzu & Türk, 2018). This approach, which emphasises algorithmic and design-oriented thinking, provides students with the opportunity to apply science and mathematics disciplines to real life by connecting with the outside world while supporting skill development (Sarı & Yazıcı, 2020). On the other hand, Arduino is the preferred microprocessor in the physical computing field with its easy-to-use, cheap and flexible structure. The starting point of this processor is engineering applications, and it allows for an original design. Individuals have the opportunity to turn an idea into reality by using different fields and technologies together with Arduino. The Arduino processor allows the production of different projects as well as interacting and communicating with the environment with the help of various sensors. This feature allows the processor to be easily integrated into educational environments for various disciplines (Cakir & Guven, 2019; Sarı, 2019). According to Wang et al. (2016), the use of Arduino in STEM activities contributes to STEM literacy. Arduino practical activities enable students to gain algorithmic thinking, collaborative working, creativity, problem-solving skills and an understanding of programming logic and engineering design processes (Sarı, et al., 2022). Although there is theoretical knowledge that Arduino hands-on activities can improve students' problem-solving skills, Hertzog and Swart’s (2016) studies did not support this finding. S. W. Kim and Lee (2017) determined that programming with Arduino did not cause any change in problem-solving skills and emphasised that appropriate learning-teaching methods and activities should be developed for Arduino-based education.

The study aimed to investigate the effect of STEM-focused Arduino practical activities on problem-solving and entrepreneurship skills. The research questions were:

(1) Do STEM-focused Arduino activities differ significantly on students' problem-solving skills?
(2) Do STEM-focused Arduino activities differ significantly on the entrepreneurial skills of the students?
(3) What are the students' thoughts on STEM-focused Arduino activities?

We planned partially structured STEM-focused Arduino activities. Students were given activity guides and asked to develop solution-oriented designs for the problem. They created a solution-oriented product using the problem-solving and algorithm development stages in the learning environment where the problem-solving and design process is effective for entrepreneurship skills.

Method

Research design

The sequential descriptive design model, one of the mixed models of Creswell (2013), was used in the study. As both quantitative and qualitative data were used in this design, it increases the validity and reliability of the study (Creswell, 2013). A pre-test post-test experimental design without a control group (Fife-Schaw, 2012) was used in the quantitative dimension of the study. In this dimension, were applied the Reflective Thinking Skills Scale for Problem-solving (RTSSPS; Kızılkaya & Aşkar (2009) and Entrepreneurship Scale (ES; Çelik et al., 2015) to the study group. We created a semi-structured interview form for the qualitative dimension of the study. The opinions of the teacher candidates were obtained through the interviews.

Study group

The study group was determined according to criterion sampling, which is one of the purposeful sampling methods. Purposeful sampling allows for in-depth study of situations, and it is thought to have rich information (Merriam, 2009). Observation units can be composed of people, events or situations with certain qualifications in studies using criterion sampling. The study group consisted of 31 students in Technology and Design in the 4th year of the Science Education Undergraduate Program at a state university in Turkey.

Materials used in the study and practical activities

This study was designed with a 11-week study plan. In the first stage of study, teacher candidates were divided into pairs. During the first 6 weeks, the pairs were given mini activities to develop basic skills related to the structure, programming language and physical components of Arduino programming (Table 1). According to Beck (2000), each person in the pairs formed according to the logic of pair programming sits side by side at a computer and works on the same design, algorithm, code or test. In pair programming, individuals regularly switch tasks at certain time intervals. Thus, we aimed to improve the programming skills of teacher candidates with mini activities.

Table 1
Basic Arduino practical activities

(1)	LED lighting with Arduino
(2)	Button-controlled LED lighting
(3)	LED control using a potentiometer
(4)	Arduino RGB LED application
(5)	LDR light sensor application
(6)	LM35 temperature sensor application
(7)	HC-SR04 ultrasonic distance sensor application
(8)	Servo motor control via Arduino
(9)	MQ4 gas sensor application
(10)	Soil moisture sensor application

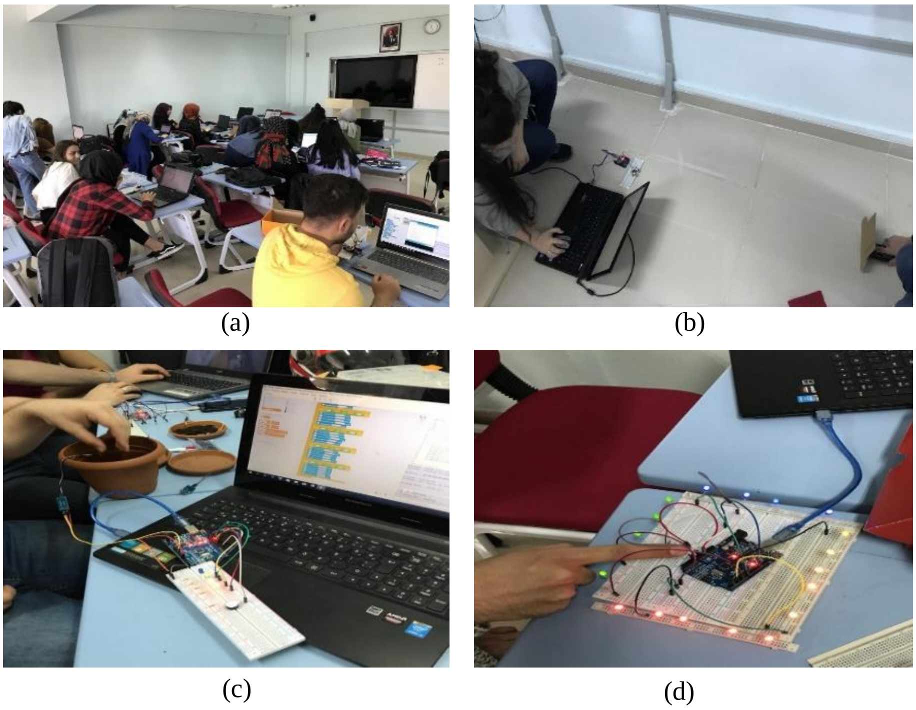

Figure 1. Pictures of the activities: (a) Basic Arduino activities, (b) Radar design, (c) Smart pot design, (d) Stadium lighting prototype

In the second stage of the study, which lasted 5 weeks, we aimed for the teacher candidates to work in small groups and complete a common project. Therefore, they carried out STEM-focused Arduino activities in groups of 3 or 4 people in a cooperative learning environment (see Figure 1 for images of the activities). We gave the groups an activity guide (worksheet) covering the problem situation and the steps of the physical computing process for each activity, which they applied for their design. We asked the students to develop solution-oriented designs on the problem situation using the steps given in Table 2. In this context, they carried out five activities according to the topics in the science curriculum (Table 3). The groups presented their work in the learning environment. After the presentations were finished, information was shared by giving feedback to the groups.

Table 2
Steps for STEM-focused Arduino practical activities

(1)	Defining the problem (determining the criteria and limitations)
(2)	Developing solution ways to the problem (creating an algorithm)
(3)	Evaluating the solutions in line with the criteria and limitations and choosing the most appropriate solution
(4)	Drawing the circuit diagram and picture of the selected solution
(5)	Testing and improving the solution on paper
(6)	Coding the algorithm
(7)	Creating the prototype considering the circuit diagram
(8)	Testing and improving the code
(9)	Editing the obtained data into a report

Table 3
STEM-focused Arduino practical activities

1. The name of the activity: Traffic light design			
Learning goal: The student … - Shows the elements in the electrical circuit with their symbols. - Sets up the scheme of the circuit s/he drew. - Understands that the science and engineering fields are related to each other. - Understands the process of creating an algorithm is a step that engineers use to solve the problem.			
Science	Maths	Engineering	Technology
Simple electrical circuits, circuit elements, symbols, and setup	Simple electrical circuit modelling, traffic light modelling, creating algorithms suitable for modelling	Design of traffic light system using simple electrical circuit (electrical engineering)	Selection of materials according to the usability criteria in design, coding by the algorithm
2. The name of the activity*:* Smart stadium lighting system design			
Learning goal: The student … - Draws a circuit diagram consisting of light bulbs connected in series and parallel. - Makes an inference by observing the brightness of the light bulbs connected in series and parallel. - Tests predictions by predicting what are the variables that affect light bulb brightness in an electrical circuit. - Designs an original lighting system. - Understands that s/he should use mathematics and science to solve the problems encountered. - Designs smart systems with physical programming tools with Arduino.			
Science	Maths	Engineering	Technology
Installation of simple electrical circuits, ways of connecting light bulbs in series and parallel connections, and its effect on light bulb brightness	Creating a circuit diagram. Comparing light bulb brightness from data. Creating and interpreting a table showing the relationship between the number of light bulbs and brightness. Intelligent lighting system modelling, creating an algorithm suitable for the model.	Designing a smart stadium lighting system that will not cause light pollution (electrical engineering)	Selection of materials in design according to usefulness criteria, coding by the algorithm
3. The name of the activity: Radar design			
Learning goal: The student … - Defines speed and expresses its unit. - Shows the relationship between road, time, and speed on the graph. - Understands that engineers must integrate science and mathematics to produce solutions to problems.			
Science	Maths	Engineering	Technology
Constant velocity motion, road, time, velocity and their units, path-time and velocity-time graphs of constant velocity motion	Creating a table for the position-time data of the moving object with the data obtained using the distance sensor, plotting and interpreting the graph, creating an algorithm suitable for the problem's solution.	Designing a radar system using the position and time data of the moving object. (highway engineering)	Selection of materials in design according to usefulness criteria, coding by the algorithm

4. The name of the activity: Radar design in friction environment			
Learning goal: The student … - Defines speed and expresses its unit. - Shows the relationship between road, time, and speed on the graph. - Discover the effect of friction force on movement in various environments. - Understands that s/he should use mathematics and science to solve the problems encountered.			
Science	Maths	Engineering	Technology
Movement, speed, position, displacement, friction force, the effect of friction force on the movement	Obtaining the position-time data of the moving object, creating a table, and drawing its graphics. Obtaining the position-time graph of the data obtained in friction environment, creating a table, plotting, and interpreting it.	Designing a radar system that shows the effect of friction force against the motion (highway engineering)	Selection of materials in design according to usefulness criteria, coding by the algorithm
5. The name of the activity: Smart pot design			
Learning goal: The student … - Explains the main factors affecting the growth and development of plants. - Takes care of a plant and reports its development process. - Understands that the process of creating an algorithm is used to solve the problem.			
Science	Maths	Engineering	Technology
Necessary conditions for the development process of a plant	Creating an algorithm for the solution of the problem, measuring the moisture required by the plant using a soil moisture sensor, creating a table, and interpreting it.	Designing a smart pot for the moisture requirement of the plant (industrial design engineering)	Selection of materials in design according to usefulness criteria, coding by the algorithm

Data collection tools

RTSSPS

The RTSSPT is a 5-point Likert scale indicating the frequency of actions: *always*, *most of the time*, *sometimes*, *rarely* and *never*. The Cronbach’s alpha reliability value for a total of 14 items was calculated as 0.83 on this scale.

ES

ES is a 5-point Likert-type scale showing the frequency of actions: *strongly disagree*, *somewhat agree*, *agree*, *strongly agree*, *completely agree*. It consists of 28 items. The statistical results were 0.910 as the KMO value and 2896,236 as Bartlett’s test data. It explained 52.136% of the total variance, and its α reliability coefficient was calculated as 0.924. The sub-dimensions (communication self-confidence, creativity, risk-taking, need to succeed) related to the scale expected to measure entrepreneurship skill were selected in terms of evaluating the effects of the study on 21st-century skills.

A semi-structured interview form was used to determine the opinions of the teacher candidates about STEM-focused Arduino practical activities. This form consisted of four questions:

(1) Do you think STEM-focused Arduino activities can be beneficial for you? Write down the reasons.
(2) Which skill development can STEM-focused Arduino activities contribute? Explain.
(3) Could STEM-focused Arduino activities have negative aspects or disadvantages in the learning-teaching process? Explain.
(4) When you start your profession, would you like to use such activities in your classroom? Why?

The teacher candidates filled in the form after the activities. The participants' identities were kept confidential and numbered as S1, S2 … in the study.

Data analysis

SPSS Statistics version 25 was used to analyse quantitative data in the study. The normality test of the data of the study group was performed using the Shapiro-Wilk test, and it was observed that the data showed a normal distribution with 95% confidence. The dependent sample I-test analysis was performed, which is consistent with the normal distribution to determine whether there is a significant relationship between the pre-test and post-test scores of the scales applied to the participants. In the study, the significance level between variables was accepted as $p < 0.05$. Another criterion that shows whether the difference between the results in the study is significant is Cohen's *d* value. As a general recommendation, Cohen says that if the *d* value is less than 0.2, the effect size may be defined as weak, if it is 0.5, it may be defined as a medium, and if it is greater than 0.8, it may be defined as strong (Kılıç, 2014).

Category analysis was used in the analysis of qualitative data. The classification was made by gathering similar data within the framework of specific concepts and themes and by organising them in a way that the reader can understand (Yıldırım & Şimşek, 2005). The reliability of data analysis was calculated by using the Miles and Huberman (1994) formula (Reliability = Consensus \ [Consensus + Disagreement] * 100), and it was 0.89. When the Miles and Huberman reliability coefficient is above 0.70, it is considered reliable for the study.

Findings

The effects of STEM-focused Arduino practical activities on problem-solving and entrepreneurship skills are presented in Tables 4 and 5 respectively. Also, Table 6 shows the content analysis results reflecting the views of the students about the activities. According to the results of the analysis presented in Table 4, there is a significant difference in favour of the post-test ($\bar{X}$ (pre) = 34.2258) - post-test ($\bar{X}$ (post) = 56.6452) in the whole scale and sub-dimensions of the scale ($p < .05$). Cohen's d effect size values are 0.5 and above. It means that there is a medium and high effect size in the whole and sub-dimensions of the scale. It is understood from the results that STEM-focused Arduino activities have a significant effect on students' reflective thinking skills towards problem-solving.

Table 4
Dependent t-test results for the RTSSPS

Factors	Test	*N*	X	SS	*t*	SD	*p*	Cohen’s *d*
Questioning	pre-test	31	11.6129	3.34343	-11.349	30	.000*	2.038
	post-test	31	20.0968	1.73887				
Evaluation	pre-test	31	13.0000	2.82843	-11.092	30	.000*	1.992
	post-test	31	19.9677	1.64284				
Causing	pre-test	31	9.6129	2.52557	-11.261	30	.000*	2.022
	post-test	31	15.6129	1.43009				
Total	pre-test	31	34.2258	7.21900	-14.672	30	.000*	2.635
	post-test	31	56.6452	3.47897				

* $p < .05$

The results of the *t* test for the significant difference for the pre-test ($\bar{X}$ (pre) = 109.2903) - post-test ($\bar{X}$ (post) = 119.4516) scores for the ES are given in Table 5. According to the data, there is a significant difference in favour of the post-test scores for students’ entrepreneurship skills and each of its sub-dimensions ($p < .05$). Also, Cohen's *d* values are observed to have small and medium effect values. According to these findings, the STEM-focused Arduino activities made a positive contribution to the development of students’ entrepreneurship skills.

Table 5
Dependent t-test results for ES

Factors	Test	*N*	X	SS	*t*	SD	*p*	Cohen's *d*
Communication	pre-test	31	39.0000	3.34664	-2.221	30	.034	0.398
self confidence	post-test	31	40.9032	3.64559				
Creativity	pre-test	31	33.6774	5.10155	-3.886	30	.001*	0.697
	post-test	31	37.2581	3.70556				
Risk-taking	pre-test	31	20.8387	2.93368	-4.121	30	.000*	0.740
	post-test	31	23.6129	2.47221				
Need to succeed	pre-test	31	15.7742	2.65468	-4.416	30	.000*	0.793
	post-test	31	17.6774	1.86882				
Total	pre-test	31	109.2903	10.28006	-4.587	30	.000*	0.823
	post-test	31	119.4516	9.19724				

* $p < .05$

We evaluated the teacher candidates' views on STEM-focused Arduino activities by category analysis and determined the codes. The themes of benefits to teacher candidates, their effect on skill development, positive and negative effects on the learning-teaching process were created by using these codes. The findings are presented in the form of tables with quotations from the responses of the participants. According to the participants, the practical activities provided them with important gains, could be effective in skill development and could have many benefits for students and the science course.

Table 6
Teacher candidates' views on the benefits of STEM-focused Arduino activities

Codes	Frequency
Professional development	11
Skill development	11
Giving a different perspective	8
Interest and attitude	8
Solution-oriented approach to daily life problems	8
Self-confidence building	7
Efficient use of technology	6

With the STEM-focused Arduino practical activities, teacher candidates demonstrated a positive effect in such areas as their professional development and skill development (Table 6). Statements from some teacher candidates related to their views are given below:

> This education made personal contributions to us professionally. (S1)
> It will be very useful in terms of expanding thinking skills and opening their horizons. (S9)
> It enables students to gain different perspectives to produce different designs according to their interests and skills. (S13)
> Using technology in science education will positively affect the students' interest and attitude towards science. (S5)
> It is important to keep up with the developing technology for future generations. (S3)
> Develops students' self-confidence. (S6)

It can be said that benefits such as developing self-confidence, gaining a different perspective and providing a solution-oriented approach to problems shown in the participants' views reflect the effects that support problem-solving and entrepreneurship skills.

Table 7
Opinions on the effects of the practical activities on skill development

Codes	Frequency
Problem-solving skills	16
Creativity	13
Psychomotor development	13
Analytical thinking	10
Collaborative study	8
Algorithmic thinking	7
21st-century skills	5
Engineering skills	3
Scientific process skills	3

Table 7 shows the opinions of the teacher candidates on skill development considering the effect of STEM-focused Arduino practical activities. Such practices can be effective in the development of 21st-century skills such as creativity, psychomotor development, analytical thinking, collaborative study, algorithmic thinking and especially problem-solving skills. Participant opinions on the subject are given below:

> Develops the skills on problem-solving and analysing the problem. (S7)
> In addition to the development of skills such as creative thinking skills, it can also improve aesthetic understanding and hand skills. (S9)
> Improves self-confidence and analytical thinking. (S6)
> It is necessary to make students gain 21st-century skills. (S8)
> Psychomotor skills are expected to improve. (S12)
> Improves algorithmic thinking skills. (S10)
> First of all, engineering skills are expected to improve. (S3)
> It will improve scientific process skills. (S2)

Table 8
Opinions for the positive and negative effects of the activities on the learning-teaching process

Theme	Codes	Frequency
Effect on the learning-teaching process (positive effect)	Skill development	20
	Learning by doing-living, concretisation	13
	Increasing interest and attitude	12
	Academic success	9
	Permanent learning	8
	Learning by having fun	5
	Efficient use of technology	5
	Contribution to career development	5
	Giving perspective	3
Effect on the learning-teaching process (negative effect)	Inability to address all gains	7
	Time problem	6
	Lowering interest and attitude	5
	Teacher-student shortage	5
	Education inequality	4
	Cost problem	4
	Competitive impact	2
	Programming language difficulty	2
	Classroom management problem	2

Participant views on the effects of Arduino activities on the learning-teaching process are given in Table 8. Teacher candidates agreed that the activities provide skill development as a positive effect on the learning-teaching process. Also, positive effects were identified in the form of learning by doing, increasing interest and developing a positive attitude towards the lesson, contributing to academic success, permanent learning, learning by having fun, effective use of technology, and contribution to career development. On the other hand, there were some negative opinions about these activities. Arduino activities cannot address all the gains in the science curriculum, and time, cost and classroom management problems may be experienced during the process, and the knowledge-skill deficiencies of teachers or students may negatively affect the process according to opinions of the study group. The statements of some teacher candidates related to the subject are given below:

> It is necessary to equip students with 21st-century skills such as problem-solving skills and critical thinking. (S8)
> I will use it because it will make the lesson love and teach by making it related to daily life and fun by living by doing. (S26)
> When we bring the works to the exhibitions, it will increase students' interest in this field and science lesson. (S1)
> The topics will become more concrete and fun thanks to these studies. (S10)
> Including technology literacy in every student is important for our future and can carry us forward. (S21)

These statements of the students clearly show the positive reflections of STEM-focused Arduino applications on the learning-teaching process. With regard to the negative aspects of STEM-focused Arduino applications, they stated:

> Not every objective of the science course may be suitable for these applications. (S5)
> There may be a loss of time in learning the process and inadequacy in meeting the objectives of the science lesson. (S7)

They emphasised that such activities could not address all the objectives in the science curriculum and that there might be a time problem in the implementation of the activities. They also emphasised that the tools and equipment to be used in applications require a cost and that inequality of opportunity may occur when not every school can meet this cost:

> Problems may occur between students in rural schools and students in developed cities. (S6)
> Students must have the materials. There are also low-income families, especially in public schools. (S1)

Also, they emphasised that in order to carry out the activities students and teachers must have the necessary competence and the learning environment must have the necessary equipment:

> Teachers and students should have sufficient knowledge about coding. (S11)
> Difficulties experienced while learning the programming language can reduce the desire. (S1)

Discussion and conclusion

The findings of the study show that STEM-focused Arduino practical activities have a significant effect on students' reflective thinking skills for problem-solving. The students developed a design aimed at solving real-life problems with programming design techniques in the activity stages (see Table 2). In this process, students are interested in problem representation, foresight and abstract concepts that improve their high-level thinking skills and problem-solving capacities to perform design tasks (Hsiao et al., 2019). Also, they carried out the stages of creating algorithms, coding, testing the code, prototyping with physical components, testing and development during the design process. It can be said that these STEM-focused activities are effective in the development of reflective thinking skills for problem-solving. S. W. Kim and Lee (2017) determined that activities with Arduino do not increase problem-solving skills and emphasised that Arduino-based education should be developed with appropriate activities. The current study shows that partially structured STEM-focused Arduino activities performed during the implementation process have an impact on problem-solving skills. Besides, the opinions of the participants given in Table 7 support this result. Teacher candidates stated that the practical activities in the context of skill development were most effective in the development of problem-solving skills. When Table 4 is examined, it may be concluded that the change in questioning skill from reflective thinking skills for problem-solving is higher than other skills (Xavg. = 8.4839). Therefore, the inquiry skills of the teacher candidates were affected the most by the activity process. Students apply their relevant knowledge to develop solutions to the problem design and produce solutions to meet the criteria and limitations in STEM-focused Arduino activities. They complete technological product design tasks by using their knowledge of STEM disciplines and their inquiry skills (Lin et al., 2020). Students' use of inquiry processes such as observing, researching, modelling, analysing, testing and evaluating is important for the development of these skills (Sarı et al., 2020). Effective STEM education should not only focus on science content knowledge but also encourage the realisation of curiosity, evidence-based reasoning and inquiry processes (Sarı & Yazıcı, 2020). The inquiry process improves students' field knowledge (Donnelly et al., 2014), motivation level (Hwang et al., 2013), problem-solving and questioning skills (Gillies et al., 2014). According to Morrison and Bartlett (2009), problem-solving and inquiry constitute the two main focal points of STEM education. Therefore, STEM-focused Arduino activities need to improve students' problem-solving and inquiry skills in terms of effective education. Similarly, according to Schnittka and Bell (2011), STEM-focused teaching enables students to know that there is more than one solution to a problem and to develop their inquiry skills.

The findings also show a statistically significant difference between the entrepreneurship skill scores of the students in favour of the post-test. The STEM-focused Arduino activities contributed positively to the development of entrepreneurship skills of students. Stages of the entrepreneurial process are observing the environment purposefully, exploring the needs, expressing the ideas clearly, choosing one of the ideas, creating a product, testing the product, adapting it to the environment and marketing. In addition to these processes, entrepreneurship includes skills such as self-confidence, problem-solving, creativity and risk-taking (Davis, 2019). Teacher candidates used the stages of entrepreneurial processes such as generating solution-oriented ideas, choosing appropriate ideas, creating and testing products by attempting to seek solutions to real-life problems with STEM-focused Arduino activities. The teacher candidates developed their own original designs and created a new value by using their creativity in the physical computing process with Arduino tools (Kang & Lee, 2020). Also, it can be said that entrepreneurship skills improved by having the opportunity to apply skills such as problem-solving, creativity and risk-taking. The opinions of the teacher candidates also support this finding. Although the participants did not directly express their views on entrepreneurship, the quantitative results are supported by the fact that they presented views reflecting the characteristics of the entrepreneurial individual, such as providing communication, self-confidence, creativity, collaborative work and problem-solving skills, offering a different perspective, and providing career development. Eltanahy et al. (2020) determined that individuals with STEM education are more aware of entrepreneurship practices. In some studies, STEM activities have been emphasised as an approach that aims to provide students with the ability to solve the problems they encounter in daily life in the most appropriate way, entrepreneurship, communication and critical thinking (Bybee, 2010). In addition, Katterfeldt et al. (2015) stated that physical computing strongly contributes to the development of self-efficacy, creativity, and experiential unity of body and mind. This study shows that entrepreneurship skills can be developed by encouraging real-life applications that increase students' productivity in STEM-focused Arduino activities.

According to the qualitative findings, it was determined that the teacher candidates had positive opinions about STEM-focused Arduino activities. Participants thought that the practices provided benefits such as contributing to their professional development, gaining a different perspective, adopting a solution-oriented approach to real-life problems, and using technology effectively. They also stated that such practices would support the students in the development of 21st-century skills such as problem-solving, creativity and design skills. These activities have positive effects for students such as providing learning by doing, increasing interest, permanent learning and creating career awareness. Today's understanding of education aims to ensure the development of individual differences and life skills through teaching activities. In this respect, the perceptions of the teacher candidates show that the planned activity and the learning outcomes obtained from the measurement tools were set up correctly. Teacher candidates need to have positive opinions about the activities in terms of adopting an interdisciplinary understanding of education suitable for meeting the needs of the age and raising entrepreneurial and productive individuals. The results of the study show that STEM-focused teaching increases students' interests and motivations, concretises the subjects, provides meaningful and permanent learning, facilitates learning, improves students' problem-solving, analysis, inference, critical thinking, creativity and collaboration skills, and the individuals have fun by learning. These results are consistent with the findings of Morrison and Bartlett (2009). As with our findings, research has found that STEM-focused activities contributed to students' positive attitudes towards science (Christensen et al., 2014; C. Kim et al., 2015; Martín-Ramos et al., 2018; Yamak et al., 2014) and significantly increased students' creative thinking skills and academic achievement (Cho & Lee, 2013). On the other hand, the negative aspects of the activities were determined according to the opinions of the teacher candidates. The participants stated that such activities could not address all the achievements in the science curriculum, and that there could be problems in the process such as time, cost and classroom management. In addition, the participants emphasised that teacher and student competencies are necessary in order for the activities to engender positive reflections on the learning-teaching process. In the physical computing process included in the activities, computational work such as the use of Arduino tools, coding and algorithm creation were carried out. These studies are technological and may seem complicated to users. Therefore, it is important for the teacher as a practitioner to have the necessary knowledge and skills in the management of the process. At the same time, it is important for students to have these skills and to have experienced such practices before they participate in these studies. Otherwise, the difficulties to be experienced due to the lack of knowledge and skills in the use of technological tools may negatively affect the attitudes and motivations of the students.

According to the literature, teachers need to have experienced this process before starting teaching and then they can transfer STEM education to science classes (Sarı et al., 2022). Teacher candidates experiencing STEM-focused activities and graduating with integrated STEM teaching knowledge can understand the relationship of STEM with real life, adopt the STEM education approach and direct students to STEM fields by positively affecting their attitudes (Corlu et al., 2014). On the other hand, considering that the main emphasis in STEM education is technological production, the positive opinions of the teacher candidates for STEM-focused Arduino practical activities and their experiences in this sense gain special importance. An idea can be turned into reality by using different fields and technologies together and by using Arduino activities in STEM education. In addition, products can be developed to solve current life problems. As a result, it can be said that Arduino activities structured according to the STEM education approach serve STEM literacy areas, increase students' interests and attitudes and improve their problem-solving and entrepreneurial skills.

Suggestions

According to the results of the research, using the physical computing process with Arduino in STEM learning environments will contribute to the quality of STEM education and the skill development of the learners. It is important to provide teacher, student and environment competencies in the positive reflection of STEM focused Arduino applications on the learning-teaching process. The study can be recommended to practitioners as an example of the integration of technology into STEM education and the use of physical computing in technological entrepreneurship education. Thus, the widespread effect of the study will also increase.

Considering the positive effects of STEM-focused physical computing activities on problem-solving and entrepreneurship, it can guide studies to develop other life skills. In future research, it may be especially interesting to examine the effect of computational thinking on entrepreneurial skills by including computational thinking in the physical computing process. This study, which was carried out with teacher candidates, can be taken as a model to examine different education levels. The results will be valuable in contributing to literature. The study is limited to teacher candidates and consisted of five activities and two thinking skills. It can provide guidance to researchers for conducting their studies with students of different learning levels. The activities implemented were planned in a mixed research design. If they are planned with the help of action research, they will be useful for eliminating difficulties in the process.

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References

Aljohani, M. (2015). Innovation and entrepreneurship integration in education: Ohio state model. *International Journal of Teaching and Education*, *3*(3), 1–20. https://doi.org/10.20472/TE.2015.3.3.001

Barton, G., & Ryan, M. (2014). Multimodal approaches to reflective teaching and assessment in higher education. *Higher Educations Research Development*, *33*, 409–424. https://doi.org/10.1080/07294360.2013.841650

Beck, K. (2000). *Extreme programming explained: Embrace change*. Digital Press.
Breiner, J.M., Johnson, C.C., Harkness, S.S., & Koehler, C.M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3–11. https://doi.org/10.1111/j.1949-8594.2011.00109.x
Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35.
Cakir, N. K., & Guven, G. (2019). Arduino-Assisted robotic and coding applications in science teaching: Pulsimeter activity in compliance with the 5E learning model. *Science Activities*, *56*(2), 42–51. https://doi.org/10.1080/00368121.2019.1675574
Çelik, H., Bacanak, A., & Çakır, E. (2015). Development of science laboratory entrepreneurship scale. *Journal of Turkish Science Education*, *12*(3), 65–78. https://tused.org/index.php/tused/article/view/482
Cho, B., & Lee, J. (2013, November). *The effects of creativity and flow on learning through the STEAM education on elementary school contexts* [Conference presentation]. International Conference of Educational Technology, Sejong University, South Korea.
Christensen, R., Knezek, G., & Tyler-Wood, T. (2014). Student perceptions of science, technology, engineering and mathematics (STEM) content and careers. *Computers in Human Behavior*, *34*, 173–186. https://doi.org/10.1016/j.chb.2014.01.046
Cooper, R., & Heaverlo, C. (2013). Problem solving and creativity and design: What influence do they have on girls' interest in STEM subject areas? *American Journal of Engineering Education*, *4*(1), 27–38. https://clutejournals.com/index.php/AJEE/article/view/7856/7916
Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers in the age of innovation. *Education and Science*, *39*(171), 74–85. http://hdl.handle.net/11693/13203
Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd ed.). Sage.
Davis, J. P. (2019). Preservice teacher learning experiences of entrepreneurial thinking in a STEM investigation. *Entrepreneurship Education*, *2*(1), 1–17. https://doi.org/10.1007/s41959-019-00009-0
Davis, J. P., Du, J., Tang, J. H., Qiao, L., Liu, Y. Q., & Chiang, F. K. (2020). Uniformity, diversity, harmony, and emotional energy in a Chinese STEM classroom. *International Journal of STEM Education*, *7*(1), 1–15. https://doi.org/10.1186/s40594-020-00232-5
Donnelly, D. F., Linn, M. C., & Ludvigsen, S. (2014). Impacts and characteristics of computer-based science inquiry learning environments for precollege students. *Review of Educational Research*, *84*(4), 572–608. https://doi.org/10.3102/0034654314546954
Eltanahy, M., Forawi, S., & Mansour, N. (2020). Incorporating entrepreneurial practices into STEM education: Development of interdisciplinary E-STEM model in high school in the United Arab Emirates. *Thinking Skills and Creativity*, *37*, Article 100697. https://doi.org/10.1016/j.tsc.2020.100697
Fayolle, A., & Gailly, B. (2015). The impact of entrepreneurship education on entrepreneurial attitudes and intention: Hysteresis and persistence. *Journal of Small Business Management*, *53*(1), 75–93. https://doi.org/10.1111/jsbm.12065
Fessakis, G., Gouli E., & Mavroudi, E. (2013). Problem solving by 5-6 years old kindergarten children in a computer-programming environment: A case study. *Computers & Education*, *63*, 87–97. https://doi.org/10.1016/j.compedu.2012.11.016
Fife-Schaw, C. (2012). Quasi-experimental designs. In G. M. Breakwell, J. A. Smith, & D. B. Wright (Eds.), *Research methods in psychology* (4th ed., pp. 75–91). Sage. https://uk.sagepub.com/upm-data/46877_Breakwell_Ch04.pdf
Garavan, T. N., & O'Cinneide, B. (1994). Entrepreneurship education and training programmes: A review and evaluation – part 1. *Journal of European Industrial Training*, *18*(8), 3–17. https://doi.org/10.1108/03090599410068024
Gillies, R. M., Nichols, K., Burgh, G., & Haynes, M. (2014). Primary students' scientific reasoning and discourse during cooperative inquiry-based science activities. *International Journal of Educational Research*, *63*, 127–140. https://doi.org/10.1016/j.ijer.2013.01.001
Gomez-Barreto, I. M., Merino-Tejedor, E., & Sanchez-Santamaria, J. (2020). University students' perspectives on reflective learning: Psychometric properties of the Eight-Cultural-Forces Scale. *Sustainability*, *12*(2), Article 729. https://doi.org/10.3390/su12020729

Hannon, P. D., Scott, J. M., Sursani, S. R., & Millman, C. (2006). The state of education provision for enterprise and entrepreneurship: A mapping study of England's HEIs. *International Journal of Entrepreneurship Education*, *4*, 41–72. https://research.tees.ac.uk/ws/portalfiles/portal/6419481/108525.pdf
Hertzog, P. E., & Swart, A. J. (2016, April). Arduino—enabling engineering students to obtain academic success in a design-based module. In *2016 IEEE Global Engineering Education Conference* (pp. 66–73). IEEE. https://ieeexplore.ieee.org/document/7474533
Hsiao, H. S., Lin, Y. W., Lin, K. Y., Lin, C. Y., Chen, J. H., & Chen, J. C. (2019). Using robot-based practices to develop an activity that incorporated the 6E model to improve elementary school students' learning performances. *Interactive Learning Environments*, 1–15. https://doi.org/10.1080/10494820.2019.1636090
Hwang, G. J., Wu, P. H., Zhuang, Y. Y., & Huang, Y. M. (2013). Effects of the inquiry-based mobile learning model on the cognitive load and learning achievement of students. *Interactive Learning Environments*, *21*(4), 338–354. https://doi.org/10.1080/10494820.2011.575789
Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (Eds.). (2016). *STEM road map: A framework for integrated STEM education*. Routledge.
Junior, L. A., Neto, O. T., Hernandez, M. F., Martins, P. S., Roger, L. L., & Guerra, F. A. (2013). A low-cost and simple Arduino-based educational robotics kit. *Journal of Selected Areas in Robotics and Control*, *3*(12), 1–7. http://www.cyberjournals.com/Papers/Dec2013/01.pdf
Juškevičienė, A., Stupurienė, G., & Jevsikova, T. (2021). Computational thinking development through physical computing activities in STEAM education. *Computer Applications in Engineering Education*, *29*(1), 175–190. https://doi.org/10.1002/cae.22365
Kang, Y., & Lee, K. (2020). Designing technology entrepreneurship education using computational thinking. *Education and Information Technologies*, *25*, 5357–5377. https://doi.org/10.1007/s10639-020-10231-2
Katterfeldt, E.-S., Dittert, N., Schelhowe, H. (2015) Designing digital fabrication learning environments for Bildung: Implications from ten years of physical computing workshops. *International Journal of Child-Computer Interaction. 5*, 3–10. https://doi.org/10.1016/j.ijcci.2015.08.001
Kılıç, S. (2014). Statistically Speaking effect size. *Journal of Mood Disorders*, *1*, 44–46. https://doi.org/10.5455/jmood.20140228012836
Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, *91*, 14–31. https://doi.org/10.1016/j.compedu.2015.08.005
Kim, S. W., & Lee, Y. (2017). Development and application of Arduino-based education program for high school students. *Journal of Theoretical & Applied Information Technology*, *95*(18), 4367–4375. http://www.jatit.org/volumes/Vol95No18/4Vol95No18.pdf
Kızılkaya, G., & Aşkar, P. (2009). Problem çözmeye yönelik yansıtıcı düşünme becerisi ölçeğinin geliştirilmesi [The development of a reflective thinking skill scale towards problem solving]. *Eğitim ve Bilim*, *34*(154), 82–92. http://egitimvebilim.ted.org.tr/index.php/EB/article/view/550/44
Kuzu, A., & Türk, M. (2018). Physical programming. In Y. Gülbahar & H. Karal (Eds.), *Teaching programming from theory to practice* (pp. 339–390). Pegem Akademi.
Lin, K. Y., Hsiao, H. S., Williams, P. J., & Chen, Y. H. (2020). Effects of 6E-oriented STEM practical activities in cultivating middle school student's attitudes toward technology and technological inquiry ability. *Research in Science & Technological Education*, *38*(1), 1–18. https://doi.org/10.1080/02635143.2018.1561432
Martín-Ramos, P., Lopes, M. J., da Silva, M. M. L., Gomes, P. E., da Silva, P. S. P., Domingues, J. P., & Silva, M. R. (2018). Reprint of 'First exposure to Arduino through peer-coaching: Impact on students' attitudes towards programming'. *Computers in Human Behavior*, *80*, 420–427. https://doi.org/10.1016/j.chb.2017.12.011
Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation* (3rd ed.). Jossey-Bass.
McDonald, C. V. (2016). STEM education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International*, *27*(4), 530–569.
Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis*. SAGE.
Morrison J., & Bartlett, R. V. (2009). STEM as a curriculum. *Education Week*, *23*, 28–31. http://ecommerce-prod.mheducation.com.s3.amazonaws.com/unitas/school/program/stem-essentials/stem-essentials-articles-stem-as-curriculum.pdf

Osman, K., Hamid, S. H. A., & Hassan, A. (2009). Standard-setting: Inserting domain of the 21st century thinking skills into the existing science curriculum in Malaysia. *Procedia – Social and Behavioral Sciences, 1*, 2573–2577. https://doi.org/10.1016/j.sbspro.2009.01.454

Sarı, U. (2019). Using the Arduino for the experimental determination of a friction coefficient by movement on an inclined plane. *Physics Education, 54*(3), Article 035010. https://doi.org/10.1088/1361-6552/ab0919

Sarı, U., Duygu, E., Şen, Ö. F., & Kirindi, T. (2020). The effects of STEM education on scientific process skills and STEM awareness in simulation based inquiry learning environment. *Journal of Turkish Science Education, 17*(3), 387–405. https://tused.org/index.php/tused/article/view/1103

Sarı, U., Pektaş, H.M., Şen, Ö.F., & Çelik, H. (2022). Algorithmic thinking development through physical computing activities with Arduino in STEM education. *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-10893-0

Sarı, U., & Yazıcı, Y. Y. (2020). STEM eğitimi ve Arduino uygulamaları hakkında öğretmen adaylarının görüşleri [Pre-service teachers' views on STEM education and Arduino practices]. *SDU International Journal of Educational Studies, 7*(2), 246–261. https://doi.org/10.33710/sduijes.701220

Schnittka, C., Bell, R. (2011). Engineering design and conceptual change in science: Addressing thermal energy and heat transfer in eighth grade. *International Journal of Science Education*, *33*(13), 1861–1887. https://doi.org/10.1080/09500693.2010.529177

Snihur, Y., Lamine, W., & Wright, M. (2018). Educating engineers to develop new business models: Exploiting entrepreneurial opportunities in technology-based firms. *Technological Forecasting and Social Change, 164*, Article 119518. https://doi.org/10.1016/j.techfore.2018.11.011

Solomon, G. T., Duffy, S., & Tarabishy, A. (2002). The state of entrepreneurship education in the United States: A nationwide survey and analysis. *International Journal of Entrepreneurship Education, 1*(1), 65–86.

Stohlmann, M., Moore, T. J., McClelland, J., & Roehrig, G. H. (2011). Impressions of a middle grades STEM integration program. *Middle School Journal, 43*(1), 32–40. https://doi.org/10.1080/00940771.2011.11461791

Wang, H., Zhou, C., & Wu, Y. (2016). Smart cup, wisdom creation: A project-based learning initiative for maker education. In *Proceedings of the 16th International Conference on Advanced Learning Technologies* (pp. 486–488). IEEE. https://ieeexplore.ieee.org/document/7757030

Yamak, H., Bulut, N., & Dündar, S. (2014). The impact of STEM activities on 5th grade students' scientific process skills and their attitudes towards science. *Gazi University Journal of Education Faculty, 34*(2), 249–265.

Yıldırım, A., & Şimşek, H. (2005). Sosyal bilimlerde nitel araştırma yöntemleri [*Qualitative research methods in the social sciences*. Seçkin Publishing.

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