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The impact of twenty-first century skills on university students' robotic achievements

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Abstract

New approaches are frequently used to provide students with twenty-first century skills. In this direction, robots are quickly integrated in today's educational environments. However, studies in which robots are integrated into the curriculum as a pedagogical tool and examine its effect on twenty-first century skills are limited. This research examines the impact of robotics training on cooperation and flexibility, autonomous, cognitive and innovation skills which are found in the skills set of the twenty-first century. 54 university students selected by criterion sampling were recruited for these 14 weeks long explanatory sequential mixed-method study. The data were collected using the Scale of the Use of 21st Century Learner Skills, Robotics Applications Achievement Test and semi-structured interview form developed by the researchers. A paired sample t-test revealed that cooperation and flexibility, autonomous, cognitive and innovation skills were significantly improved. Moreover, linear regression analysis showed that all skills other than innovation were significant predictors of students' robotic achievement. The results reported in this study shed new light on robotic education.

Keywords Educational Robotics · 21st Century skills · Cooperation and Flexibility · Autonomous · Cognitive · Innovation Skills

1 Introduction

The social structure of today is in a transition encompassing many fields such as commerce, society, health, and education (Belmonte et al., 2021) in the light of a technological revolution that started in the beginning of the twentieth century

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and is making itself more evident each passing day (Baller et al., 2016). This transition has paved the way for technology to replace humans in routine jobs depending on muscle force (National Research Council, 2011), to leave non-routine, complex problems to manpower, and for individuals to possess different skills in the twenty-first century (Jang, 2016). Accordingly, it is indicated that the fundamental objective of today's education is to equip individuals with necessary information and skills to be successful in the society and economy of the twenty-first century (Finn et al., 2014). It is observed around the world that researchers are seeking ways to provide these skills to students (Sulaiman & Shahrill, 2015).

The traditional teacher-centered education method does not allow for students to develop innovative abilities since it supplies students a series of fixed curriculum that leads to passive learning (Zhu et al., 2019). In order to prepare students for life in an ever-changing society, new and innovative teaching methods and technologies are required (Screpanti et al., 2021). Being one of these new technologies, educational robotics (ER), with a series of activities from installation to coding and testing robots, is considered a way to equip individuals with the skills needed to be successful in the twenty-first century (Khanlari, 2013; Scaradozzi et al., 2015).

Notably in developed countries, robotics has rapidly gained attention in educational settings of today (Miller & Nourbakhsh, 2016). ER is not only a powerful tool in terms of academic success but also in terms of improving skills such as problem solving (Benitti, 2012; Chalmers et al., 2012), scientific research (Benitti, 2012), reasoning (Rodríguez et al., 2017), cooperation and communication (Smyrnova-Trybulska et al., 2016), creativity (Gabriele et al., 2017), critical and upper-level thinking (Gaudiello & Zibetti, 2016). Even though ER are seen as flexible and influential learning tool (Atmatzidou & Demetriadis, 2016), approaching robots as a learning pedagogy is still in its infancy (Matarić & Scassellati, 2016). Its reasons include the fact that ER are carried out through extracurricular activities (Vitale et al., 2016) and that they are not part of the curriculum in teaching and learning processes (Kanbul & Uzunboylu, 2017). The inclusion of different technological tools in any education process should be related to the betterment of the pedagogic process (Erdogan et al., 2013). However, there are the limited number of studies in the literature on the use of robots as a pedagogic tool (Alimisis, 2013). Additionally, studies aimed at using ER to improve 21st-century skills of students are needed (Stork, 2020). Thus, this study aims to determine the impact of robotics training on cooperation and flexibility, autonomous, cognitive and innovation skills which are found in the skills set of the twenty-first century. Acting upon this short-coming, researchers, by reviewing ER as a curriculum, intend to put forth its impact on the students' twenty-first century skills in their research. Data obtained as a result of the research are of vital importance for practitioners since they include a structured curriculum plan for ER. Moreover, the research presents significant findings for researchers regarding the impact of ER on cognitive, innovation, autonomous, cooperation and flexibility skills which are found in the skills set of the twenty-first century. The results obtained include clues for both researchers and practitioners on whether robotics training can be used pedagogically as new teaching technology in schools or not.

2 Literature

2.1 Educational robotics

Robots are one of the most important products of new technologies and are used for different purposes in various fields such as entertainment, commerce, automotive, construction, and military forces (Basoeki et al., 2013). It is observed that robots have recently started to be used in education, particularly in science and technology teaching, in levels ranging from preschool to higher education and that there are various ventures worldwide for the utilization of robots in education (Alimisis & Kynigos, 2009). Robots can be used as aids in a class by undertaking mentor (Goodrich & Schultz, 2007) or peer roles (Okita et al., 2009) and as a learning tool by making robots with a series of activities comprised of coding and building robots (Karademir Coşkun & Yurttaş Kumlu, 2020). When effective learning is considered to take place by doing, experiencing, and discovering new things (Papert, 1991), robots can be said to have a crucial potential as an effective learning tool (Cheng et al., 2018).

The use of robots in education is examined by many branches including science (Shiomi et al., 2015), mathematics (Brown & Howard, 2014), special education (Karademir Coşkun, 2020), language teaching (Hein & Nathan-Roberts, 2018), music teaching (Karademir et al., 2018), and nutrition (Short et al., 2014). Studies show that robotics training motivate students to be actively involved in the learning process (Turan & Aydogdu, 2020) and encourage autonomy (García-Valcárcel-Muñoz-Repiso & Caballero González, 2019). Additionally, several studies have shown that robots are effective tools for improving student's motivation and learning performance (Redó & Orcos, 2019). Learning activities in robotics contribute to the development of students' autonomous learning, group work, efficient cooperation, and communication skills (Smyrnova-Trybulska et al., 2016). Numerous studies have indicated that pedagogic robots positively affect students' critical thinking, problem-solving, and metacognition skills (Alimisis, 2013) and that coding makes language learning easier (Mubin et al., 2013). Within this framework, ER is considered instrumental teaching tools containing a series of advantages such as improving some skills (García-Valcárcel-Muñoz-Repiso & Caballero González, 2019); encouraging entrepreneurship (Blackley & Howell, 2019), and increasing students' digital competencies (Gorjup & Liarokapis, 2020).

2.2 21st-century competences

Educational reform for the needs of the twenty-first century has been a substantial subject of debate worldwide (Voogt & Roblin, 2012). Individuals of the twenty-first century are expected to possess superior skills that would help them overcome complex tasks (Van Laar et al., 2017) and at the same time to adapt to changing work conditions (Carnevale & Smith, 2013). It is observed with the increasing importance of 21st-century competencies that various institutions accelerated their studies aimed at defining these skills. For instance, the International Society for Technology in Education (ISTE), which is one of these institutions, ranks the competencies they deem fit for learners: empowered learner, digital citizen, knowledge constructor, innovative designer, computational thinker, creative communicator, and global collaborator (ISTE, 2016). Another institution, namely Partnership for 21st Century (P21), assigned 21st-century competencies into three categories. These are learning skills (creativity, innovativeness, critical thinking and problem solving, cooperation and flexibility), literacy skills (literacy in information and media and information and communication technologies), and life skills (flexibility and accommodation, responsibility and self-management, social and intercultural skills, productivity and accountability, and leadership) (P21-The Partnership for 21st Century Skills), 2009).

The competencies defined by international institutions show that it is necessary to possess more than one competence to be successful in the twenty-first century. It is vital for students to be equipped with these competencies prior to the start of their working life. In this context, new pedagogic approaches, content, teaching technologies, and learning and evaluation strategies should be developed (Gordon et al., 2009), and educational settings should be designed to encourage students to be more active, think critically, solve problems, and cooperate with one another (O'Neal et al., 2017) in order to equip learners with twenty-first century competences.

When the literature is reviewed, it is seen that different terminologies and classifications are used to define twenty-first century competencies (See: P21-The Partnership for 21st Century Skills, 2009; Binkley et al., 2012; Lonsdale & Anderson, 2012; Trilling & Fadel, 2009). Even though there exists different definitions and categories in the literature, it is observed that definitions of twenty-first century competencies involve similar associations and components (Wang et al., 2019). Based on the definitions of twenty-first century competencies, this research addresses and evaluates problem solving, creative thinking, and critical thinking skills under "cognitive skills", contact with superiors, self-regulation, learning how to learn, and decision-making skills under "autonomous skills", cooperation and communication skills under "cooperation and flexibility skills", and innovation skills under "innovation" theme and includes these concepts as independent variables.

2.3 Cognitive skills

While defining the processes of the mind, the term "cognition" comprises many notions related to the mind such as attention, perception, memory, and problem solving (Bayhan & Artan, 2007). Cognitive skills involve a series of mental functions such as memorizing-remembering, focusing-attention blocking, data processing speed, and spatial and causal reasoning (Robinson, 2012). "Cognitive skills" is a general term covering many forms of intellect (Ozawa et al., 2022). It is associated with academic performance (Finn et al., 2014) and educational success (Plomin & Von Stumm, 2018) influencing the success and learning of students. Cognitive abilities economically affect both individual progress and national growth (Hanushek & Woessmann, 2008). Research has shown that the relation between cognitive skills and individual and national progress is considerably strong (Green & Riddell, 2003). The literature suggests that ER promote cognitive (Toh et al., 2016), linguistic (Lee et al., 2011), and conceptual skills (Kerr, 2009) by providing students with active information build-up. While Andjic et al. (2015) argue that students can process information faster thanks to ER, Afari and Khine (2017) claim that ER can help students with acquiring basic skills such as problem solving and critical thinking. In this research, ER are expected to have a positive contribution on students' cognitive development by providing a "learning through experience" environment and actively involving the students in the process.

2.4 Autonomous skills

Autonomous skills express autonomous learning skills that surface through the integration of self-management, self-control and individual or group study skills (Pajares and Kranzler, 1995 cited by Göksun, 2016). Particularly learner autonomy has become a subject area regarded highly by many scholars in the last 30 years (Borg & Al-Busaidi, 2012) and is accepted to be of vital importance (Agadzhanova, 2020). Learner autonomy comprises the capacity and willingness of a person to act independently and to cooperate with others (Dam et al., 1990), the fact that the learner can take initiative to determine his/her objectives, making a clear study plan, and the fact that the learner can select the skills and methods to be used and evaluate what he/she has learnt (Agadzhanova, 2020). Autonomy is not an innate behavior but one that can be gained purposefully and systematically through natural or official means of learning (Holec, 1981). Autonomous learning skill has become a necessity in the twenty-first century when self-guided learning has come to the fore with the increase in lifelong learning and online learning environments (Padmadewi et al., 2020). The literature shows that robots increase students' self-regulated learning (Weng et al., 2020) and students' self-regulated learning motivation (Jones & Castellano, 2018; Yang et al., 2022). However, for powering students' self-regulated learning motivation, adaptive robots need to be well configured for the learning environment (Jones et al., 2017). Learning environments have been swiftly transferred to online platforms from classroom settings. ER can be a significant method in developing students' autonomous learning skills since the process of carrying out activities in ER include making a study plan, group study, and selecting the skills and methods to be used in the process.

2.5 Innovation skills

Innovation defines creative activities where people change objective reality (Zheng & Shao, 2007). Although developing innovation skills require many talents (OECD, 2011), it is an urgent need of the era (Wenjin, 2007) and a necessity caused by globalization (Demirel & Seçkin, 2008). Innovation skills contain a series of qualities such as coping with uncertainties, trying new ideas, and risk-taking (Rogers, 2003). An innovative individual is defined as a person willing to take risks and who has access to upper social class and scientific resources while acting as a role model in transferring new ideas to a social system (Rogers, 2003). Developing innovation skills is the responsibility of universities (Ke, 2007) and one of the objectives of modern educational institutions (Zviel-Girshin & Rosenberg, 2021). New pedagogies are required to include innovation into teaching and learning processes (Erdogan et al., 2013). Research has shown that ER encourages students with intrinsic motivations to innovation (Anwar et al., 2019). Zhu et al. (2019) claim that ER will inspire students to produce innovative ideas and to materialize these ideas. ER can encourage innovation and creativity by enabling all students to come up with different solutions to the same problem (Zviel-Girshin & Rosenberg, 2021).

2.6 Cooperation and flexibility skills

Cooperation is an important educational output that provides the opportunity to develop or evaluate an idea that has been learnt through participation and practice (Kuhn, 2015). Co-operative learning is a complex skill that requires positive dependency, individual accountability and identical cooperation (Kagan, 1994). In terms of adopting active cooperation of all members of a team in decision-making and the responsibility of the decisions made (Foley, 2001), cooperative learning supports individuals to possess a wider set of skills (Piniuta, 2019) that would help the progress of societies and economies. The memorability of knowledge (Rojas-Drummond & Mercer, 2003) may contribute to the development of a series of skills including the development of social competence (Ginsburg-Block et al., 2006), increase of academic performance (Sulaiman & Shahrill, 2015), enhancement in cognitive development (Zhang, 1998), and flexibility in problem solving (Baghaei et al., 2007). ER develops students' cooperation skills, cooperative learning motivations (Eguchi, 2014) and students' teamwork skills (Holmquist, 2014). While Demetroulis and Wallace (2021) point to the fact that the participation of the students to ER increases teamwork and cooperation skills, Glezou (2021) has put forth that robotics is a strong means of teaching twenty-first century skills to students. The presence of cooperative activities in ER affects positive teacher-student interactions (Sisman et al., 2021) and enables the provision of cooperation to help solve problems (Chootongchai et al., 2021). Students participating in robotics activities gain social skills like teamwork and become competitive in a productive manner (Zygouris et al., 2017).

2.7 Research questions

The main research problem of the study is 'What effect do educational robotics have on 21st-century skills of university students?'. In line with this, these questions framed the study:

1. Is there a significant difference between the pretest and post-test scores of ER achievement, cognitive, autonomous, innovation, and cooperation and flexibility skills of the students?
2. Are cognitive, autonomous, innovation, cooperation, and flexibility skills individually significant predictors of the students' ER achievements?

3 Method

3.1 Research design

Explanatory sequential mixed method which was used in the research is a design that quantitative data are collected and analyzed first, and then the second phase is planned as regards the results of the analyses and qualitative data are collected in the second phase (Creswell, 2003). This research was primarily initiated with a preliminary application of the scales and achievement test, 14-week ER course were given, and at the end of this course, the scales and achievement test were re-applied to the students and the data obtained were analyzed. According to the obtained data analysis, the second phase was planned, and the students were interviewed by having prepared semi-structured interview forms. After having analyzed the research data obtained, all data were interpreted holistically.

3.2 Participants

The participants of the research comprised 54 university students receiving education from a state university in the 2019–2020 academic year. The criterion sampling method was used in the selection of the participants. Criterion sampling involves selecting cases that meet some predetermined criterion of importance (Patton, 2001). Within this scope, the criteria were determined as gender, receiving education in different departments, and not having received any education or training in ER. The reasons for including participants from different genders and departments are as follows: (1) women tend to be less interested in subjects teaching technical information like ER (Roy, 2018; Gottfried & Plasman, 2018), (2) some differences have been detected in various studies in terms of gender and ER (See: Sullivan & Bers, 2019; Milto et al., 2002), and (3) the probability that students in computational departments would be more interested in the course and thus, a biased evaluation would have been obtained which would, in turn, affect the research. The criterion stating that participants should not have received any training and education was added to provide that change to be seen in dependent and independent variables would not be affected by preliminary information.

Within this context, student data were analyzed using Chi-square test to investigate the balanced distribution of the gender criterion. The result of the analysis showed that 44.4% ($n=24$) were females and 55.6% ($n=30$) were males, and the difference observed between the categories was not significant ($p>0.005$). It can be noted that gender balance, which was an important aspect of the selection of the study group, was achieved.

Distributions of the students' departments, which was the second criterion, were as follows: 25.9% were in the Department of Science Teaching, 18.5% in the Department of Early Childhood Education, 16.7% in the Department of Elementary Mathematics Teaching, 11.1% in the Department of Nuclear Energy Engineering, 9.3% in the Department of Classroom Teaching, 5.6% in the Department of Occupational Health and Safety, 3.7% in the Department of Social Sciences Teaching, 7.4% in the Department of Archeology, and 1.9% in the Department of Coaching. The last criterion was the fact that the participants had not received any prior ER course. The students participating in the research had not received any prior ER course. 27 students participated in the semi-structured interviews. Participation in semi-structured interviews is based on volunteering.

3.3 Data collection tools

ER achievement test This test was developed by the researchers aimed at measuring the success of the students in ER. Initially, the teaching program acquisitions tested as a result of the pilot application were converted into a table of specifications. The table of specifications was based on Bloom's updated taxonomy, and a total of 19 acquisitions were given, 8 in the recall step and 10 in the comprehension step. During the development of the test, three experts from the field of Computer and Instructional Technologies had prepared 50 questions by the table of specifications. In order to ensure linguistic validity, the questions were read by two university students and sent to three experts with a graduate degree in the field of instructional technologies who had given Arduino training for evaluation. Following the feedback received from the experts, a 46-question achievement test was prepared by combining 4 questions with others. The test obtained was implemented on the group that had received ER course before. Item score matrix was generated with the data obtained, and the significance between the group's item scores were examined by calculating 27% of high and low groups. For the second step, the distinctiveness index of the items related to the questions were calculated, and 12 items with a distinctiveness index lower than 0.30 (Karslı & Ayas, 2013) were removed from the test. Average item difficulty was calculated for the test developed and found as 0.302. However, four difficult questions were removed from the test to approximate the difficulty of the test to the acceptable level of 0.50 (Çokluk et al., 2012). For final analysis, average item difficulty was brought to 0.465, which was closer to the desired value. In determining the items to be removed, their representative strength value on the table of specifications was taken under consideration. KR-20 value of the test was calculated to determine the test's internal consistency. As a result, KR-20 value was found as 0.72, which was determined to be considerably reliable since it was between the values 0.60 and 0.80 (Kalaycı, 2008). In the end, a 30-question "ER Achievement Test" was developed.

The scale of the use of 21st century learner skills This scale was developed by Orhan Göksün (2016) based on the resources of OECD, AASL (2007), Wagner (2008) and Trilling and Fadel (2009). The independent variables of this research are composed of the sub factors of the scale including cognitive, autonomous, cooperation and flexibility and innovation skills. Each of the scales sub factors was included into the analyses as separate independent variables.

The scale is composed of a total of four factors and 31 items. Sub factors express 34.75% of the total variance. The internal consistency coefficient of the scale is

0.892. Moreover, confirmatory factor analysis performed has confirmed the 4-factor structure of the scale ($\chi 2/df = 0{,}65$; $p = 1{,}00$; RMSEA = 0,00). Cognitive skills, one of the sub-factors, involve the processing and coding of information in cognitive processes and the awareness of the products that emerge as a result of these cognitive processes (Orhan Göksün, 2016). Factor load distributions of the subfactor consisting of a total of 17 items is between a value of 0.602 and 0.400. Cronbach alpha reliability coefficient of the factor is 0.877. The factor alone expresses 15.655% of the total variance. Another factor, the autonomous skills, involves autonomous learning skills that emerge with the integration of self-management, self-control, and individual or group study skills (Orhan Göksün, 2016). While factor loads of the 5-item factor range between 0.557 and 0.439, it has been found that the factor expresses 7.876% of the total variance. Furthermore, the reliability coefficient is at a desired value of 0.706. Another sub-factor, namely cooperation and flexibility skills, points to the success of the activity-based upon cooperation and making learning environments flexible by expanding them (Orhan Göksün, 2016). Within this context, it is seen that the factor loads of the five items of the sub-factor are between 0.524 and 0.403 and expresses 5.876% of the total variance. Its reliability coefficient is 0.672. The last factor, the innovation skills, is used to show conformity to new technologies (Orhan Göksün, 2016). This factor is comprised of two items whose item loads are.809 ile 0.745 and expresses 5.347% of the total variance. Its reliability coefficient is 0.818.

Semi-structured interview form The interview form provides detailed information collection by providing opportunities to discuss some issues in more detail (Lacey & Luff, 2001). In this study, the interview question was structured to consist of a question under the theme of "effect on robotics education". The interview question was structured as not directing the participants (Turner, 2010) and it includes details about the main theme can be obtained (Taylor, 2005). In order to improve the quality of data collection by testing the interview form (Chenail, 2011), the form was reviewed by two field experts who have PhD in computer and instructional technologies. It was arranged according to their opinions received and made available to the participants via an online platform as based on volunteering.

3.4 The implementation phase of the research and data collection

Preparation of ER program with Arduino A 56-h educational program was prepared, which covered ER with Arduino that would be implemented throughout the research. Acquisitions and competencies related to the acquisitions were defined in the 14-week educational program. In parallel to the defined competencies, activities and evaluation methods were determined. The activities in the program predominated mainly by the method of demonstration-performance were combined by the examples found in daily life, and it was aimed for the students to transform the knowledge acquired from the lesson outcomes into real-world exercises. In addition, simple exercises were used in the first weeks, but more complex activities were asked from the students in the upcoming weeks. For instance, while the HCSR 04-Ultrasonic distance sensor was taught in Week 7 and parking sensor was assigned to be prepared, in Week 13 when relay and its coding were described, an activity to transform an instant coffee machine into a remotely controlled smart coffee machine. Materials to be used in the educational program (videos and printed resources) were put into service for the students on a video storing site. The testing and arrangement of the educational program was carried out with the pilot group. During pilot execution, the distribution of the educational program's acquisitions, the balance between theoretical and practical knowledge, the compatibility of the activities with daily life, the detection of the tools and materials needed for the educational program, and the effectiveness of the course materials (printed and digital resources) were tested, and students' opinions on these matters were requested. Moreover, activity examples of the pilot group were stored on an e-portfolio, and the participants'' progress and the efficiency of the program were observed by examining them weekly. According to the data obtained, some changes were made in the educational program, and a sample of the ER Program with Arduino can be found in Annex 1.

Pilot study The pilot study was carried out with 21 male and 23 female students from the Faculty of Education, Faculty of Engineering, Faculty of Science and Letters, Vocational School of Health and Vocational School. A 2-month study was conducted with the pilot group, and as a result, the compatibility of the aforementioned educational program was tested, and necessary adjustments were made. In addition, the physical environment where the education would be given was tested, and a laboratory was arranged for the actual implementation of the program by establishing the best hardware and structures for the trainings. A list was made for the additional robotic supplies needed for the implementation of the program, and these supplies were purchased for the activities changed in the educational program. Moreover, validity and reliability retest of the achievement test and application of the assessment instruments, their form of application, and the clarity of the assessment instruments were carried out in the pilot study. As a result of the pilot study, the best environment for the implementation of the scales was considered to be online. There were no problems with the clarity of the scales.

During this process, improvements were made on the aforementioned matters by observations, interviews and collecting data through scales.

Implementation of the research The research was carried out at the computer laboratory. The research was initially started with the preliminary implementation of the scales and achievement test. The scales were applied on an online platform. The students completed a 14-week ER Program with Arduino.

While the program continued, the students were asked to prepare their own e-portfolios and add their ER examples weekly by taking videos (Fig. 1). Thuswise, the efficiency of the courses was observed by examining the students' e-portfolios at various intervals during this 14-week process.

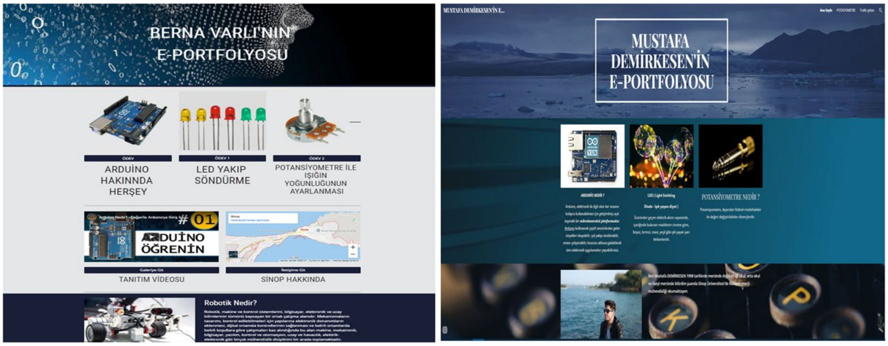

Fig. 1 Samples from student e-portfolios

While the program continued, the students were assisted with educational videos prepared in conformity with the educational program and uploaded online, and memorability of the courses was tried to be achieved (Fig. 2).

At the end of the 14-week program, post-test application of the scales was performed. Data analyses were performed after the data applied were made ready for analysis, and qualitative data were collected by sending the semi-structured interview form to the participants which was prepared to determine implicit variables in parallel to the findings obtained.

3.5 Data analysis

Paired samples t-test, simple linear regression and content analysis were utilized for the analysis of research data. Data analyses started primarily with the investigation of the tests' assumptions. Simple linear regression analysis was carried out between the students' post-test achievement scores and post-test scores of cognitive, autonomous, innovation, and cooperation and flexibility skills. To test the linearity between the dependent and independent variables and clear extreme values, scatter plots between two variables were studied. Some values were found to fall outside the scattering plot. Then, to determine extreme values on the data set, box plots were examined, and values considered

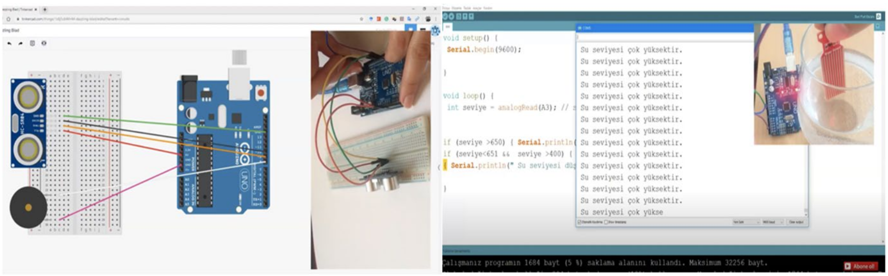

Fig. 2 Sample images from the educational videos

as extreme values were removed from the data set. As a result, the data set decreased to 48 from 54. In order to test the normality assumption, ER posttest achievement scores and kurtosis and skewness coefficients of the independent variables were analyzed. The analyses showed that kurtosis and skewness coefficients had a value between + 2 and -2 (Fields, 2009) in bivariate normality distributions, which means that the normality assumption was met.

Another test used for data analysis was the paired samples t-test. In order to determine the normality of the pretest and posttest scores of the variables subject to paired samples t-test, namely success scores, cognitive skills, autonomous skills, innovation skills, cooperation and flexibility skills, kurtosis and skewness coefficients of the scores were studied. It was established that the kurtosis and skewness scores of the pretest and posttest scores of the variables had a value between + 2 and -2 and that it was normally distributed (Field, 2009).

Qualitative data were referred to express and support the data obtained from regression analysis. Qualitative data were subject to content analysis and only coded at the first cycle. In vivo and values coding were utilized at the first cycle coding so that categories could be presented (Saldana, 2009). While in vivo coding defines the wording or phrases directly taken from the participants' expressions, values coding involves coding of the values, attitudes, and beliefs of the participants (Miles et al., 2014). The problem of subjectivity encountered very frequently in qualitative analysis (Arastaman et al., 2018) was tried to be overcome by conducting various reliability and validity tests. For instance, contextual factors related to independent variables were clearly explained to provide transmissibility (Lincoln & Guba, 1986), and themes obtained from qualitative data were reported by being matched with these contextual factors. Participant expressions used as a base in the interpretation of these themes were given in detail and with direct quotes in the results section and evidence was provided for reflectivity and credibility (Lincoln & Guba, 1986). During the coding phase, coherency between the coders (Miles and Huberman, 1994) was tested by comparing the codes obtained by two experts. The findings obtained were discussed in light of the literature, and it was identified that findings high in credibility were found when compared to the literature (Eisenhart & Howe, 1992).

4 Results

4.1 Is there a significant difference between the pretest and post-test scores of ER achievement, cognitive, autonomous, innovation, and cooperation and flexibility skills of the students?

When Table 1 is examined, it is seen that there is a significant difference between the participants' achievement test total score before and after ER ($t(47) = 11.231$, $p < 0.05$). When the averages of the pretest and posttest scores were compared, it was established that students' achievement posttest scores ($X_{success} = 67.313$) were higher than the pretest scores ($X_{success} = 24.333$).

Table 1 Dependent samples t-test results

Variable	Test	n	X	S	sd	t	p
Achievement Test	Pre-test	48	24,33	10,82	47	11,23	.000
	Post-test	48	67,31	23			
Cognitive Skills	Pre-test	48	64,45	6,03	47	6,47	,000
	Post-test	48	68,60	6,10			
Autonomous Skills	Pre-test	48	18,97	2,73	47	2,84	,006
	Post-test	48	20,18	2,63			
Cooperation and Flexibility Skills	Pre-test	48	17,83	3,32	47	2,86	.006
	Post-test	48	19,33	2,89			
Innovation Skills	Pre-test	48	6,87	1,31	47	2,27	,028
	Post-test	48	7,41	1,36			

Based on this data, it can be said that the success of the students increased after ER course. When the other variables were investigated, it was observed that there was a significant difference between the pretest scores of cognitive skills ($t(47) = 6.471$, $p < 0.05$), autonomous skills ($t(47) = 2.848$, $p < 0.05$), cooperation and flexibility skills ($t(47) = 2.861$, $p < 0.05$) and innovation skills ($t(47) = 2.274$, $p < 0.05$) of the participants. When the averages of the pretest and post-test scores were compared, it was specified that post-test scores of cognitive skills, autonomous skills, cooperation and flexibility skills, and flexibility skills were higher than their pretest scores.

4.2 Are cognitive, autonomous, innovation, cooperation, and flexibility skills individually significant predictors of the students' ER achievements?

Regression analysis was carried out to test the relation between ER achievements of the students and their cooperation and flexibility, autonomous, cognitive, and innovation skills. ANOVA values were studied to assess if the regression model of the variables related to the variance explained was statistically

Table 2 Simple linear regression analysis results

Variable	B	Standard Error	t	P	R	R^2
Constant	-46,05	34,413	-1,34	,087	,438	,192
Cognitive Skills	1,65	,500	3,31	,002		
Constant	8,46	24,66	0,343	,733	,334	,112
Autonomous Skills	2,92	1,21	2,407	,020		
Constant	-12,04	20,14	0,598	,003	,506	,256
Cooperation and Flexibility Skills	4,09	1.03	3,982	< .001		
Constant	43,05	18,37	2,34	,023	,194	,0377
Innovation Skills	3,27	2,44	1,34	,186		

significant prior to the commencement of the regression analysis. According to the test results, the predictive power of cognitive (p = 0.002), autonomous (p = 0.025), cooperation and flexibility (p = 0.013), and innovation skills (p = 0.41) on ER achievement was significant. Table 2 presents the results of simple linear regression analysis performed to determine the contribution of independent variables to the regression equation of success.

Table 2 shows that cognitive ($R = 0.438$, $R^2 = 0.192$, $F_{(1,46)}) = 10{,}9$, $p < 0.05$), autonomous ($R = 0.334$, $R^2 = 0.112$, $F_{(1,46)}) = 5{,}79$, $p < 0.05$) and cooperation and flexibility ($R = 0.506$, $R^2 = 0.256$, $F_{(1,46)}) = 15{,}9$, $p < 0.05$) skills are significant predictors of ER achievement. When variances explanatory of ER achievement of these skills are compared, cooperation and flexibility, cognitive and autonomous skills were separately found to be explanatory at a rate of 25%, 19% and 11%, respectively. Innovation skill was not found to have a statistically significant contribution to the model ($p > 0.05$).

When interviews with the participants were examined, it was established that some data supported the results of the regression analysis, but some did not. While the relation between one independent variable and achievement could be directly understood from some statements of the participants, some statements refer to more than one independent variable crosswise. For instance, it is seen that the relationship between cognitive skills and ER achievement is directly expressed in the statement of Participants 3 and 5 put forth as "*ER courses have improved my cognitive skills…*" Nonetheless, while Participant 12 expresses this relation as "*I have improved myself in coding and had the experience of making easy and cheap technological tools in my own house*", Participant 14 is seen to have focused on cognitive skills with this statement: *"It helped me understand the operating logic of machines."* It is also observed that some participants commented on the relation between ER and cognitive skills focusing on course outcomes. For instance;

> *Participant 18: Coding and electronics knowledge*
> *Participant 19: I have become familiar with computer codes. I have learnt vehicle parking sensor codes and designing it. I have learnt coding applications and sensors (distance, and* etc.*). I have acquired the knowledge I need to design a code.*
> *Participant 24: It has enhanced my knowledge on computers, and I have learnt robotics coding language.*
> *Participant 25: I have gained the skill of making a basic robot in robotics coding course.*

There are some statements of the participants referring to the relation between cooperation and flexibility skills and ER success. For instance, Participant 14 is observed to emphasize on the cooperation variable with this summary of ER process as "*I have had the chance to help more people by posting my studies on Youtube*". Moreover, Participant 17 directly refers to cooperation by this statement: *"group work has led me to express myself better."*

Participant 6 refers to autonomous skills with the following statement: *"It increased the things I tried to do, and I could do."* Furthermore, Participant 11 is seen to have referred to autonomous skills with this statement: *“I have had the opportunity to utilize my own work in simple systems that I will design in the upcoming days.”* Participant 7 expresses the relation between autonomous skills and ER as such: *“We have learnt to create tangible products on our own with today’s technology.”*

In addition, it was determined by qualitative data analysis that some statements of the participants referred to more than one independent variable. For instance, the statement of Participant 11 put forth as “*we have gained the skills to quickly solve problems that occur in our daily lives and to code in smart qualities to tools that make our lives easier”* implies that the students’ innovation, cognitive and autonomous skills have improved. A similar cross expression is found in the statement of Participant 24: “*It has been a fruitful guide on new ideas and inventions.”* Participant 24, with this statement, emphasizes that both innovation and cognitive skills have improved. The statement of Participant 2 put forth as “*I make my work easier for myself by coding the objects I use daily at home and save time and energy”* refers to the improvement of cognitive and autonomous skills with the help of ER applications. While autonomous skills are referred to in the statements of Participant 15 used in the same sentence as “*it has made me question what else I could do” and “it provided for ideas to become more systematic”,* the rest of the sentence emphasizes that innovation skills have also improved: “*it opened up our horizon by enabling us to find ways to make our job easier in daily life and even by making us create projects.”*

5 Discussion and conclusion

The results show that the increase in the ER achievement scores of the students is significant and that a positive improvement is observed in the cognitive, autonomous, innovation, cooperation and flexibility skills. It was determined for twenty-first century skills that while cognitive, autonomous, cooperation and flexibility skills were significant predictors of robotics achievement, innovation skills were not. Of the total variance related to robotics success, 25% is explained by cooperation and flexibility, 19% by cognitive and 11% by autonomous skills. These results demonstrate that the contribution of the ER education program to twenty-first century skills is positive. The results are supportive of studies that have previously reported positive contributions of ER to students’ twenty-first century skills (Agapito, 2021; Negrini & Giang, 2019).

One of the twenty-first century skills investigated in the research is cognitive skills. At the end of the 14-week, 4-h weekly ER program, the students’ cognitive skills were significantly improved. Atmatzidou and Demetriadis (2016) have carried out an 11-week, 2-h weekly ER program for students aged between 15 and 18 years and concluded that students’ information-processing thinking skills were improved. Other studies in the literature similarly report that ER, in different grades, is effective in improving cognitive skills such as problem-solving, thinking strategies, and learning new concepts (Afari & Khine, 2017;

Çakir et al., 2021). In qualitative findings, students' statements such as "I have understood how machines work", "I have gained the ability to design a basic robot", and "I have developed coding skills" are suggestive of the fact that cognitive skills improved and support the literature.

Findings demonstrate that students' autonomous skills have significantly improved. One of the factors bringing out this condition is the learning environment. According to Deci et al. (1981), environments stimulating learner autonomy increase students' intrinsic motivations and self-esteem. The fact that students start the ER program with easy activities and have the opportunity of learning through experience thanks to the chance to work individually increases students' motivation and self-esteem. This change is reflected in a student's statement: "it increased the things I tried to do, and I could do". It can be said that the stimulating effect of increased self-confidence and intrinsic motivation and learning environment on autonomy enables autonomous skills to improve.

Another skill investigated within the scope of twenty-first century skills is innovation. The results of the study reveal a significant increase in the innovation skills of the students. A reason for this can be the fact that the students did not have any prior experience with ER. According to Rogers (2003), first-time experiences can be evaluated as innovations. Qualitative findings also suggest that the students widened their perspectives through ER and could produce projects that would ease daily life. Similarly, Badeleh (2021) addresses innovation as a dimension of creativity and states that robotics training improves the innovation skills in students.

The last skill investigated in the research is cooperation and flexibility. According to Hwang and Wu (2014), it is vital for teachers to create a cooperation-oriented learning environment and support these environments by different activities and resources. During the execution phase, students have participated in different activities carried out each week and found the opportunity to reinforce what they have learned in the classroom. According to Latip et al. (2020), ER gives the opportunity of a hands-on activity and contributes to the improvement of cooperation skills. The classroom design and its dynamic and flexible structure in the relevant research can be considered to have improved the students' cooperation and flexibility skills, which is also seen in qualitative findings. A student airing a video on YouTube is an example of expanding the learning environment. The student also pointed out that he/she also had the chance to help many more people by doing so.

The research also determined that cognitive, autonomous cooperation and flexibility skills significantly predict the students' robotics success. This result hazards important opinions about the design of robotics teaching programs. As emphasized in the literature, learning environments based on cooperation are recommended for the efficiency of ER teaching (Schina et al., 2021). Nevertheless, the students should also be encouraged to work on their own or in groups, whichever they prefer (Bredenfeld & Leimbach, 2010). This condition is associated with the flexible structure the learning environments possess. It is also vital for students to access ER sets in their own time and expand their learning process by trial and error. Cognitive skills explain 19% of ER successes. In the literature, it has been reported that ER is helpful in improving students' comprehension of concepts like coding and sensor and in increasing their skills like problem-solving and information-processing thinking (Xia & Zhong, 2018). It can be put forth that designs that plan cognitive skills meticulously are needed in teaching programs. Tasks in ER education should be designed from easy to difficult and from structured to flexible tasks. Taking notice of cognitive skills is also related to the improvement in autonomous skills. In his study, Orhan Göksün (2016) demonstrates that autonomous skills are associated with cognitive skills. Therefore, it is important to give students a chance to carry out activities requiring cooperation in the learning environments and also to plan activities oriented at their individual learning process and assign structured tasks and ambiguous tasks that would enable them to realize their own projects (Jordan & McDaniel, 2014). Another result of the research is that innovation skills are not significant predictors of robotics success. Although a significant improvement was seen in the innovation skills of the students, the fact that it is not a significant predictor of ER achievement is a remarkable finding. This may have been caused due to the fact that the students were given structured tasks during the 14-week ER teaching program. Another reason could be the duration of the educational program. A 56-h program is considered a long period of time when compared to the other studies on ER education in the literature (Schina et al., 2021). Another reason could be the fact that the students got used to ER applications at the end of this process.

6 Implications

In the following section, we explore the implications of our research findings concerning the implementation and advancement of ER courses. The outcomes of our investigation not only illuminate the efficacy of ER courses in augmenting students' skills and accomplishments, but also offer critical insights for educators, policymakers, and stakeholders. By evaluating the implications derived from our study's results, we endeavor to contribute to the ongoing initiatives aimed at enhancing educational quality and adequately preparing students for the demands of the twenty-first century.

6.1 Program implications

- The results of our study emphasize the potential of ER courses to enhance students' skills and achievements in STEM fields. Consequently, educational policymakers should contemplate the integration of ER courses into the national curriculum. Such integration may contribute to the improvement of education quality, fostering a culture of innovation, and preparing students to face the challenges of the twenty-first century effectively.

- The significant improvements in students' achievement scores and skills following the ER course indicate that such courses can be highly effective when properly designed. Curriculum designers should consider integrating interdisciplinary approaches and real-world problem-solving activities that target the development of cognitive, autonomous, cooperation, and flexibility skills, as these have been identified as significant predictors of ER achievement. To optimize the effectiveness of ER courses, we propose the following strategies: Design ER tasks that foster collaboration, necessitate adaptability, and cultivate students' autonomous learning skills. Additionally, structure these tasks and activities with a progression from simple to complex, facilitating gradual skill development in an academically rigorous manner.
- In addition to structured tasks aimed at enhancing innovation skills, it is advisable to incorporate open-ended assignments that promote independent project development among students. For example, by tasking students with the creation of an intelligent traffic management system capable of optimizing urban traffic flow using real-time data from cameras, sensors, and other sources, students will be required to contemplate various factors, such as traffic patterns, road conditions, and public transportation schedules, during the design process.

6.2 Research implications

- Future research may explore the effectiveness of varying ER course designs or instructional strategies in fostering cognitive, autonomous, innovation, cooperation, and flexibility skills. Such investigations can contribute to a better understanding of best practices for implementing ER courses in diverse educational settings.
- Researchers could investigate the long-term effects of ER courses on students' skill development, academic performance, and professional success. Longitudinal studies may help ascertain the enduring impact of these courses, informing the development of sustainable educational programs.
- Scholars can assess the potential benefits of incorporating ER concepts into the teaching of other subject areas, such as mathematics, science, or language arts. This interdisciplinary approach may provide novel insights into the role of ER in promoting comprehensive skill development and enhancing learning outcomes.
- Further research should explore the myriad factors affecting students' ER achievement, including individual differences, motivation, or instructional methods. A deeper understanding of these factors may enable educators and researchers to devise tailored interventions that optimize the impact of ER courses on student learning.

Annex 1

Table 3 ER Program with Arduino

WEEK	Learning Outcome	Activity	Qualifications	Descriptions	Assessment And Evaluation
1.WEEK	• Explain the types and usage areas of Arduino and different microprocessors • It establishes a connection between the electronic devices in daily life and Arduino • Examines the Arduino set • Explains the purpose of the sensors • Gives examples of the equivalents of sensors in daily life	-Who is who? (Meet Event) -Find the equivalent in daily life (Finding examples of Arduino circuits in daily life)	To be able to explain the technical structure of Arduino, to recognize other circuit elements, to define the functions of sensors, to recognize and associate circuits in daily life	A meeting with the group is carried out. Arduino and kits are mentioned, and their functions are explained. Sensors are explained and group work is carried out for examples from daily life	The online competition prepared in electronic environment (KAHOOT) is played
2. WEEK	• Tests the connection between the software and Arduino • Extracts error messages • Identifies, finds, and loads ready-made libraries • Explains the input units and their functions • Explains output units and functions • Calculates any resistance you have • Draws sample circuit diagrams • Calculates the current flowing through the circuit • Selects the resistor that should be added to the circuit	Circuit drawing activity	Installing Arduino's software, connecting, adding libraries, drawing circuits and calculating the necessary resistances for the circuit	Arduino IDE program is installed and port and COM values are explained for connection. It shows how to find ready-made libraries. Input and output units and their functions are explained and a short game is played for repetition. How to draw a circuit diagram via Tinkercad – curcuit, how to calculate the current is explained. Different resistors are brought to the classroom and the resistor calculation activity is performed	A midterm exam including Arduino and electrical information is given.

Table 3 (continued)

WEEK	Learning Outcome	Activity	Qualifications	Descriptions	Assessment And Evaluation
3. WEEK	• Draws the circuit diagram of turning on the LED light • Calculates the current flowing through the circuit • Selects the appropriate resistance for the circuit • Set up the circuit on the breadboard using Arduino • Knows and edits Digital write(), Digital read(), Pinmode() and Delay() commands	LED flashing, Code the traffic light	Sets up the circuit diagram, codes using the Arduino IDE, understands the circuit of examples in daily life and realizes simple examples	The lesson starts with the LED turning on activity. The commands required to light the LED are explained and examples are printed. The circuit diagram is drawn and the circuit is set up on the breadboard. Coding is provided with the Arduino IDE The working principle of traffic lights, which is one of the examples in daily life, is discussed. A miniature circuit of the traffic light is built and coded with the help of Arduino	They are asked to set up a strobe circuit using Arduino and code it at 0.5 s intervals
4. WEEK	• Writes the commands that enable to light the Led via Arduino IDE • Discusses the working principle of traffic lights • Set up the traffic light circuit using Arduino • Codes the traffic light circuit via Arduino IDE				
5. WEEK	• Recognizes the potentiometer • Defines its function • Draws the potentiometer circuit diagram • Gives examples from daily life • Explains the difference between analog and digital • Knows AnalogRead() and AnalogWrite() commands • Explains the differences of the variables • Defines variables • Codes the potentiometer • Combines potentiometer and LED circuit • Installs a smart lamp system • Codes the smart lamp system	Creating a smart lamp system	It can use and code potentiometer in its circuits, it can make analog circuit and coding, combine it into two different circuits, define variables	The lesson starts with potentiometer examples and trainees define potentiometer based on these examples. Analog pins and commands are explained. What the variable is, how to define it and variable types are transferred. The potentiometer circuit is drawn and coded. By combining the potentiometer and the LED circuit, the smart lamp system is developed and coded	They are asked to produce a guessing game using a potentiometer. The resulting game is evaluated

Table 3 (continued)

WEEK	Learning Outcome	Activity	Qualifications	Descriptions	Assessment And Evaluation
6. WEEK	• Recognizes Buzzer • Defines its function • Draws the circuit diagram of the buzzer • Gives examples from daily life • Uses Tone() and noTone() commands • Performs logical operations using the if-else loop • Sets up note values and note library • Sets up and codes the buzzer circuit • Makes fruit piano with fruits from Arduino	I'm making a piano out of fruit	He can use and code the buzzer in his circuits, produce different tones, understand the audio circuits in daily life	The lesson starts with buzzer examples. The buzzer diagram is drawn. The tone() and noTone() commands are explained. The if-else loop is explained through different examples. The numbers and libraries to which the note values correspond are s hown. An example of an instrument played by touching the fruit is made and coded	They are asked to set up and code the circuit that produces different sounds from the potentiometer and the buzzer
7. WEEK	• Recognizes HCSR 04- Ultrasonic distance sensor • Defines its function • Explains the working principle • Defines the functions of trig and echo pins • Defines the function of the serial monitor • Uses Serial.begin() and Serial.print/ln() commands • Draws the circuit of the ultrasonic distance sensor and installs it on the arduino • Encodes the sensor via the Arduino IDE • Prints the distance to the screen • Develops and codes parking sensor circuit	I am making parking sensors	It can use and encode the distance sensor. Can establish integrated circuit systems by combining them with different circuits	HCSR 04- Ultrasonic distance sensor is introduced, its functions in daily life are discussed. A video showing the usage logic is watched. Monitoring, the importance of reading, and special codes for the distance sensor are explained. Distance measuring samples are made. Parking sensor is coded by establishing a common circuit with the buzzer	Height measuring meter is applied

Table 3 (continued)

WEEK	Learning Outcome	Activity	Qualifications	Descriptions	Assessment And Evaluation
8. WEEK	• Q2 recognizes the gas sensor • Defines its function • Explains the working principle • Examines different gas sensors • Draws the circuit of the Q2 gas sensor and sets it up on the Arduino • Encodes the sensor via the Arduino IDE • Prints values to the screen • Develops and codes smart gas measuring device.	Intelligent gas meter	It can use and encode the gas sensor. Can establish integrated circuit systems by combining them with different circuits	The gas sensor is introduced, its functions in daily life are discussed. A video showing the usage logic is watched. The codes specific to the gas sensor are explained. Distance measuring samples are made. Smart gas measuring devices are examined. A similar circuit is built and coded with Arduino	The early warning system is made by adding a buzzer and LED to the circuit
9. WEEK	• Recognizes LDR- Photoresistance sensor • Defines its function • Explains the working principle • It installs on Arduino • Encodes the sensor via the Arduino IDE • Prints values to the screen • Develops and codes smart lamp that goes out in daylight	Smart lamp that turns off in daylight	It can use and encode the LDR- sensor. Can establish integrated circuit systems by combining them with different circuits	The LDR sensor is introduced, its functions in daily life are discussed. Values in daylight and darkness are taken from the LDR and printed on the screen. Automatic street lamps are examined according to daylight. A similar circuit is built and coded with Arduino	A midterm exam including Arduino structure and programming languages was given
10. WEEK	• Gear recognizes the motor • Defines its function • Explains the working principle • Mounts on Car Chassis • Knows the functions of the integrated • Explains the function of L293D IC • It sets up the circuit of the L293D motor drive IC • It establishes the connection between the integrated and the motors • It moves the car chassis forward, backward, right and left	I'm building my first car	It can set up the circuit of the motor drivers, move the motor, code the integrated and inter-motor connectors	Daily life examples of gear motors to be used for the wheels of the car are discussed. Engines are mounted on the chassis. The function of the IC required for the movement of the motors is explained and the connection diagram of the L293D IC and its connection with the motors is made. The engine is moved forward and backward by adding codes	A task book is prepared for moving the car to different positions. Participants perform these tasks

Table 3 (continued)

WEEK	Learning Outcome	Activity	Qualifications	Descriptions	Assessment And Evaluation
11. WEEK	• It establishes the connection circuit between the motor and the distance sensor • Codes a robot that moves when it sees the obstacle • Designs the robot that does not crash into obstacles • Codes the robot that does not crash into obstacles	Obstacle avoiding car	It can provide control of motor drivers with sensors	The working principle and codes of the distance sensor are reminded. With the distance sensor, conditional statements (if-else) are established for the method of the motors. The moving car when it sees the obstacle is coded. Then, a car that moves without hitting obstacles is designed and coded	The car that avoids the obstacle is built and it is checked whether it works smoothly
12. WEEK	• Bluetooth – recognizes the HC05 communication card • Defines its function • Explains the working principle • Draws the connection diagram with Arduino • It establishes the connection circuit • Uses SoftwareSerial() and available() commands • Creates the remote-controlled lamp burning circuit	Lamp control with remote control	Can understand the logic of wireless communication. It can provide wireless communication between Arduino and sensors	The working principle and codes of HC-05 are explained. The connection diagram is established. Led is added to the circuit for an integrated system. By providing a remote connection, the LED is blinked	They are asked to perform the sound on and off application via Bluetooth
13. WEEK	• Recognizes the relay • Defines its function • Explains the working principle • Examines different types of relays • Draws the relay circuit and sets it up on Arduino • Arduino encodes the board via the IDE • Prints values to the screen • Sets up a smart coffee machine system	Intelligent coffee machine system	Can use relay and encode. Can establish integrated circuit systems by combining them with different circuits	The relay is introduced, and discussions are held on its functions in daily life. Application examples of how to make electronic devices smart with a relay are shown. The smart coffee machine system is inspected. A similar circuit is built and coded with Arduino	They are asked to develop a smart coffee machine system. An end-of-course assessment exam is conducted
14. WEEK	PROJECT STUDIES				

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