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Meryem Meral
Erzincan Binali Yildirim University, Turkiye

Sema Altun Yalçın
Erzincan Binali Yildirim University, Turkiye

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Meryem Meral, Sema Altun Yalçın

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Abstract

The purpose of this study was to evaluate how educational robotics applications integrated with collaborative learning and entrepreneurship affected the innovative thinking skills of middle school students. An explanatory-sequential mixed-method design was adopted for the study. The study involved 40 seventh graders studying at a small-sized middle school. The quantitative dimension of the study employed a single-group pretest-posttest design, while the qualitative dimension was conducted through semi-structured interviews. The "Innovative Thinking Skills Scale" was administered to the students in the study both before and after eight weeks of robotics training. The data obtained from the scales were analyzed using statistical methods. As a result of this analysis, it was concluded that the innovative thinking skills of the students increased significantly at a statistical level. Analysis of the interviews held with students after they underwent robotics training indicated a marked advancement in their innovative thinking skills.

Introduction

As a result of technology causing radical changes in all aspects of our lives and affecting every domain, the integration of technology has manifested itself in various fields, including education (Davies and West, 2014). Integrating technology into education involves utilizing a range of approaches, frameworks, and resources (Georgina and Olson, 2008). Educational robotics applications stand out as a method for incorporating technology into education. The field of educational robotics has its roots dating back to the 1960s and 1970s. During this period, the role of robotics in education began to emerge through the use of the Logo programming language for education aimed at young students. This educational approach laid the foundations of what is now known as "Educational Robotics" and has become an important component of school curricula worldwide (Patino-Escarcina et al., 2021). In recent years, robotics, which has been increasingly emphasized in the field of pedagogy, encompasses the design of programmable and controllable robots and the use of sensors, motors, etc. (Rogers et al., 2010). Educational robotics, in this context, is a branch of robotics that encompasses applications where robotics is integrated into the teaching and learning process in line with pedagogical objectives (Mikropoulos and Bellou, 2013). In this regard, numerous educational robotics kits, software, and programming platforms are utilized for pedagogical purposes (Mubin et al., 2013).

Educational robotics aims to enhance skills in STEM fields (Eguchi and Uribe, 2017), foster 21st-century skills such as critical thinking, creativity, innovation, and problem-solving (Aris and Orcos, 2019; Adams et al., 2010), promote the development of leadership, teamwork, and social skills (Ioannou and Makridou, 2018), and support individuals' self-confidence and motivation (Piedade et al., 2020). Many educational robotics applications aligned with these goals have been found to support students' cognitive skills such as problem-solving (Gratani et al., 2021), creativity (Eteokleous et al., 2018; Gubenko et al., 2021; Zhang and Zhu, 2022), critical thinking (Ioannou and Makridou, 2018), and computational thinking (Valls Pou et al., 2022). It has been observed that students find educational robotics applications enjoyable, leading to increased attitudes and motivation towards learning and technology use (Aris and Orcos, 2019; Chin, 2014; Kahndlhofer and Steinbauer, 2016). Additionally, it has been revealed that educational robotics applications contribute to increasing students' self-confidence and self-efficacy (Piedade et al., 2020). Considering the multitude of beneficial outcomes linked with educational robotics, proposals have been made for its deeper integration into educational practices, the development of tailored curricula for this domain, and the widespread adoption of educational robotics instruction in schools, advocating for the introduction of educational robots to children from an early age (Yang et al., 2020; Papadakis et al., 2021; Rani et al., 2023).

Problem Statement

According to Altin and Pedaste (2013), a wide range of methodologies were employed in integrating educational robotics into educational environments. Among the methodologies highlighted, including constructivist learning, project-based learning, problem-solving-based learning, scenario-based learning, and competition-based approaches (Altin and Pedaste, 2013; Sartatzemi et al., 2005; Karahoca et al., 2011; Stein, 2004), "collaborative learning" emerges as a notable preference in the incorporation of educational robotics into pedagogical frameworks (Denis and Hubert, 2001). The most distinguishing feature of this approach is the use of educational robotics as a tool for the development of students' teamwork and collaboration skills (Demetroulis et al., 2023). In other words, students have the opportunity to develop group work, collaboration, and social skills with educational robotic tools. Another important aspect of this approach is the presence of leadership within the group and the determination of task distributions (Altin and Pedaste, 2013). As a result, students gain a sense of responsibility. Studies have indicated that the collaborative learning approach in educational robotics can have an impact not only on students' social skills but also on their entrepreneurial skills (Martins et al., 2016; Kirch et al., 2019; Johansen and Schanke, 2013).

This is attributable to the inclusion of leadership, social skills, teamwork, and innovation perception among the constituent sub-dimensions of entrepreneurial skills (Meral and Altun-Yalçın, 2022). Innovative thinking stands out as a pivotal facet within the spectrum of entrepreneurial competencies (Meral and Altun-Yalçın, 2022). Innovative thinking emerges as a cornerstone of entrepreneurial skills (Meral and Altun-Yalçın, 2022), as entrepreneurial individuals exhibit a propensity to conceive novel ideas and swiftly adjust to changing environments (Haynie and Shepherd, 2009). Consequently, a robust correlation exists between entrepreneurial capabilities and the aptitude for innovative thinking (Edwards-Schachter et al., 2015).

Innovative thinking has been defined by Rogers (2003) as "the individual's transformation of new knowledge or ideas into a product." Barak (2013), on the other hand, defines innovative thinking as "a cognitive process that paves the way for the implementation of new or significantly enhanced ideas." Building upon these definitions, innovative thinking can be described as "the process of presenting creative and original ideas, leading to problem-solving or gaining different perspectives on existing situations" (Morad et al., 2021). Individuals with innovative thinking skills learn to find creative solutions to problems, adapt more easily to changes, take risks in their work and career lives, and develop their own potential (Yudha et al., 2018). Innovative thinking holds a significant place among 21st-century skills due to its strengthening of collaboration and communication, contribution to technological competitiveness, significant role in problem-solving in both work and personal life, and promotion of entrepreneurship and globalization (Gut, 2011). Therefore, the development of individuals' inclination towards innovation is important.

Studies have provided evidence for the effectiveness of educational robotics applications in the development of innovative thinking skills (Eguchi, 2016; Eguchi, 2017; Gubenko et al., 2021). However, these studies have not directly conducted experimental research on the development of innovative thinking skills, focusing instead on skills related to creativity and computational thinking that may be associated with innovative thinking. Additionally, in these studies, constructivist learning, scenario-based learning, and project-based learning approaches have generally been preferred over collaborative learning approaches that directly address entrepreneurship, which is closely linked to innovative thinking. Therefore, there is a perceived need for research focusing on educational robotics applications based on collaborative learning approaches that directly address entrepreneurship, as well as for a more comprehensive investigation of innovative thinking skills using mixed methods. Moreover, Yudha et al. (2018) emphasized the importance of collaborative work in the development of students' innovative thinking skills, highlighting the significance of sharing new arguments among all individuals within a group. Furthermore, Siddique et al. (2010) demonstrated that collaborative work and cooperation facilitate students in finding innovative solutions. Based on these study findings, it can be argued that the role of the collaborative learning approach in innovative thinking is significant.

Furthermore, systematic reviews in the field of educational robotics indicate that Lego Mindstorms, Arduino, BeeBot, Python, and Scratch platforms are commonly used in many relevant studies (Çetin and Demircan, 2020; Souza et al., 2018). Despite the preference for these platforms and sets, the existence of alternative sets and software has been noted as a limitation due to their insufficient representation in research. Therefore, it is believed that the selection of the Fischer Technik set and RoboPro software, which are not commonly featured in research, will contribute to the field. The present study aims to determine whether and to what extent a robotics coding education approach based on entrepreneurship and collaboration impacts middle school students' innovative thinking skills. As such, the research seeks to investigate the effects of collaboration-based and entrepreneurship-supported educational robotics applications on middle school students' innovative thinking skills, addressing the following questions:

1. Do entrepreneurship-supported educational robotics applications have a significant impact on middle school students' innovative thinking skills?
2. Do entrepreneurship-supported educational robotics applications have a significant impact on the sub-

dimensions of innovative thinking skills among middle school students?

Method

Research Design

In this study, researchers opted for an explanatory mixed-method approach, which involves collecting primarily quantitative data followed by qualitative data to provide further insights into the quantitative findings (Tashakkori and Creswell, 2007; Bowen et al., 2017). The rationale behind opting for the explanatory mixed method in this study is to probe into the research inquiries comprehensively and augment the dataset, thus enhancing the study's credibility (Creswell, 2003; Ivankova et al., 2006). During the quantitative phase, the researchers employed the single-group pretest-posttest model, which is one of the experimental designs utilized. In this model, a solitary group is exposed to an independent variable, and measurements are taken before and after the application (Marsden and Torgerson, 2012). The impact of the independent variable in this model is evaluated by analyzing the difference between the pretest and posttest (Meyer et al., 2019). Subsequently, in the qualitative phase, researchers conducted a semi-structured interview featuring open-ended questions crafted by the research team. These interviews served as a means to capture participants' perspectives on the observed situations or events (Patton, 2014).

Participants

The universe of the study consists of middle school students, and the sample comprises 40 7th-grade students studying at a small-sized middle school affiliated with the Erzincan Provincial Directorate of National Education. In the research, a non-probabilistic sampling method was chosen, specifically the convenience sampling method. The convenience sampling method is preferred for practical reasons, such as ease of access and geographic proximity (Etikan et al., 2016).

Table 1. The Demographic Characteristics of the Sample

		N	Grade
Experimental group	Pre-test	40	7th grade
	Post-test	40	7th grade

Implementation Process

The "Innovative Thinking Scale" was administered to the experimental group before the experimental intervention. Subsequently, collaborative and entrepreneurship-based robotics coding education was provided to the students for 8 weeks, with 4 hours per week. Following this education, the "Innovative Thinking Scale" was administered again to the entire experimental group. Then, semi-structured interviews were conducted with 14 students to reveal perceptions regarding innovative thinking skills. A thorough description of the experimental intervention process is presented below.

The Process of Experimental Intervention

The educational program focused on entrepreneurship and collaborative learning in robotics coding, spanning 8 weeks with weekly sessions lasting 4 hours each, and students grouped into teams of five. In the initial week, students were introduced to the "Fischer Technik" Lego set and its software interface, "Robo Pro." Activities were structured to target specific aspects of the Engineering Design Process (EDP) and entrepreneurial skills. These activities included creating various robotic systems such as traffic lights, merry-go-rounds, automatic doors, barrier gates, refrigerators, washing machines, sensor-operated hand dryers, and sensor-operated stair lighting. The design of these activities was informed by frameworks such as E-STEM (Entrepreneurship-based STEM Application Steps) by Meral and Altun Yalçın (2022), G-FeTeMM (Entrepreneurial STEM Project Development Process) by Deveci (2019), and entrepreneurship sub-dimensions outlined in Özcan's study (2019). Furthermore, the integration of educational robotics followed a collaborative learning approach as proposed by Altin and Pedaste (2013). This approach emphasizes teamwork among students to achieve shared objectives, alongside task delegation within the group and the cultivation of dynamic and strategic skills (Demetroulis, et al., 2023). Furthermore, the distribution of tasks within the group and the development of dynamic and strategic skills are inherent characteristics of this approach (Altin and Pedaste, 2013). In line with this, the implementation stages of the designed activities are provided below:

- Presenting the "Fischer Technik" Lego set and the "Robo Pro" software to students
- Organizing teams with rotating leadership roles weekly
- Introducing a general problem scenario for students to explore
- Creating prototypes based on the given problem scenario by each student
- Building the selected prototype model using Lego pieces
- Programming the necessary code
- Delivering presentations to exhibit the original designs

As the group leader, each student in the cohort distributed tasks and outlined each person's responsibilities every week. Further, each group leader assigned a distinct problem scenario to students participating in the activity, requiring them to write codes to match each scenario. Observing expert provided problem scenarios to group leaders, who avoided direct intervention but offered advice when needed. Every group shared original Lego designs with the entire class at the end of the 8-week period, fostering collaboration and knowledge sharing in the process.

The linkage between the phases of the robotics education and the subdimensions of entrepreneurship:
Self-confidence: Students alternated in writing diverse codes for various problem scenarios, each fulfilling responsibilities designated by the group leader. They endeavored to independently resolve encountered issues, with observations indicating that their efforts and perseverance in problem-solving improved their self-confidence (Fitriani et al., 2020).

Perception of innovation and creativity: The students generated a variety of problem scenarios and crafted diverse codes to overcome these challenges. During model construction, they tackled deficiencies and technical hurdles.

Furthermore, in the final stage, they devised unique designs. Barak and Goffer (2002) assert that proficiency in original design and problem-solving not only augments innovation and creativity but also elevates their perceptions of these skills.

Social skills and teamwork: Over the course of eight weeks, students engaged in collaborative group work, fostering cooperation and mutual support. Throughout the process, they worked to cultivate a positive team spirit and develop strategies for reaching shared goals.

Leadership and the tendency to stand out: For every activity, a designated student took on the leadership position. These leaders delegated tasks to their peers and facilitated the distribution of responsibilities across the entire group. Collaborating with fellow group members, they collectively formulated the overarching plan for the work process. Leaders were responsible for managing time, overseeing model construction, and composing various codes.

Risk-taking: Students were encouraged to freely express their ideas within the group, despite objections from their peers. They were encouraged not to fear making mistakes. Consequently, students were motivated to experiment with their solutions, even if they didn't immediately yield the desired outcome or solve the problem. The implementation process of the research is outlined in Figure 1.

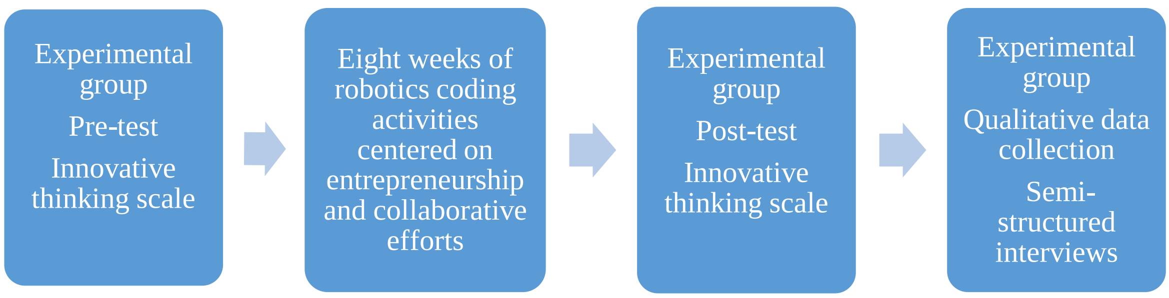

Fig-1. The Phases of the Implementation Process

Data Collection Tools

The study utilized the "Innovative Thinking Scale for Middle School Students" developed by Deveci and Kavak in 2020 to evaluate the innovative thinking skills of the students. This scale comprises five subdimensions: innovative self-efficacy, openness to innovation, innovative problem-solving, innovative perseverance, and innovative group leadership. The reliability of the scale was evaluated using Cronbach's alpha coefficient, which yielded a value of 0.91. The scale used for measuring innovative thinking skills consists of 25 items scored on a range of 1-5, where 1 being the lowest and 5 being the highest. The scale is based on a 5-point Likert-type, with responses ranging from "Strongly Disagree" to "Strongly Agree". The higher the score obtained from the scale, the higher the level of innovative thinking skills demonstrated. The Cronbach's alpha values for the sub-dimensions of the scale are as follows: innovative self-efficacy (0.81), openness to innovation (0.82), innovative problem-solving (0.76), innovative perseverance (0.70), and innovative group leadership (0.62). The qualitative data were collected using a semi-structured interview form. This form contains five open-ended questions to assess students' innovative thinking skills.

Data Analysis

A Shapiro-Wilk test was used to test the normality of the quantitative variables. A paired sample t-test was used when the data followed a normal distribution to examine mean differences and significance levels between pre- and post-tests. The analysis was conducted separately for both the overall scale and its subdimensions. The content analysis technique was used to analyze the qualitative data. Content analysis is a method that summarizes a phenomenon and provides a comprehensive description of it. This technique involves the creation of concepts or categories that explain the phenomenon after it has been analyzed (Mayring, 2015). Content analysis is used by researchers to analyze data intuitively, sensitively, and interpretively (Hsieh and Shannon, 2005).

Validity and Reliability

It is crucial to provide students with the necessary information to ensure the validity of the quantitative phase of the study. Students were instructed to fill out the scale completely and accurately. It was not excessively prolonged to prevent the loss of subjects and to prevent the maturation effect. By incorporating both qualitative and quantitative data, the study was able to obtain a richer dataset, which in turn helped to enhance the external validity of the research. McMillan and Schumacher (2010) suggest that using a mixed-method approach is an effective way to ensure research validity by compensating for any weak data that may be obtained through a single method. Additionally, the study employed Cronbach's alpha reliability analysis of valid and reliable scales. Cronbach's Alpha values obtained for the pre-test and post-test of the innovative thinking scale were 0.93 and 0.86, respectively. A Cronbach's alpha value greater than 0.70 indicates the scale's reliability (Taber, 2018). In terms of the validity of the qualitative dimension of the research, students must provide honest responses (Rose and Johnson, 2020). Therefore, students were reassured, and communication was established with them at the beginning of the study. The research process was conducted jointly by three experts to ensure expert control. While coding qualitative data, codes and categories were validated by both experts and participants using direct quotations. The reliability of the qualitative data was calculated using the formula suggested by Miles and Huberman (2014) (Reliability = Agreement / Agreement + Disagreement). The agreement between codes and categories independently created by two different researchers in the field resulted in a reliability coefficient of 91%. As this value exceeds 70%, the analysis of qualitative data was deemed reliable (Miles and Huberman, 2014).

Findings

Findings on the Quantitative Data

The Shapiro-Wilk test was employed to evaluate the normality of the quantitative data sourced from the "Innovative thinking skills" scale, and the results of this assessment are outlined in Table 2.

Table 2. The Results of the Normality Test for the Data of the Scale

Scale		N	Shapiro-Wilk	Kurtosis	Skewness
Innovative thinking	Pre-test	40	.07	1.682	-.670
	Post-test	40	.04	1.668	-1.182

The results of the normality test are presented in Table 2 for the pre-test and post-test scores of the "Innovative thinking skills" scale. Since the sample size was below 50, Shapiro-Wilk test results were used (Shapiro and Wilk, 1965). The significance value for the pre-test data is above 0.05, indicating a normal distribution (Razali and Wah, 2011). As for the post-test data, since the kurtosis-skewness value falls within the range of -2 to +2, it is assumed that the entire data set follows a normal distribution (George and Mallery, 2010)

Table 3. The Results of the Paired Samples t-test for the Scale

Scale		N	$\bar{X}$	Sd	t	p
Innovative thinking skills	Pre-test	40	3.308	0.690	30.317	.000
	Post-test	40	4.147	0.671	39.077	

*p<0,05

Table 3 shows the results of the paired samples t-test for the innovative thinking scale. The mean of the post-test scores of the scale ($\bar{x}$=4.147) is higher compared to the pre-test ($\bar{x}$=3.308). Additionally, since the p-value is less than 0.05 ($p<0.05$), the post-test significantly outperformed the pre-test.

Table 4. The Results of the Paired Sample t-test for the Sub-dimensions of the Scale

Sub-dimension	Measurement	N	$\bar{X}$	Sd	t	p
Innovative self-efficacy	Pre-test	40	3.490	.794	27.776	.000
	Post-test	40	4.350	.210	24.991	
Openness to innovation	Pre-test	40	3.395	.852	25.181	.000
	Post-test	40	4.308	.703	38.726	
Innovative problem-solving	Pre-test	40	3.215	.833	24.406	.000
	Post-test	40	3.900	.854	28.864	
Innovative perseverance	Pre-test	40	3.100	.861	22.763	.000
	Post-test	40	4.016	.880	28.863	
Innovative group leadership	Pre-test	40	3.008	.832	22.868	.000
	Post-test	40	3.866	.879	27.801	

*p<0,05

Based on the findings presented in Table 4, there is a significant difference in every sub-dimension of the "Innovative thinking skills" scale. This improvement is shown to favor the post-test, with p-values lower than 0.05, indicating statistical significance. These sub-dimensions are innovative self-efficacy, openness to innovation, innovative problem-solving, innovative perseverance, and innovative group leadership.

Findings on the Qualitative Data

Content analysis was used to analyze the qualitative data, and the results are presented using frequency and percentage values in Tables 5, 6, 7, 8, and 9.

Table 5. Students' Opinions regarding the First Question

Category	Code	Frequency (F)	Percentage (%)
Yes	Different coding	6	28
	Change in model	6	28
	Collaborative problem-solving	4	18
	Assembling parts	4	18
	Complete focus on the solution	1	5
	Diverse tasks	1	5
Total		22	100

In Table 5, responses to the question "Did you come up with new ideas and solutions while implementing robotic applications? How?" were categorized under the "Yes" category. Among the responses in the "Yes" category, the codes with the highest frequency (f=6) were "different coding" and "change in model". Students expressed that they identified different problem states, created various codes, and experimented with different models to innovate upon the existing model. Additionally, the codes "collaborative problem-solving" and "assembling parts" (f=4) ranked second in terms of frequency. Students mentioned collaborating with their group mates to solve problems and develop new solution ideas. They also indicated discovering different ideas while assembling parts. Furthermore, one student noted that assigning different tasks to each group member encouraged innovative thinking. Moreover, another student expressed focusing entirely on contemplating solutions to problems.

S1: "While constructing the merry-go-round, I designed the horses in various forms."

S2: "I ensured the motor's operation by changing its position when it failed to work."

Table 7. Students' Opinions regarding the Second Question

Category	Code	Frequency (F)	Percentage (%)
Yes	Trial and error discovery	7	41
	Thinking differently	6	35
	Valuing thoughts	2	12
	Warning against mistake	1	6
No	Disregard for thoughts	1	6
Total		17	100

As shown in Table 6, responses to the question "Did you resort to untried solutions during robotic applications despite objections from friends?" were categorized into "Yes" and "No." Among the responses in the "Yes" category, the code with the highest frequency was "trial and error discovery" (f=7). Following this was the code "thinking differently" (f=6). Students expressed resorting to new paths through trial and error, discovering different ways of thinking, and sharing them with their group mates. Two students mentioned resorting to solutions because they valued their peers' ideas and believed that their ideas were also valued. Another student mentioned warning their friends when they misplaced parts. Another student expressed difficulty sharing solution paths with their friends due to the feeling that their opinions were not worthwhile.

S3: "I developed a different solution method to correct the contactless issue with the barrier gate."

S4: "I alerted my friends when they plugged the cables into the wrong places."

Table 7. Students' Opinions regarding the Third Question

Category	Code	Frequency (F)	Percentage (%)
Cognitive	Learning new things	6	14
	Exploring new paths	6	14
	Learning software	4	9
	Learning coding	4	9
	Learning by experimenting	4	9
Affective	Motivation	6	14
	Interest	5	11
	Desire to design new products	4	9
Other	Career field	4	9
	Energy conservation	1	2
Total		44	100

In Table 7, responses to the question "What do you think about creating something new after receiving robotics education?" were categorized under "cognitive," "affective," and "other" categories. Among the "cognitive" categories, the codes with the highest frequency were "learning new things" (f=6) and "exploring new paths" (f=6). Students mentioned learning new things and discovering new paths to solve problems through the robotics education they received. Some students mentioned learning how software works (f=4) and how to code (f=4). Additionally, students stated that they learned through trial and error how the model operates with codes (f=4). In the "affective" category, the codes with the highest frequency were "motivation" (f=6) and "interest" (f=5). Students showed motivation towards creating new designs and models, with robotics education being a significant contributor in this regard. They mentioned being more interested in creating different codes and models and expressing a desire to design new products (f=4). Some students (f=4) expressed their interest in learning about career fields related to robotics and engineering, believing that this would help them improve in creating new things. One student indicated their intention to develop products aimed at energy conservation through robotics education.

S5: "Learning about the mechanisms of machines motivated me."

S6: "I aspire to focus on these career fields in the future. I consider this to be beneficial."

In Table 8, responses to the question "Can you evaluate your robotics education in terms of your desire to solve problems?" were categorized under the "cognitive," "affective," and "psychomotor" categories. In the "cognitive" category, the code with the highest frequency was "ease in problem-solving" (f=8). Students mentioned frequently resorting to problem-solving during their robotics education, striving to solve problems as they encountered continuous challenges. They claimed that robotics coding education facilitated their problem-solving.

Table 8. Students' Opinions regarding the Fourth Question

Category	Code	Frequency (F)	Percentage (%)
Cognitive	Ease in problem-solving	8	24
	Logical reasoning	2	6
Affective	Self-confidence	5	15
	Motivation to learn	5	15
	Collaboration	4	12
	Assistance	4	12
	Inspiration	2	6
Psychomotor	Repairing parts	3	9
Total		33	100

Two students mentioned successfully solving problems by logical reasoning. In the "affective" category, the codes with the highest frequency were self-confidence (f=5) and motivation to learn (f=5). Students expressed being motivated to learn to solve new problem states and gaining confidence as they were able to solve problems. Some students (f=4) mentioned that collaboration and assistance were quite effective in fostering their interest in problem-solving. They mentioned being able to solve problems by collaborating with their group mates and benefiting from each other's ideas. Two students mentioned that robotics education was inspiring in terms of their interest in working with electronic devices. The code belonging to the "psychomotor" category is the skill of repairing parts (f=3). Students expressed that they could be more proficient in repairing parts as they were interested in creating models and assembling parts through robotics education.

S7: "I observed that problems were solved more easily by collaborating."

S8: "The robotics education inspired me to repair electronic circuits."

Table 9. Students' Opinions regarding the Fifth Question

Category	Code	Frequency (F)	Percentage (%)
Motivation	Perseverance	9	22
	Frequent experimentation	9	22
	Model creation	8	19
	Coding	8	19
Management	Managing the coding process	5	13
	Time management	2	5
Total		41	100

Responses to the question "Can you evaluate your robotics activities in terms of persistence in seeking new solutions?" were categorized under the motivation and management categories in Table 9. In the "motivation" category, the codes with the highest frequency were "perseverance" (f=9) and "frequent experimentation".

Students mentioned persistently trying to solve problems in their robotics education, stating that the process motivated them to do so. Even if they made mistakes at first, they developed solutions many times. The codes “model creation” (f=8) and “coding” (f=8) indicate that students needed to experiment extensively while creating models, assembling parts, and coding. As part of the “management” category, the code “managing the coding process” (f=5) implies that coding should be completed according to requirements; the code “time management” (f=2) indicates that coding should be completed as quickly as possible.

S9: “We aimed to produce the best-coded model in the shortest time possible.”

S10: “We made numerous attempts to solve the problems, did not give up, and succeeded.”

Discussion and Conclusion

This study integrated a collaborative learning approach and entrepreneurship sub-dimensions with educational robotics applications to explore the impact of educational robotics on middle school students’ innovative thinking skills. The quantitative data obtained from the study showed a significant increase in students’ innovative thinking skills across the overall scale and all sub-dimensions in favor of the post-test. Additionally, the qualitative analysis of the research demonstrated that eight weeks of educational robotics applications increased students’ innovative thinking abilities. Therefore, the results of this study indicate that educational robotics applications enhance middle school students’ innovative thinking skills.

The outcomes of this investigation corroborate prior research in the field, suggesting that educational robotics fosters the enhancement of students’ creativity, thereby facilitating the development of innovative thinking skills (Çakır et al., 2021; Eguchi, 2017; Gubenko et al., 2021). Hence, the findings of this study support the existing literature. Furthermore, the qualitative findings of this study reveal that students explored new strategic avenues, encountered novel situations, and acquired fresh perspectives, consequently nurturing the growth of innovative thinking skills. Consequently, this study’s quantitative and qualitative findings reinforce each other. Additionally, Scaradozzi et al. (2015) advocate for the use of Lego robots in educational settings to enhance reasoning, foster critical thinking, and stimulate creativity. Thus, Lego robots can be utilized in educational settings to improve students’ cognitive abilities.

Upon examining the sub-dimensions of innovative thinking skills, it was observed that there were statistically significant increases in the areas of innovative self-efficacy, openness to innovation, innovative problem-solving, innovative perseverance, and innovative leadership. Innovative self-efficacy is associated with students’ abilities to generate new ideas, take risks, solve problems creatively, and adapt to change (Schar et al., 2017), and it has been observed that these skills develop through educational robotics applications. Findings from interviews also indicate that students were able to develop an innovative perspective, cope with different coding and situations, and solve problems by generating new ideas through educational robotics education. As expressed by the students, they identified different problem states, produced different coding, demonstrated their innovative styles by making changes to the model, and brainstormed on how to combine the pieces differently. Kasalak and Altun (2017) found that simple robotics programs strengthened students’ self-efficacy perceptions, while Durak et al. (2019) demonstrated that students learned new things and developed many skills as a result of robotic programming.

Moreover, it can be contended that the procedures implemented in entrepreneurship, based on a collaborative learning approach, have also played a significant role in this favorable progress. Collaborative learning, which supports the exchange of ideas and mutual assistance through teamwork, fosters trust relationships among individuals and promotes solution-oriented thinking. As a result, it encourages individuals to think innovatively (Siddique et al., 2010; Yudha et al., 2018). Furthermore, the design of an original prototype and the identification of different codes and problem states within the application steps integrated with entrepreneurship compelled students to think innovatively. By assigning students different tasks, providing conditions for their full concentration, and fostering collaborative efforts throughout the process, students were able to produce and design innovatively. According to Boldureanu et al. (2020), entrepreneurship inspires students to believe in their ideas and put them into practice. Innovative thinking allows the transformation of these ideas into different applications through action and experiential learning (Bell, 2015).

The significant development in the sub-dimension of openness to innovation can be explained by the increase in students' ability to cope with different situations as they become accustomed to educational robotics applications over the weeks, as indicated by the qualitative data. Besides demonstrating respect for differing viewpoints, students' eagerness to venture into uncharted territories, probe alternative modes of thinking, and communicate them with their peers signifies the advancement of their openness to innovation abilities, including their willingness to voice their opinions, even amid disagreement. The formation of group spirit through the collaborative learning approach and the implementation of the entrepreneurship sub-dimension of social skills and teamwork during the application phase can also be among the reasons for this development. As Almajed et al. (2016) observed in an exploratory study, collaborative learning creates an emotional connection within the group, making students feel comfortable and secure, thereby improving their learning attitude. This study's quantitative and qualitative findings support one another in terms of openness to innovation skills, and they are consistent with the literature. The significant development in the sub-dimension of innovative problem-solving is supported by the views that students encounter various problems, struggle to solve them within a limited time, and become more accustomed to robotic activities over time, making it easier for them to solve problems. Students encountered many problem states and glitches each week. For instance, they looked for solutions to technical issues such as a malfunctioning motor, improper coding, or incorrect assembly. To solve these problems, students developed innovative perspectives and strategies by collaborating within the team. According to Sawyer and Obeid (2017), collaborative learning motivates students to solve problems more quickly, which is also supported by the results of this study.

A significant increase was also observed in the sub-dimension of innovative perseverance. According to qualitative findings, students were motivated to learn new things and solve problems. They clearly expressed that their confidence in problem-solving improved, as they persisted in tackling problems tirelessly through repeated attempts and offered alternative solutions when their peers made mistakes. The students also mentioned finding satisfaction in reasoning through solutions, being inspired to pursue a career in educational robotics, being able to solve problems more easily with collaboration, and feeling more motivated to fix electronic circuits and damaged parts. As such, students' motivation and self-confidence contribute to their innovation perseverance in this area. Numerous studies in the field have also shown that robotics coding education enhances students' self-confidence and motivation (Aris and Orcos, 2019; Cejka et al., 2006; Chin et al., 2014; Ragus and Leung, 2023). This study further demonstrates that educational robotics, based on a collaborative learning approach, is highly beneficial, as students could benefit from each other's ideas by working and assisting each other in groups.

The progress observed in the development of the sub-dimension of innovative leadership is linked to students' engagement in leadership roles for at least one week, where they were tasked with delegating responsibilities within the group and overseeing time management and coding tasks. Moreover, student leaders expressed their commitment to managing the coding process, ensuring effective time allocation, and providing guidance to their peers. Each student's experience in assuming a leadership role and guiding the group accordingly contributed significantly to the enhancement of their innovative leadership skills. Stewart et al. (2021) found that teaching robotics coding improves students' leadership skills. Ruiz-Gallardo et al. (2012) found in their study that students' leadership skills could be enhanced through entrepreneurial and collaborative learning approaches. This study found that clearly defining the leader's tasks and incorporating group leadership roles during the application phases of entrepreneurship and collaborative learning-based robotics education helped students embrace leadership. In summary, the results of this study show that eight weeks of collaborative learning and entrepreneurship-integrated educational robotics applications lead to substantial improvements in students' innovative thinking abilities. Throughout this period, students not only collaborated to gain new perspectives and value each other's ideas but also engaged in multiple problem-solving attempts, devised various codes and problem scenarios, formulated novel designs, assumed leadership roles in managing coding processes, contemplated career paths in the field, and enhanced their confidence and motivation in problem-solving and product creation.

Limitations and Suggestions for Future Research

A single-group pre-test-post-test design was employed in this study. Nevertheless, future research should use controlled group models and replicate the study with larger sample sizes to enhance the validity. The findings suggest that integrating educational robotics programs with collaborative learning and entrepreneurship positively contributes to innovative thinking skills. Future researchers could explore how educational robotics impacts different skills or variables associated with innovative thinking skills. Additionally, utilizing observation alongside qualitative research methods could provide more detailed insights. One of the key considerations in the study is the prohibitive cost of the "Fischer Technik" robotics set. This high cost may impede accessibility across different socioeconomic levels. Therefore, conducting studies using more affordable robotics tools could be advantageous. Furthermore, based on the results, it is believed that incorporating collaborative learning-based educational robotics programs into classrooms to foster entrepreneurship skills could greatly benefit students by enhancing skills such as leadership, creativity, and entrepreneurship.

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Author Information

Meryem Meral
https://orcid.org/0000-0002-5167-6946
Erzincan Binali Yildirim University
Turkiye
Contact e-mail: *meryemmeral96@gmail.com*

Sema Altun Yalçın
https://orcid.org/0000-0001-6349-2231
Erzincan Binali Yildirim University
Turkiye