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Three-stage robotic STEM program ignites secondary school students' interest in STEM career and attitudes toward science

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Abstract
The electricity-related topics in the secondary school science curriculum are near-universal standards across countries. We prepared a three-stage robotic STEM program incorporating coding, robotic integrated science (in the topic of electricity), STEM engineering processes, and their educational structures. We investigated the impact of the three-stage robotic STEM program on attitudes toward science and STEM career interests, which are the most important psychological triggers of learning. We conducted our research using a comparative quasi-experimental design with pretest-posttest experimental and control groups with 73 students in 7th grade in a public secondary school. While the experimental group students completed their performances by building and running the circuits in the activities of the three-stage robotics-STEM program, the control group students completed their performances by building and running the without-coding version of the circuits in these activities. Our research findings unveil an exciting prospect: by integrating block-based coding, robotics, and STEM engineering processes into electricity topics, we can significantly enhance and diversify student activities on electricity. Moreover, our finding reveals that the robotics-STEM program applied in the experimental group positively affects students' STEM career interests and attitudes toward science compared to the control group. By showcasing the benefits of a thorough three-stage robotic STEM program with about fifty activities, this study has the potential to advance science education by skillfully integrating several disciplines, including science (such as understanding sensors and electrical circuits), technology, and engineering (such as creating robotic designs and assembling hardware components), and mathematics (using algorithms and data analysis).

Keywords STEM education · Educational robotics · Arduino · Attitude toward science · Interest in STEM career

Extended author information available on the last page of the article

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1 Introduction

Cultivating individuals who actively explore and embrace digital advancements with science and technology at their core is a fundamental aim of education systems across nearly every nation. Because of this trend in less developed or developed ones (Javed et al., 2024a, b), science education is evolving towards STEM education, a new discipline in which science, technology, engineering, and mathematics are integrated (Dökme et al., 2022; Samsul et al., 2023). Robotic applications have given new life to STEM education, which had faded from popularity since it was more challenging to incorporate the engineering component of STEM in scientific classrooms (Koyunlu Ünlü & Dökme, 2022). This has revealed excellent opportunities for advancement in STEM classes. Students can nurture cognitive abilities and develop problem-solving and engineering design skills through the complex stages of building and programming robots. With the help of microcontrollers that can be programmed with a variety of software applications and block programming tools, even kids in elementary and secondary schools may complete STEM projects (Alfieri et al., 2015; Chevalier et al., 2020; Ouyang & Xu, 2024). These technological advances encourage students to develop an interest in computer science, engineering, and science learning experiences from an early age. However, our experiences at numerous scientific centers, science fairs, and other platforms have demonstrated that students make robotic applications within the context of STEM projects without having a systematic learning construction or integrating robotics into science topics. Activities that integrate robotics into science require both a serious curriculum and disciplined work by students (Ouyang & Xu, 2024). The three-stage robotics STEM program designed in our current research has a critical value as it has a systematic learning structure in which robotics is integrated into science subjects. That is because the main focus of this program is not only to create robotic demonstrations, as in many science fairs but also to enrich the science learning process with robotic applications. The program's design, which will offer a learning structure ranging from simple to advanced levels without causing any cognitive gaps in its scientific and robotics components, also sets it apart from the competition.

The following section contains a thorough literature review of the effects of robotic applications on students' affective and cognitive outcomes. While numerous studies have explored the potential benefits of robotics in educational settings, more comprehensive analyses still need to be conducted to delve into the nuanced intricacies of how these interventions are designed, implemented, and aligned with established educational frameworks. This gap underscores the need for further research that not only evaluates the outcomes of robotic interventions but also critically examines the underlying pedagogical approaches to ensure effective integration and maximize learning outcomes (Luo et al., 2024). Our three-stage robotic STEM program, designed to contribute to a more effective robotics education process for students at an early age, was applied to the experimental group during the intervention process of the current study. The STEM Career Interest Survey (STEM-CIS) and Attitude Towards Science Scale (ATSS) were used to measure the program's effectiveness. The effect of a three-stage robotic STEM program was investigated by comparing the STEM-CIS and ATSS scores of the experimental and control groups within and

between the groups. The study's research problem is as follows: How does a three-stage robotic STEM program affect students' STEM career interests and attitudes toward science?

2 Review

The current century has witnessed significant changes in the digital and robotic domains, indicating advances in STEM fields worldwide influence national economies and societal well-being (He et al., 2024; Javed et al., 2024a, b; Masrom et al., 2021). Qualified professionals are the key drivers of advancement in STEM subjects, and their availability and quality are contingent upon the academic pipeline from elementary to university education that produces highly qualified students in STEM fields (Abd-El-Khalick et al., 2015; Javed et al., 2024a, b). This pipeline that generates the upcoming generation of scientists, engineers, technologists, and informatics experts begins with early STEM education in schools. Effective and efficient flow through this pipeline depends on certain affective factors, such as science motivation, attitudes toward science that students acquire through school, and STEM career interests (Özkan & Dökme, 2024). These factors, which trigger students' learning and success in science, especially in the early stages of the academy, can be positively changed during the educational process (Dökme et al., 2022). Learning science might be a tedious process for children at first, requiring them to take emotional or affective stimulants. For instance, children's cognitive strain during the science learning process is reduced when games support science education because they enjoy the gaming part of the educational process (Wang et al., 2022). Another example closely tied to our research is integrating technologies and engineering children may depend on in daily life (like robots) into science topics to trigger their interests and make their learning processes more suitable (Brand, 2020; Ouyang & Xu, 2024; Park et al., 2023; Sung et al., 2023).

According to a study on the impact on student outcomes, robotics coding activities used in science classes raised students' motivation, creativity, and attitude (Guven et al., 2022). Numerous studies on science education have focused on the critical necessity of this kind of in-class engagement, which will develop in students emotional triggers for science learning outcomes that require disciplined study. In one such study, Hadiati et al. (2019) examined students' reasoning based on the model of their working style in classroom activities they carried out with Arduino and found a positive impact on their scientific attitudes. Similarly, in a Korean early childhood education environment, Sung et al. (2023) investigated the viability and effectiveness of a STEAM program in their national curriculum. Before and after completing the STEAM curriculum, which includes robotics activities, children were examined on computational thinking, vocabulary, numeracy, self-regulation, and social behavior. Their findings showed a notable gain in expressive vocabulary and computational thinking among young children in the treatment group. Furthermore, based on an assessment designed for a specific robotic material, gender demonstrated a significant interaction effect with increased social behavior, computational thinking, and self-regulation. Muniandy et al. (2022) investigated the impact of their robotics pro-

gram with the RoboBuilderRQ+110 robotic set on students' attitudes toward science, and they found that their robotics program has a positive and significant effect on students' attitudes toward science. In four categories studied—social implications of science, normalcy of scientists, attitude toward scientific inquiry, and adoption of scientific attitudes—Welch and Huffman (2011) found students who participated in a robotics competition had a more positive attitude toward science and science-related areas.

In a long-term study that thoroughly examined robotics participants, Weinberg et al. (2007) revealed positive changes in evaluating female students' talents and interest in STEM vocations. Studies focusing on the reasons for students' inadequate tendency to choose and pursue a science major emphasize the importance of students' psychological characteristics, such as interests in science and attitudes toward science, especially in pre-college education (Blotnicky et al., 2018; Han, 2017). These affective variables, like attitude and interest, influence students' decisions to pursue scientific studies and careers and trigger students' learning and success in science (Crawford et al., 2021). Hudson et al. (2020) used 37 s and third-graders from two classrooms at a primary school in the Southeastern United States to examine the effects of a robotics-based intervention on elementary-aged children's interest in STEM topics and careers. Their interventions, such as WeDo Lego Robotics construction and coding sessions by qualified STEM-speaking professionals, yielded positive results. Mich and Ghislandi (2019) examined how the ROBOESTATE project, a summer camp that uses educational robotics activities to engage STEM, affected kids' career choices. Based on their findings, Mich and Ghislandi (2019) claimed that ROBOESTATE-like courses raised boys' and particularly girls' interest in STEM fields.

The potential advantages of robotics in educational settings have been examined in the many studies mentioned above, but our current research differs from them in two key aspects.

First, our three-phase robotic STEM program is designed to help students at an early age gradually acquire higher-order cognitive skills through a disciplined, science activity-rich approach. Second, robotics in this program is not the destination but a tool for science education.

3 Theoretical framework

This section will briefly describe the theoretical structures of "STEM careers interest and attitudes toward science" used in research concerning the measurement tools used to collect data.

3.1 Career Interest

Lent et al. (1994) proposed a promising theoretical framework on interest and career choice based on the social cognitive career theory (SCCT). A major goal of SCCT is to explain three interrelated aspects of career development (Lent et al., 1994): (1) the process of identifying and developing academic and career interests, (2) the process of choosing among various educational and career options, and (3) the process

of achieving academic and career success. SCCT builds on three intricately interconnected variables: self-efficacy beliefs, outcome expectations, and personal goals (Bandura, 1986; Lent et al., 1994).

Four primary sources fuel *self-efficacy beliefs*, as follows (Bandura, 1986; Lent et al., 1994):

- Personal performance accomplishments: knowledge of the individual's personal experiences or the experiences he has gained from his studies to acquire a skill. Success, despite difficulties, pushes the individual to make efforts when other challenges arise.
- Vicarious experiences: sharing the experiences of others by modeling their behavior. When an individual sees that the people he is paired with are successful due to their efforts, it strengthens his belief that he, too, will be successful if he makes the same effort as them. Likewise, if an individual sees that people fail in the face of their efforts, this will weaken his belief in his own self-competence.
- Social persuasions: These are the suggestions an individual receives regarding ways to cope with a situation. Constructive evaluations of the person's behavior will increase the individual's self-efficacy beliefs, and the efforts he will make with verbal persuasion by the people around him will also increase.
- Physiological and emotional states: The ability to control anxiety, stress, and fear in assessing an individual's self-efficacy. If the individual is frequently exposed to situations for which he is not ready and where failure is inevitable, his self-efficacy beliefs will weaken.

Outcome expectancies are related to beliefs about the outcomes or consequences of performing certain behaviors (Bandura, 1986; Lent et al., 1994). SCCT suggests that outcome expectations are important determinants of career choices and goals. Self-efficacy belief is related to the individual's own capacity. However, outcome expectations are about the results an individual expects to achieve when a behavior is carried out. People will be more likely to participate in an activity if they see that it is valuable and leads to positive outcomes. Outcome expectations are important triggers not only in people's choices but also in their efforts and persistence in activities within the scope of these choices (Bandura, 1986; Lent et al., 1994).

SCCT proposes two types of *personal goals*: choice goals (participating in a particular activity) and performance goals (achieving a certain level of performance). Although environmental factors and personal experiences help determine a person's behavior, setting specific goals helps the individual organize their behavior in an orderly manner, increasing the likelihood of achieving desired intentions. According to SCCT, personal goals play an important role in the self-regulation of behavior. Studies have observed that challenging goals increase the performance of individuals compared to easy goals. When individuals are successful with more effort, challenging goals play a motivating role by making the individual more satisfied. Studies show that individuals with high self-efficacy set challenging goals, while those with lower self-efficacy beliefs gravitate towards easy goals. SCCT's model of interest, given in Fig. 1, is characterized by critical aspects such as self-efficacy, outcome

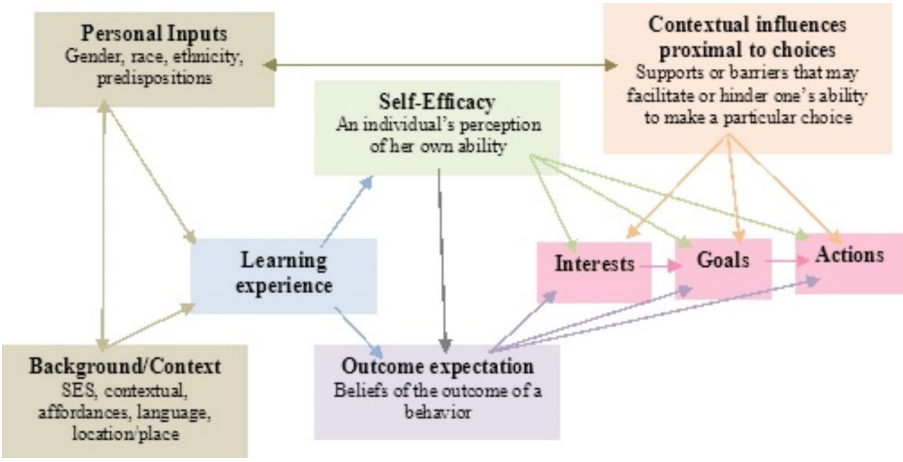

Fig. 1 The social cognitive career theory' model of interest (Lent et al. 1994 and Kier et al. 2014)

expectations, personal inputs, and contextual supports and barriers (Bandura, 1986; Lent et al., 1994).

Interest in career-related activities is located at the center of the theoretical diagram (Fig. 1), which shows that this interest emerged due to self-efficacy and outcome expectations. As another way of putting it, people are more likely to stay interested in and persist with a particular activity if they believe they can succeed at it (self-efficacious) and expect to achieve positive results. When interest develops because of self-efficacy and outcome expectations, it supports intents or objectives for maintaining or enhancing one's involvement in specific activities.

3.2 Attitude

Attitude, a set of positive or negative tendencies that includes emotion, beliefs, and behaviors towards an attitude object, has been addressed in its affective, behavioral, and cognitive dimensions for many years. Although the traditional attitude trilogy has survived to the present day, this broad nature of attitude has prevented studies on measuring attitude from supporting these three dimensions (Minson & Dorison, 2022). Therefore, criticisms of the triple attitude led researchers to address attitude structures as cognitive, affective, and behavioral separately rather than considering these components under one roof (Maio et al., 2018). For individuals with a positive attitude towards any attitude object, the cognitive aspect of their attitude refers to positive beliefs, thoughts, and attributes associated with it. While the affective aspect of their attitude is related to their feelings or emotions about this object, their behavioral aspect also refers to associated behaviors or experiences (Zhang & Gibson, 2021). The difficulties of measuring a hypothetical construct such as an attitude, which cannot be directly observed, have led social psychologists to investigate attitudes by investigating the underlying causes of an individual's voluntary behavior (Özkan & Dökme 2024). As a result of the theory of reasoned action (TRA) developed by Fishbein and Ajzen (1974), a conceptual framework was developed that included

the concepts of "behavioral intentions," "attitude toward behavior," and "subjective norms." Behavioral intention is the determinant internal factor in TRA. What underlies behavioral intention is "attitude towards that behavior" and "subjective norms" within the framework of the expectation-value theorem. Attitudes towards behavior include both the beliefs regarding behavioral outcomes (expectancy) and the evaluation of behavioral outcomes (value). As for subjective norms, these are the beliefs associated with behavior that constitute normative beliefs in society. In fact, it indicates that how individuals' social environment perceives a behavior influences their behavioral intentions. Because of criticisms of TRA that behavioral intentions do not always result in real behavior, Ajzen (1985) created the theory of planned behavior (TPB) by adding "perceived behavioral control" to "attitude towards behavior" and "subjective norms" (Fig. 2).

Perceived behavioral control refers to the degree to which a person believes they can carry out a specific behavior. Based on their own capacity to carry out the behavior, people perceive and evaluate "how easy or difficult the performance or behavior might be." Perception and evaluation of the individual's own ability related to a behavior vary by environmental circumstances and the type of behavior. If people feel that they have successfully performed a certain behavior, their intention to perform it is stronger. The concept of perceived behavioral control is rooted in self-efficacy theory and is related to self-efficacy. Self-efficacy is the conviction that one can successfully execute a set of behaviors to achieve a goal. As a result, TRA and TPB (Fishbein & Ajzen, 1974) have elucidated the internal processes behind the behavior that emerges as an action until it turns into action and the role or ratio of attitude in these internal processes (Özkan & Dökme, 2024).

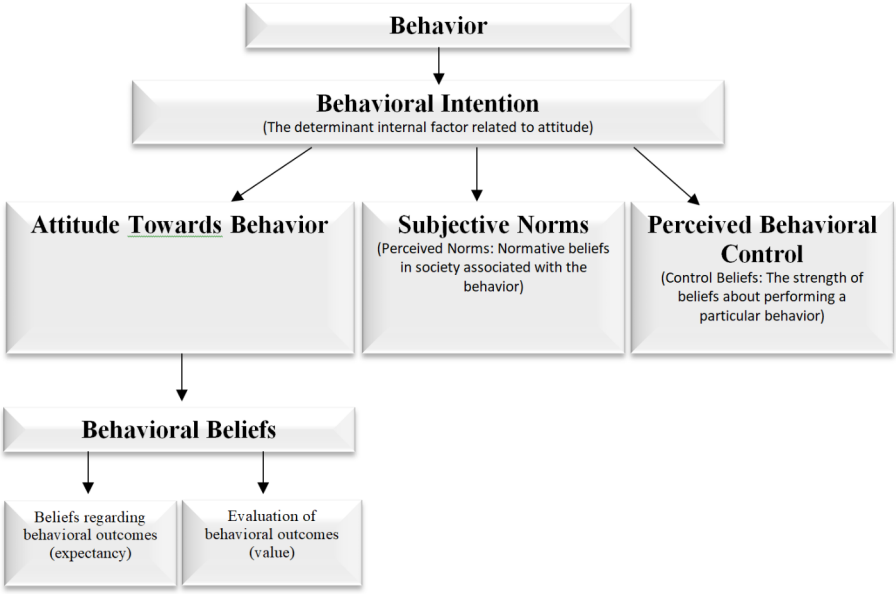

Fig. 2 Schematic representation of TRA and TPB (Fishbein & Ajzen, 1974)

4 Methods

This study was designed as a comparative quasi-experimental method with pretest-posttest experimental and control groups to investigate the effect of the three-stage robotic STEM program on 7th-grade students' STEM career interests and attitudes toward science.

4.1 Sample selection and power analysis

The sample size was verified using the "A Priori Power Analyzes" method during the sample selection. The target sample size for the one-sample t-test was calculated as 76 for the effect size 0.6, Alpha 0.05, Power 0.8, and Allocation ratio 1.7 (Faul et al., 2007). Purposeful sampling, one of the non-random sampling methods, was used in sample selection. One control and two separate experimental groups were assigned from the 7th-grade student classes in a public secondary school. Initially, there were 76 students, 48 in the experimental and 28 in the control group. However, since three students in the control group did not participate regularly during the three-stage robotics-STEM program, the control group completed the study with 25 students. While the experimental group students completed their performances by building and running the circuits in the activities of the three-stage robotics-STEM program, the control group students completed their performances by building and running the uncoded version of the circuits in these activities. The details are under the heading "Implementation Process."

4.2 Instruments

The first measurement tool in our research is the Attitude Toward Science Scale (ATSS), developed by Wang and Berlin (2010) and adapted into Turkish by Tosun and Genç (2015). ATSS is a one-dimensional, five-point Likert type that consists of 26 items. Its reliability coefficient is 0.916. The second measurement tool, the STEM Career Interest Survey (STEM-CIS), developed by Kier et al. (2014) according to social cognitive career theory and adapted into Turkish by Koyunlu Ünlü et al. (2020), was used. STEM-CIS is a 5-point Likert type with science, technology, engineering, and mathematics subscales. Each subscale consists of 10 items. There are 40 items in total. The reliability coefficient of the STEM-CIS scale was calculated at 0.93. It was calculated as 0.86 for the science sub-dimension, 0.88 for the technology sub-dimension, 0.94 for the engineering sub-dimension, and 0.90 for the mathematics sub-dimension (Koyunlu Ünlü et al., 2020).

4.3 Implementation process

The authors first created written activities for the three-stage robotic STEM programs, after which they produced initial applications. An early pilot implementation was conducted to evaluate the temporal organization, proactively identify obstacles, and validate implementation tactics before initiating the final implementation phase. The shortcomings of the robotic STEM activities within the framework of time, stu-

dent, practitioner, and scale difficulties were highlighted following the pilot program, considering the perspectives of both students and practitioners' experiences. They were modified to prepare them for the actual consequences. The content of the three-stage robotics program is given in Table 1. All three stages of the 46-hour, three-stage robotic STEM program include plenty of activities where students can gain knowledge, skills, and experience by doing and experiencing. The activities in this program can be applied to any age group, from seven to seventy, who will be introduced to robotic applications for the first time. After completing all the preparations, we implemented three-stage robotic STEM programs in the experimental groups studying 7th grade at a public secondary school. The stages of the three-stage robotics-STEM program for the experimental group and its equivalents for the control group are detailed below.

4.4 First stage of the three-stage robotic STEM programs

Students in the experimental group who completed the program's first stage (Table 1) acquired knowledge, skills, and experiences in programming using all codes in mBlock via a virtual robot. While preparing the content of the 30 activities in this stage, we took the following principles into account: The activities were designed with a learning structure that will progress from easy to difficult, from simple to complex, and steps of "knowledge, comprehension, application, analysis, and synthesis (Abuhassna & Yahaya, 2018). Only experimental group students completed these fourteen-hour activities outside the science curriculum.

4.5 Second stage of the three-stage robotic STEM programs

Students build series, parallel, and mixed circuits in the program's second stage. They measure the current intensity and potential differences in their circuit. With these applications, they discover the concepts of "electric current," "potential difference between the ends of a circuit element," "resistance," and Ohm's law. The independent variable of our quasi-experimental research is a process at this stage of the program. At this stage, there are two differences in the experimental and control group activities:

1. While the control group students set up the circuits in the activities with "bulb (or LED), buzzer, potentiometer, button, and sensor" circuit elements, they supplied the energy from the power source or batteries. However, the experimental group students provided energy from the Arduino microcontroller for their same circuits. The number and content of all activities in the experimental and control groups were equivalent in this regard, except for the energy supplier. All of these activities involved analog circuits that did not require coding. After exploring serial, parallel, and series-parallel mixed circuits with LEDs and buzzers, students in experimental and control set up and operated the circuits with light, humidity, distance, and temperature sensors in codeless forms.
2. The experimental group students built additional circuits for all the circuits built in case 1. These additional circuits were intelligent and required additional circuit

Table 1 Implementation content in experimental groups

Three-Stage Robotic STEM Programs			Outcome
	Activity Name	Sample Activities	
Stage 1 Block-Based Coding Applications with mBlock	Programming a Virtual Robot with "Motion, Looks, Sound, Pen, Events, Control, Sensing, Operators and Variables" Code Block (21 activities)	Create and run a program that will make the panda move in a "Z" shape that covers the screen in 12 s. Create and run a program to have Panda draw a rectangle that spans the screen and leave a self-copy at each corner.	Students who successfully complete these sections can cod and program with all code blocks at the basic level (Performances in activities require skills related to "knowledge, comprehension and application".)
	Mixed activities using all cod blocks (8 activities)	Create and run a program that will allow a football player to throw the ball into the goal 20 times in a row; each time, the referee will count 1, 2, 3 in the bubble, and a spectator will shout "goal."	Students who successfully complete this section can cod and program by using all code blocks at an advanced level (Performances in activities require skills related to "knowledge, comprehension, application, and analysis.")
	Cartoon design activity (1 activities)	Design, program, and run a cartoon about a child's dream of going into space and his adventures there.	Students who successfully complete this section can create a product using all code blocks. (This performance in activity requires skills related to "knowledge, comprehension, application, and synthesis.")
Stage 2 Codeless and Coded (Intelligent) Circuits	Establishing and operating serial and parallel circuits with LED buzzers, etc. using Arduino (Without code)	Create and run the serial circuits with 1, 2, 3, and 4 LEDs. Measure the current passing through the circuit and the potential differences between the ends of the LEDs, and interpret your measurement results within the framework of Ohm's law.	Students who successfully complete these sections can build the intelligent circuits, prepare their codes, and operate the circuits (These performances require skills at the level of "knowledge, comprehension, application and analysis").
	Establishing and operating serial and parallel circuits with LED buzzers, etc. using Arduino (Coded Intelligent circuits)	In the serial circuit you created with 4 LEDs, code and run it so that the LEDs light up continuously, sequentially, at 1-second intervals.	
	Building and running sensor circuits with Arduino (Coded intelligent circuits)	Install and run the circuit and programming that will alarm when the soil in the pot dries out..	

Table 1 (continued)

Three-Stage Robotic STEM Programs			Outcome
	Activity Name	Sample Activities	
Stage 3 Idea Generation: Developing Engineering Products for Daily Life Problems	Engineering design cycle	Sample engineering design cycles	Students who successfully complete these sections can create products related to intelligent circuits. (This performance in activity requires skills related to "knowledge, comprehension, application, analysis and synthesis.")
	Design and development of original lighting prototype	Design and prototype a night light that will turn on when babies cry when they wake up at night.	
	Design and development of an audio warning system prototype	Design and prototype a product that warns Mr. Abraham, who is a farmer in her village, when cows that damage her fields approach her fields.	
	Design and prototype a product that will facilitate a process in your daily life.		

robotic coding. Students incorporate their learning outcomes in this stage with the programming knowledge, skills, and experience they gained in the program's first stage. They create and operate intelligent circuits that work with codes. For example, in a simple LED circuit, the LED gives light when the switch is closed, but the LED does not provide light when the switch is opened. However, if this circuit is operated with the command "turn on and off at 1-second intervals," an LED flashing at 1-second intervals is obtained. After exploring serial, parallel, and series-parallel mixed circuits with LED and buzzer, students in the experimental group built and ran intelligent circuits with sensors by coding. To clarify it more, Fig. 3 illustrates visuals of a simple example activity carried out in parallel in the experimental and control group.

4.6 Third stage of the three-stage robotic STEM programs

In the third stage of our three-stage robotics program, students designed and prototyped an engineering product to solve a daily life problem, using the existing knowledge, skills, and experiences they gained in the second stage. Student performances at this stage vary within the framework of their creative thinking skills and capacity. Undeniably, the students in the experimental group showcased a remarkable transformation of their creative abilities, producing a wide array of highly refined and distinctive outputs compared to their counterparts in the control group.

All students in the experimental and control groups completed STEM-CIS and ATSS as pre- and post-tests at the beginning and end of the implementation.

5 Results

The results of the analysis of whether there is a significant difference between the pretest scores of the experimental and control group students in terms of STEM-CIS and ATSS scores are given in Table 2.

Table 2 shows no significant difference between the STEM career interests of the experimental and control group students (Sig.>0.05) before the Robotics-

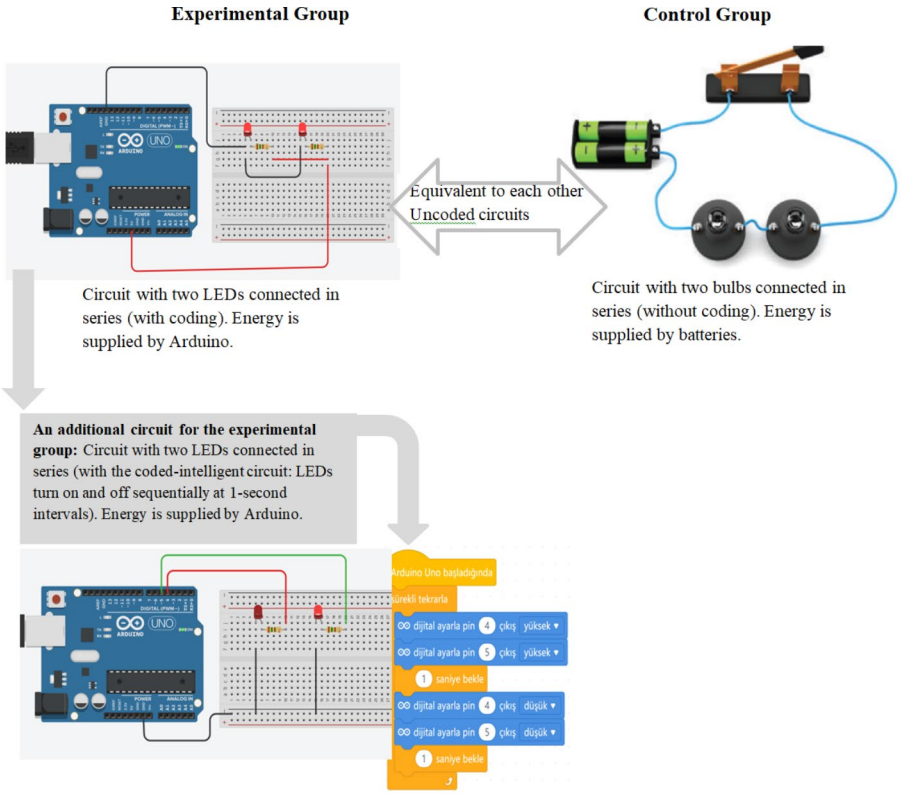

Fig. 3 Visuals of an example activity carried out in parallel in the experimental and control groups

Table 2 STEM-CIS and ATSS pretest comparisons between groups

	Group	N	$\bar{x}$	SD	t	Sig.
STEM-CIS- Science Pretest	Experimental	48	34.08	5.156	0.815	0.504
	Control	25	32.64	10.016		
STEM-CIS- Mathematics Pretest	Experimental	48	37.17	6.739	2.235	0.107
	Control	25	32.84	9.660		
STEM-CIS- Technology Pretest	Experimental	48	36.46	6.324	1.330	0.234
	Control	25	34.08	8.779		
STEM-CIS- Engineering Pretest	Experimental	48	34.19	9.225	0.202	0.957
	Control	25	33.72	9.655		
ATSS Pretest	Experimental	48	92.77	17.661	0.827	0.411
	Control	25	90.08	10.120		

STEM intervention for all sub-dimensions. A similar result was found for attitude towards science. There is no significant difference between the ATSS pre-test scores (Sig.>0.05) of the experimental and control group students (Table 2). According to Table 2, the experimental and control groups before the interven-

tion are equivalent to each other regarding both STEM career interests and attitudes toward science.

The analysis results regarding the between-group comparison of the posttest scores of the experimental and control groups in terms of STEM-CIS and ATSS scores are in Table 3. Table 3 shows a significant difference ($p < 0.05$) STEM-CIS mathematics and technology subscale scores between the experimental and control group. Moreover, there is a significant difference between the ATSS posttest scores of the experimental and control group students in favor of the experimental group students (Table 3). These significant differences show that the robotics-STEM program applied in the experimental group positively affects students' STEM careers related to mathematics and technology and students' attitudes toward science. The effect size (Cohen's d) and power analysis were calculated for each independent test using the results in Table 3. All achieved powers obtained between the STEM-CIS scores of experimental and control groups are higher than 0.8, except for the engineering sub-dimension. Also, the achieved powers obtained between the experimental and control groups of ATSS are higher than 0.8.

The analysis results regarding the within-group comparison of the pre-and post-test scores of the experimental group in terms of STEM-CIS and ATSS scores are in Table 4. Table 4 shows a significant difference ($p < 0.05$) between the pretest and posttest STEM-CIS science and technology subscale scores of the experimental group students. Also, according to Table 4, a significant difference ($p < 0.05$) exists between the experimental group students' pretest and posttest ATSS scores. These significant differences indicate that our intervention with robotic STEM positively affected students' interest in STEM careers related to science and technology and students' attitudes toward science. The effect size (Cohen's d) and power analysis were calculated for each dependent test using the results in Table 4. The achieved powers obtained between the pretest and posttest of STEM-CIS-Science and STEM-CIS-Technology are higher than 0.8.

The analysis results regarding the within-group comparison of the pre-and post-test scores of the control group in terms of STEM-CIS and ATSS scores are in Table 5. Table 5 shows no significant difference between the STEM-CIS pretest and posttest scores of the control group students (Sig.>0.05), except for

Table 3 STEM-CIS and ATSS posttest comparisons between groups

	Group	N	$\bar{x}$	SD	t	Sig.	Cohen d	Power
STEM-CIS-Science Posttest	Experimental	48	36.73	5.496	1.925	0.062	0.65	0.83
	Control	25	33.12	8.492				
STEM-CIS- Mathematics Posttest	Experimental	48	37.02	7.303	2.608	0,014	0.62	0.80
	Control	25	31.28	11.451				
STEM-CIS- Technology Posttest	Experimental	48	39.25	7.070	2.724	0.027	0.64	0.82
	Control	25	33.72	10.126				
STEM-CIS- Engineering Posttest	Experimental	48	35.33	9.047	2.001	0.050	0.52	0.67
	Control	25	31.40	7.348				
ATSS	Experimental	48	97.63	15.752	2.791	0,007	0.75	0.91
	Control	25	87.60	13.907				

Table 4 STEM-CIS and ATSS pretest and posttest comparison within experimental group

	N	$\bar{x}$	SD	t	Sig.	Cohen d	Power
STEM-CIS-Science Pretest	48	34.08	5.156	-3.042	0.004	0.44	0.91
STEM-CIS-Science Posttest	48	36.73	5.496				
STEM-CIS- Mathematics Pretest	48	37.17	6.739	0.213	0.832	0.03	0.07
STEM-CIS- Mathematics Posttest	48	37.02	7.303				
STEM-CIS- Technology Pretest	48	36.46	6.324	-3.000	0.004	0.43	0.90
STEM-CIS- Technology Posttest	48	39.25	7.070				
STEM-CIS- Engineering Pretest	48	34.19	9.225	-1.116	0.270	0.16	0.29
STEM-CIS- Engineering Posttest	48	35.33	9.047				
ATSS Pretest	48	92.77	17.661	-2.370	0.022	0.34	0.75
ATSS Posttest	48	97.63	15.752				

Table 5 STEM-CIS and ATSS pretest and posttest comparison within control group

	N	$\bar{x}$	SD	t	Sig.	Cohen d	Power
STEM-CIS-Science Pretest	25	32.64	10.016	-0.041	0.692	0.08	0.1
STEM-CIS-Science Posttest	25	33.12	8.492				
STEM-CIS- Mathematics Pretest	25	32.84	9.660	1.353	0.189	0.27	0.36
STEM-CIS- Mathematics Posttest	25	31.28	11.451				
STEM-CIS- Technology Pretest	25	34.08	8.779	0.201	0.842	0.04	0.07
STEM-CIS- Technology Posttest	25	33.72	10.126				
STEM-CIS- Engineering Pretest	25	33.72	9.655	1.448	0.160	0.28	0.38
STEM-CIS- Engineering Posttest	25	31.43	7.348				
ATSS Pretest	25	90.08	10.120	1.111	0.278	0.22	0.28
ATSS Posttest	25	87.60	13.907				

the technology dimension of STEM-CIS (Sig.=0.0482). (Buranın silinmesi lazım değer 0.842 olduğu için) Similarly, there is no significant difference between the ATSS pretest and posttest scores of the control group students (Sig.>0.05), according to Table 5. These results can be explained by the fact that teaching within the scope of the science curriculum did not affect students' STEM career interests and attitudes toward science. The effect size (Cohen's d) and power

analysis were calculated for each dependent test using the results in Table 5. These results confirm the dependent test results.

6 Limitation

The experimental and control groups were students from different school classes in the same socio-economic region, and many variables were kept under control for both groups. However, due to the nature of robotic applications, the "time" variable could not be kept equal in the experimental and control groups because the coding activities in the experimental group required extra time. This additional time was because the experimental group students, unlike the control group students, were subjected to coding learning, which is the first stage of the robotics STEM program. The research team had initially planned to compare the performance and learning outcomes of the experimental and control groups. However, due to the inability to control the "time" variable, the research team decided to investigate the effect of the three-stage robotics-STEM program only on students' affective outcomes. The fact that the experimental group was exposed to the intervention for a more extended period than the control group may affect the findings in favor of the experimental group if the independent variable is learning outcomes and in favor of the control group if the independent variable is affective outcomes. In other words, learning is directly proportional to how much time a student spends engaging in an academic task they can successfully perform (Denham & Lieberman, 1980). The more time and effort students spend learning a subject, the better they learn. However, long-term procedures that students are deliberately exposed to during the learning process can reduce their affective traits, such as motivation, interest, and attitude, due to boredom (Marsh, 1983). Therefore, we chose to take a risk and investigate the effect of robotic intervention on students' affective traits rather than on their cognitive characteristics. If we had chosen to use cognitive measures, we would have weakened the experimental aspect of the method because of the time factor.

7 Discussion

The three-stage robotic STEM program we prepared reveals significant differences in favor of the experimental group in the STEM career interest and attitudes towards the science of the intervention group students compared to the control group students. Our research differs from previous studies in the literature in that it incorporates coding, robotic integrated science, STEM engineering processes, and their educational structures (Avello et al., 2020; Benetti, 2012; Sapounidis et al., 2022; Tselegkaridis & Sapounidis, 2022; Zhang et al., 2021). Hence, readers will receive more information from us if we interpret our results in light of our implementation process (Table 1), contrasting them with other robotic intervention studies that have been conducted in the past. Our three-stage robotics-STEM application design was effective because it included activities moving from basic

to complex and from easy to troublesome in the first and second stages (Table 1). Moreover, these stages allowed students to progress through plenty of activities within the framework of this hierarchy (Alserhan et al., 2023). When commended in light of cognitive load theory (Sweller, 2020), this cognitive architecture in these stages reduced the working memory load of our experimental group of secondary school students. In the first stage of our program, students constructed their coding cognition in "knowledge, comprehension, application, and analysis" with activities in which they could use the functions of all code blocks separately and together. Students produced a synthesizing-level output during the last "cartoon design" activity. The studies by Ardito et al. (2020), Erumit et al. (2020), and Grover et al. (2019) are related to teaching informatics to middle school students, similar to the first stage of our program. These studies guide in planning and designing their research on teaching programming for middle school learners, addressing beginner programming concepts such as variables, expressions, and loops. In particular, the study by Ardito et al. (2020) demonstrates the impact of block-based computing applications on developing students' computational thinking skills in the components of "engineering/construction," coding, and "problem-solving and collaboration."

Relating to the second stage of our three-stage robotic STEM program, it is essential to integrate robotic applications into curriculum concepts and principles within the frame of STEM education. Students in this stage learn science concepts and principles and design circuits. Hence, the activities at this stage are a preliminary preparation for the third stage of our program, which requires performances at the highest level of cognition. Because of the nature of STEM education, students created and designed an engineering product as part of the final construction of their cognition using their higher-order thinking abilities (Koyunlu Ünlü & Dökme, 2022). Based on the principles clarified in the framework of SCCT (Bandura, 1986; Lent et al., 1994), this phased performance adventure caused a significant increase in the STEM career interest of the experimental group students because self-efficacy beliefs, which are the essential component of their career interest, were nourished in this process that improved students' capacities in robotics and science. Another reason that increased the students' STEM career interests is that they found these activities valuable and expect positive returns in their future careers (Lent et al., 1994) because the world is evolving quickly into the context of robotics and artificial intelligence. Students are more likely to maintain their interest in and persevere in science-related robotics activities and STEM jobs if they are self-efficacious, meaning they believe they can succeed at them and anticipate seeing positive results.

Incorporating science courses with robotics has become crucial for our alpha-generation youngsters as well as for science content in a world where robotics and artificial intelligence rule the day (Sapounidis et al., 2022; Tselegkaridis & Sapounidis, 2022). While students in the experimental group were learning "electrical circuits," they carried out the activities not with batteries as in the control group but with Arduino microcontrollers and coding, which can offer many alternatives. In the three-stage robotics STEM program, activities performed with Arduino and coding instead of batteries positively affected not only students'

interest in STEM careers but also their attitudes toward science. Discussing in light of TRA (Fishbein & Ajzen, 1974), those Alpha students' beliefs (expectations) and evaluations (value) of science underwent a positive shift with the intervention because science was robotics-embedded. Also, in a frame of TPB (Ajzen, 1985), Alpha students' attitude toward science increased because of their perceived behavioral control, the degree to which students believe they can carry out a specific behavior. Clearly, in line with SCCT (Fig. 1) and TPB (Fig. 2), the excellent educational architecture of the three-stage robotic STEM program that integrates robotics and science has positively developed the "performance beliefs" that are based on students' self-efficacy within the scope of future professional expectations. As a result, students' STEM career interests and attitudes towards science have increased.

Most of the papers present in the review section of the article (Guven et al., 2022; Hadiati et al., 2019; Mich & Ghislandi, 2019; Muniandy et al., 2022; Sung et al., 2023) that reveal the effect of robotics on students' affective outcomes, such as attitude and interest, do not provide justifications based on the theoretical basis of this effect—except for one (Hudson et al., 2020). However, Hudson et al. (2020), who have a student sample at an early age like ours, based the reasons for the positive impact of the robotic intervention on children's interest in STEM subjects and careers on constructivism theory. They argued that educational robotics programs allow students to experience STEM in action, developing their knowledge, skills, and interests in STEM subjects and careers through physical construction, reflection, and active participation.

Activities of our program's second and third stages related to designing and producing engineering goods, constructed on coding, overlap with the study by Basuki et al. (2018). The crucial motivation of the study by Basuki et al. (2018) is that "based on the research of the National Governors Association, the United States showed the impact of education in the fields of STEM is very good for one's career in the future so that this area becomes very important to be developed. Moreover, "robotics is an innovative way of intertwining science, technology, engineering, and mathematics (STEM)." Basuki et al. (2018) designed learning modules based on the STEM robotics curriculum using the robot as an education module to improve student learning outcomes, manifested in the extracurricular form of robotics, especially in the education level of secondary school. Their curriculum is integrated with the 2013 national standard curriculum from the National Ministry of Education and Culture, specifically in science and mathematics. After 1 year of implementation, their study shows the method helps increase students' interest in the STEM subject and improve the learning outcomes of schools in subjects of science and mathematics higher than students who do not follow robotics extracurriculars.

8 Conclusion

The electricity-related topics in the secondary school science curriculum are near-universal standards across countries. Related to this topic, our research findings unveil an exciting prospect: By integrating block-based coding, robotics, and STEM engineering processes training into electricity topics, we can significantly enhance and diversify student activities on electricity. Our research underscores an outstanding relationship: Secondary school electricity activities integrated with robotic coding positively influence students' STEM career interests and attitudes toward science. This relationship offers a promising, bright future for raising a generation enthralled by the nexus between science and technology. The three-stage robotic STEM program illuminates that incorporating topics merging coding with electrical concepts enriches student activities, fostering a dynamic learning environment. For further studies, we recommend studies involving evaluating students exposed to a three-stage robotic STEM program with performance rubrics. This, however, should require having an assistant teacher. That is because, according to our experience in the experimental group, the fact that a single teacher carries out the applications does not make it possible to regularly and systematically assess and evaluate the students' performances in the classroom.

The implications of this study extend to educators, policymakers, and curriculum designers. For educators, the results suggest that incorporating hands-on, technology-driven activities, such as robotics, can significantly enhance students' engagement and motivation in STEM subjects. Policymakers are encouraged to invest in STEM education initiatives that include modern technological tools and methodologies. Funding and support for teacher training programs focused on robotics and STEM pedagogy will be critical in scaling the success of such interventions. Moreover, integrating STEM education as a core component of national curricula can help address workforce demands in the science and technology sectors.

For curriculum designers, this study highlights the importance of developing interdisciplinary programs that combine robotics, engineering, and science with real-world problem-solving.

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Author contributions The first author (FA) conducted a literature review for the research and designed the study. FA made the first design of the three-stage robotics STEM program. FA developed the activities in the first two phases of the design, and the second author (SA) developed the activities in the final phase. SA conducted the implementation of the research and analyzed the data obtained from the measurement tools. FA wrote the article.

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Data availability The titles of the activities in our three-stage Robotics Program are in Table 1 in the article, along with some sample activities. If the article is accepted, we can share all the activities (approximately 60) in an additional file.

Declarations

Ethics approval and consent to participate All of the procedures performed in studies involving human participants were in accordance with the ethical standards and the Helsinki Declaration and its later amendments or comparable ethical standards. University Ethics Committee with the document dated 30.03.2023-E.624,757 and numbered E-14588481-605.99-73341141.

Competing interests The authors declare that they have no competing interests.

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