MODESTUM
EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(6), em2642
ISSN:1305-8223 (online)
OPEN ACCESS
Research Paper
https://doi.org/10.29333/ejmste/16414

Effects of a block-based Arduino robotics course on computational thinking skills and STEM career interests of Vietnamese students

Le Chau Dat [1], Huong Thi Pham [2*], Nga Thanh Nguyen [3]

[1] Gia Dinh High School, Ho Chi Minh City, VIETNAM
[2] School of Foreign Languages, College of Economics, Law, and Governance, University of Economics Ho Chi Minh City, Ho Chi Minh City, VIETNAM
[3] Department of Physics, Ho Chi Minh City University of Education, Ho Chi Minh City, VIETNAM

Received 29 November 2024 ▪ Accepted 21 April 2025

Abstract

With the growing demand for high-tech careers in the 4.0 Industrial Revolution, the 2018 general education curriculum in Vietnam emphasizes career orientation and science, technology, engineering, and mathematics (STEM) education, and integrating robotics into education is crucial for preparing students for future careers. This study examines the impact of a block-based Arduino robotics course on computational thinking (CT) skills and STEM career interests. This study also investigates the perceptions of robotics among Vietnamese upper-secondary students. With a mixed method approach, this study surveyed students' CT skills and STEM career interests before and after the course, analyzed their products, and interviewed students about the course. Quantitative results indicate significant improvements in all CT areas and STEM career interests. Qualitative data reveal that the course enhanced students' engagement, allowing them to connect academic concepts with real-world applications, and effectively inspiring their career aspirations in the science and engineering fields. This research supports the value of robotics in STEM education and provides recommendations to enhance course design for better results in CT skills and students' interest in STEM careers.

Keywords: block-based, Arduino, robotics course, computational thinking skills, STEM career interests

INTRODUCTION

The development of the 4.0 Industrial Revolution, along with the explosion of artificial intelligence (AI) has created an urgent need for new human resources worldwide (Hieu et al., 2020; Zainal et al., 2018). It is projected that by 2025, about half of all work tasks will be completed by automated systems (Koorn et al., 2018; US Bureau of Labor Statistics, 2019). Currently, the integration of robotics into education has attracted increasing interest from researchers worldwide (Arís & Orcos, 2019; Chevalier et al., 2020), and many countries are incorporating robotics courses into their national curriculum systems (Yang et al., 2020). Research highlights that educational robotics courses offer hands-on learning experiences, enhance foundational knowledge and skills across science, technology, engineering, and mathematics (STEM) disciplines (Karaahmetoğlu & Korkmaz, 2019), positively impact students' interest in STEM subjects, as well as prepare them for future STEM careers (Barger, 2015; Chen & Chang, 2018; Ching & Hsu, 2024; Nugent et al., 2016).

Computational thinking (CT), programming ability, and AI have become integral to contemporary students' scientific and technological education (Hsu & Chen, 2022). CT skill is a vital 21st century skill that encompasses concepts such as robotics, coding, informatics, and information processing (Ertugrul-Akyol, 2019). Programming education is an effective way to cultivate students' CT (Yang et al., 2020). In programming education, many processes and concepts can often remain abstract for students (Karaahmetoğlu & Korkmaz, 2019). Robotic kits have become increasingly integrated into programming education, making abstract concepts more tangible by allowing

✉ chaudat2000@gmail.com ✉ huongpt.2742@ueh.edu.vn **(*Correspondence)** ✉ nganthanh@hcmue.edu.vn

Contribution to the literature

- This study provided an example of implementing a block-based Arduino course at a high school in Vietnam.
- By using a mixed-method analysis, this study demonstrated that a block-based Arduino robotics course could positively affect students' CT skills, STEM career interests, and attitudes toward the robotics course.
- This study highlights the necessity, advantages, and challenges of organizing robotics courses in Vietnam, thereby proposing appropriate measures to develop this model in Vietnam and other developing countries in the future.

students to directly engage in programming robots and better visualize complex ideas (Karaahmetoğlu & Korkmaz, 2019), creating interactive, engaging environments that develop CT skills in K-12 learners (Ching & Hsu, 2024). Recent studies in robotics have focused on using Arduino (Chen & Chang, 2018; Guven et al., 2022; Le, 2021; Le et al., 2023; Yin et al., 2022), and block-based programming (Guven et al., 2022; Ince & Koc, 2021; Karaahmetoğlu & Korkmaz, 2019; Zainal et al., 2018) to promote CT due to their ease of use and the potential for complexity (Ince & Koc, 2021). These tools helps students grasp abstract concepts, which are central to CT development, and make CT learning enjoyable and accessible to students of all ages, genders, and abilities (Ince & Koc, 2021).

In Vietnam, the new national general education curriculum (GEC) presents an ideal opportunity to integrate STEM robotics activities (Le et al., 2023; Ministry of Education and Training, 2018b) and career-oriented education (Ministry of Education and Training, 2018a). The use of robotics in education has gained traction for enhancing STEM learning (Tran et al., 2023). However, one of the challenges in the scientific inquiry process is the lack of equipment for conducting experiments (Nguyen et al., 2024). Limited opportunities for practical experience in school programs have led to low confidence among students in pursuing STEM robotics education (Le et al., 2023). Despite robotics not being formally embedded in the broader school curriculum, elements of algorithmic thinking and CT have been introduced through initiatives like the Bebras Vietnam computational thinking challenge and early programming education in primary and secondary schools (Tran & Nguyen, 2023). The integration of robotics content with career orientation is a relatively new approach in Vietnam and requires further exploration to realize its full potential.

Therefore, this research aims to design and implement a "block-based Arduino autonomous car" robotics course and then investigate how the course impacts students' CT skills and STEM career interests. The study also explores students' attitudes towards the robotics course. Three main research questions are explored in this study:

1. How does the "block-based Arduino autonomous car" robotics course affect students' CT skills?
2. How does the "block-based Arduino autonomous car" robotics course affect students' STEM career interests?
3. What are the students' attitudes towards the robotics course?

LITERATURE REVIEW

STEM Robotics

STEM robotics education is a field where students interact with robots to explore knowledge across multiple disciplines, applying these concepts to solve real-world problems (Khanlari, 2013; Le et al., 2023). It emphasizes hands-on activities, helping students improve their practical skills and develop problem-solving abilities (Gavrilas & Kotsis, 2024; Yang et al., 2020). In STEM robotics topics, students design and build their projects using sensors, processors, and motors through active research activities (Barak & Zadok, 2009). This approach encourages students to take on the role of researchers, following all steps from problem identification to assembling and programming (Church et al., 2010). Programming robots effectively, along with course design based on educational robots, is crucial (Yang et al., 2020). Robotics education allows students to see the real-world application of classroom knowledge while exposing them to automation technologies and challenges of technical fields (Barger, 2015).

Teaching STEM robotics involves specific principles related to robotics tools and operational principles (Le et al., 2023). Most school robotics activities are held as extracurriculars, such as competitions or hands-on experiences outside of regular classes (Altin & Pedate, 2013; Barak & Zadok, 2009). Li et al. (2020) suggest that coding is not the most critical aspect of STEM robotics; instead, the focus should be on developing related interdisciplinary skills and knowledge.

In Vietnam's 2018 GEC, robotics-related content for the subject of informatics is included as an elective module for grade 10 (Ministry of Education and Training, 2018b). The content covers: practicing with components of educational robots, connecting educational robots to computers, and programming to control educational robots (Ministry of Education and

Training, 2018b). In Vietnam's major cities like Ho Chi Minh City and Hanoi, STEM robotics education has started through extracurricular activities, engaging students with robotics kits like Lego Wedo and Lego Mindstorm (Le et al., 2023), or hands-on Arduino robots (Nguyen et al., 2024). However, the lack of funding, facilities, professional knowledge, and limited teaching time remain significant challenges for implementing STEM robotics education in schools (Le et al., 2023). Limited exposure to hands-on STEM experiences in teacher training has left many Vietnamese teachers feeling unprepared for teaching STEM robotics (Le et al., 2023). Integration and problem-solving capacity related to reality are difficult problems with teachers (Nguyen et al., 2019)

Arduino-Assisted Robotics Coding

Arduino is an open-source platform with hardware (Arduino microcontroller) and software (Arduino IDE) for building electronic projects, from simple circuits to complex systems, through steps of hardware design, assembly, software design, and coding (Yin et al., 2022). Arduino is widely recognized for its various benefits. Low cost is the key factor for students and teachers to apply Arduino inside and outside school (Chen & Chang, 2018; Pérez & López, 2019; Zainal et al., 2018). Arduino's intuitive setup and simplified programming language make it an excellent tool for secondary students (Yin et al., 2022). Its flexibility and compatibility enable users to design and create freely by themselves (Chen & Chang, 2018). Arduino's compatibility with various sensors–measuring temperature, humidity, speed, light, and more–promotes engagement with the environment through direct interaction (Guven et al., 2022). Arduino projects cover key STEM areas such as physics, programming, and engineering while offering real-world problem-solving opportunities (Yin et al., 2022). Using the Arduino controller, students can understand the concepts of electronic components and robotic parts and learn to design, manufacture, and combine these robotic parts with scientific and mathematical knowledge (Chen & Chang, 2018).

A review of related literature shows that Arduino-based robotics projects have improved STEM learning and CT skills (Karaahmetoğlu & Korkmaz, 2019; Quan & Gupta, 2020; Yin et al., 2022). It is noted that Arduino activities help students with engineering design tasks such as problem scoping and prototyping. Arduino projects can also provide great opportunities for students to learn and improve various CT skills, such as decomposition, pattern recognition, abstraction, and algorithm design. They can also be an effective tool for assessing students' CT skills (Yin et al., 2022).

Rather than using commercial chassis and pre-made structures, students in Arduino projects are encouraged to create unique artifacts with inexpensive materials like cardboard (Pérez & López, 2019), balsa wood, foam board, cardboard, steel wire, wooden sticks, and so on. These materials can be easily modified both mechanically and artistically, promoting creativity and the integration of arts through hands-on making and tinkering (Le et al., 2023; Pérez & López, 2019).

Block-Based Programming

There are two main types of coding: text-based and block-based. Text-based coding involves writing commands using a specific syntax, which can be challenging for beginners due to its complexity (Guven et al., 2022). Block-based coding simplifies the process by allowing students to use drag-and-drop blocks, making it more accessible for younger learners (Karaahmetoğlu & Korkmaz, 2019). For beginners in robotics, understanding the relationship between sensors, processors, and motors is crucial, and block-based programming platforms provide an intuitive environment for this learning (Altin & Pedate, 2013).

Studies show that block-based coding enhances problem-solving, creativity, and algorithmic thinking (García et al., 2020; Guven et al., 2022). Platforms like Scratch and Snap! enable the development of complex, constructionist projects, offering a practical way for learners to engage with high-level programming tasks (Fleger et al., 2023). Scratch's drag-and-drop interface is particularly useful for creating educational content like simulations and learning applications (Hieu et al., 2020). These environments make it easier for students to grasp complex algorithms and programming structures (Fleger et al., 2023).

Machine learning (ML) is a subfield of AI dealing with the field of study that gives computers the ability to learn without being explicitly programmed (Mitchell, 1997). Teaching ML in school helps students to be better prepared for a society rapidly changing due to the impact of AI (Wangenheim et al., 2021). Several tools integrate ML into block-based programming environments, such as ML4Kids, Cognimates, and LearningML, which extend platforms like Scratch (García et al., 2020; Williams et al., 2023). These extensions allow users to intuitively create ML models by assembling command blocks in a puzzle-like fashion, enabling students to perform functions, control objects, and describe events (García et al., 2020; Williams et al., 2023).

PictoBlox is a visual programming software built on Scratch and designed to make coding simpler and easier (Wanzala et al., 2021). It operates across multiple platforms, including Windows, macOS, Linux, and Android, making it accessible to users of all ages and skill levels. PictoBlox block-based programming enables students to explore creativity through robotics activities, game development, animation, ML, and AI projects (Cruz et al., 2021). It also includes extensions for hardware, robotics, and AI, allowing users to engage in tasks such as computer vision, facial recognition, character recognition, and speech recognition (Cruz et al., 2021).

Computational Thinking Skills

CT is defined as "solving problems using the basic concepts of computer science, designing systems, and thinking like a computer scientist" (Wing, 2006, p. 33). A key feature of CT is the ability to represent problems and solve them using computational power (García et al., 2020). CT has become an essential skill for everyone (Ching & Hsu, 2024; Hsu & Chen, 2022; Tran & Nguyen, 2023), and it is universally learnable (Yang et al., 2020). Every student is now expected to possess CT skills at least at a basic level like reading, writing, and basic math skills (Ince & Koc, 2021). CT can be applied to everyday problem-solving and across various learning domains (Yang et al., 2020) with programming education serving as an effective way to foster this skill (Yang et al., 2020). According to Korkmaz and Bai (2019), CT skills contain five factors: creativity, which involves generating innovative ideas and solutions; algorithmic thinking, the ability to design, evaluate, and apply logical steps to solve problems; critical thinking, which emphasizes analyzing and evaluating information systematically; cooperativity, focusing on collaborative efforts and teamwork to achieve shared goals; and problem-solving, involving structured approaches to identify and overcome obstacles effectively.

Educational robotics has been identified as a promising approach for young learners to develop CT skills, owing to its ability to provide physical, interactive learning experiences and immediate feedback (Chevalier et al., 2020). Robotics activities offer hands-on, tangible learning environments that promote productive CT development. The interdisciplinary and complex nature of robotics makes it an excellent tool for enhancing students' CT (Arís & Orcos, 2019; Barak & Zadok, 2009; Chevalier et al., 2020; Li et al., 2020). With the growing availability of robotics kits, CT development through programming robots has become more accessible, even for young learners who may lack advanced coding skills (Ching & Hsu, 2024).

STEM Career Interest

Delivering STEM education to enhance individuals' competencies and future career interests has become a critical focus for teachers and researchers (Kopcha et al., 2017). STEM career interest is defined as an individual's enthusiasm for pursuing STEM-related careers in the future (Luo et al., 2021). To be competitive in the 21st century, researchers, educators, and policymakers emphasize the importance of fostering students' interest of learning STEM knowledge and skills, pursuing STEM careers, and engaging in STEM-related college studies (Taasoobshirazi et al., 2024; Tyler-Wood et al., 2010). Secondary education is particularly critical for developing students' interest in science (Maltese et al., 2014) as well as their interest in applied sciences. Experiential activities at school play an essential role in shaping students' decisions about whether to pursue careers in science (Sheldrake et al., 2017). To prepare high school students for engineering careers and related college majors, it is recommended that they be exposed to engineering courses, topics, activities, tools, and materials, under the guidance of qualified teachers (Oh et al., 2013). Research shows that students participating more in STEM experiential activities have higher confidence in their STEM abilities (Ta & Le, 2024) and greater interest in STEM careers (Ribeirinha et al., 2025;). Hands-on activities and practical work have been shown to create a more positive attitude towards STEM (Yoon & Ryu, 2024). Using hands-on learning objects significantly impacts the development of problem-solving skills, understanding of computation, and interest in engineering professions (Budiyanto et al., 2022; Fidai et al., 2020).

Research worldwide demonstrates that robotics activities provide students with practical experiences, fostering their interest in STEM and encouraging them to pursue technical careers in the future (Barger, 2015; Chen & Chang, 2018; Nugent et al., 2016). Nugent et al. (2016) found that robotics programs such as summer camps, clubs, and competitions not only improve students' technical knowledge, programming skills, teamwork, and problem-solving abilities but also enhance their understanding of technology's role in society, increasing their confidence and interest in technical careers. Chen and Chang (2018) emphasized that students applying STEM knowledge to design, assembly, and program robots equipped with environmental sensors gain hands-on experience in engineering processes and understand engineers' responsibilities in real-world scenarios. Ince and Koc (2021) highlighted the potential of robotics in daily life and shaping career interests in fields like engineering, IT, and automation.

In Vietnam, career orientation is defined as a key competency in the 2018 GEC (Ministry of Education and Training, 2018a). The importance of guiding students toward STEM fields has also gained significant attention from researchers (Ho & Dinh, 2018; Ta & Le, 2024). Researchers have integrated career orientation objectives into teaching physics (Le & Nguyen, 2023), mathematics (Trieu et al., 2021), biology (Pham & Nguyen, 2023), and technology (Le, 2021). Integrating robotics curriculum and career orientation is a relatively new approach that deserves further exploration.

Based on the job descriptions in the career research book published by the International Labor Organization Country Office for Vietnam (2020), we introduced students to some STEM careers that can involve in the robotics project, which are shown in **Table 1**.

Table 1. STEM careers that can involve robotics project

Career	Role in the robotics project
Electronics engineer	Designs and integrates electronic systems, including sensors, circuits, and microcontroller programming.
ICT technician	Installs and maintains communication systems, ensures connectivity, and supports software deployment.
Industrial engineer	Optimizes the production process, ensures cost-efficiency, and coordinates the assembly of the robot.
Mechanical engineer	Designs and builds the physical structure of the robot, including motors, gears, and movement mechanisms.
Electrical engineering technicians	Provides technical support for hardware and software troubleshooting and assists with wiring and power management.

Table 2. Research design

Pre-test	Experiment	Post-test
- Pre-test on STEM career interests and CT skills (1 period)	- Block-based Arduino robotics course (12 periods)	- Post-test on STEM career interests and CT skills - Semi-structured interviews

5E Learning Model

The 5E model includes five stages: engage, explore, explain, elaborate, and evaluate (Guven et al., 2022), which are essential in constructivist learning to improve educational outcomes (Bybee, 2019; Omotayo & Adeleke, 2017). This model fosters a rich learning environment and enhances the quality of science education by encouraging students to interact with their peers and surroundings, thereby reshaping their understanding (Bybee, 1997). Many studies have utilized the 5E instructional model in robotics courses (Budiyanto et al., 2022; Guven et al., 2022). The 5E model enhances robotics education by providing a structured, hands-on framework that fosters curiosity creativity, and CT skills (Budiyanto et al., 2022; Guven et al., 2022), helps students engage more actively, makes abstract concepts more tangible, strengthens connections between science and everyday life (Guven et al., 2022).

METHODOLOGY

Research Design

In this research, a mixed-method experimental design (one group pre- and post-test experiment) was applied, including the implementation of a block-based Arduino robotics course, pre- and post-test of students' interest in STEM careers and CT skills, and semi-structured interviews with students about their experiences of the course, career orientation, and attitude toward robotics. The design of the research is given in **Table 2**.

Research Context

The study was conducted in an 11th-grade summer class at a private high school in Ho Chi Minh City, Vietnam. The summer class was organized for students to enroll in certain subjects from the curriculum as well as participate in STEM learning sessions. The school is equipped with a Maker Space to facilitate STEM education. There are three physics teachers involved in the course. One teacher from the school took the lead in teaching, while two other teachers from other schools moved around the groups to observe and assist students in completing their tasks. All three teachers are well-versed in the course structure, teaching methods, and the necessary knowledge related to robotics products.

Participants

Participants of this study consisted of 29 11th grade students (14 females and 15 males) from the summer class in 2024. The students were all 16 years old. Based on the pre-test results, 5 out of the 29 students in the class have previous programming experience, and 3 have prior exposure to Arduino. The students are asked to self-organize into five teams, with each team consisting of five to seven students.

Out of the 29 students participating in the course, only 7 students were able to take part in the interview. This was due to changes in the school's schedule, which delayed the interviews to just before the end of the summer term. On that day, most students were participating in extracurricular activities, and no additional class periods could be arranged for the course. These students were coded as S1 to S7. Among the interviewees, one student served as the group leader (S1), one as the secretary (S6), and the rest were members of the group (S2, S3, S4, S5, and S7).

Block-Based Arduino Robotics Course

The course was designed following the 5E model. Learners collaborated in teams, assuming the roles of research and development (R&D) employees working on a company project, simulating a real-world professional environment. In addition, students are also provided with some basic information about several professions related to this project. This approach was designed to enhance students' CT skills, bridge the gap

Table 3. Overview of the 5E process

Stage	Objectives	Description	Corresponding CT skill factors
Engage (1 period)	Sparks curiosity, introduces R&D and connects to STEM careers.	Introducing students to the R&D process. Students take on the role of an R&D team at an automotive company, tasked with designing a self-driving robot. They divide into groups, assign roles, brainstorm key tasks, and identify technical requirements such as line-tracking, sensor usage, and ML integration. STEM careers related to robotics are also introduced.	Critical thinking, problem-solving, & collaboration
Explore (2 periods)	Encourages hands-on experimentation and discovery.	Students learn about PictoBlox and Arduino-based hardware. They engage in hands-on tasks: controlling motors with an L298N driver, interpreting signals from line-tracking sensors, and training image recognition models for road sign detection.	Critical thinking, algorithmic thinking, & collaboration
Explain (1 period)	Reinforces learning through discussion, peer teaching, & reflection	Students share their findings from the exploration stage, discussing motor control, sensor integration, Arduino programming, and ML.	Critical thinking, algorithmic thinking, & collaboration
Elaborate (6 periods)	Applies knowledge to design build and the robot	Students apply their knowledge to design and build their self-driving robot. They are tasked with developing the robot's schematic, algorithm, and design blueprint. The design must include all the basic components of the robot, such as sensors, motors, and control systems. Students assemble and program their robots based on the design.	Critical thinking, problem-solving, algorithmic thinking, creativity, & collaboration
Evaluate (2 periods)	Encourages reflection and assessment via exhibitions and career posters	Each group presents their product, where the robots are tested. After that, students will evaluate their own group's product and receive feedback from other groups. In addition, each group creates and presents a poster introducing STEM careers, with each group assigned a specific career listed in **Table 1**.	Critical thinking, problem-solving, & collaboration

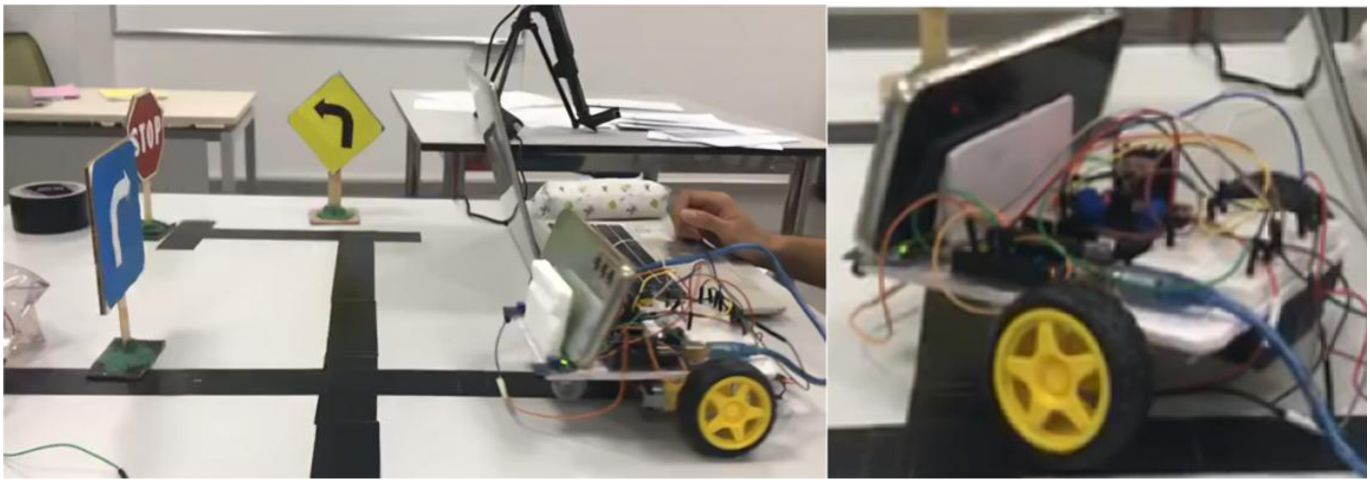

Figure 1. The line following robot with traffic signal recognition operates in a miniature street setup, with black "streets" and traffic signs (Source: Field study)

between education and real-world engineering experiences, and foster their interest in STEM careers.

The course progression and time durations are outlined in **Table 3**. Each period takes 45 minutes. The entire implementation of the 5E process spans 12 periods. The total time for the course is 14 periods, including introductory session, pre-test, post-test, and an additional session for interviews; starting on July 24th and ending on August 20th. The detailed progression of students throughout the course is presented in **Appendix A**.

Robotics Product

The course aimed to guide students to develop a "line following robot with Traffic signal recognition." This robot is designed to perform line following and traffic signal classification using two line detection sensors and a ML model for image classification.

The robot is programmed using the PictoBlox software, with the drag-and-drop programming tool and ML extension (**Figure 1**).

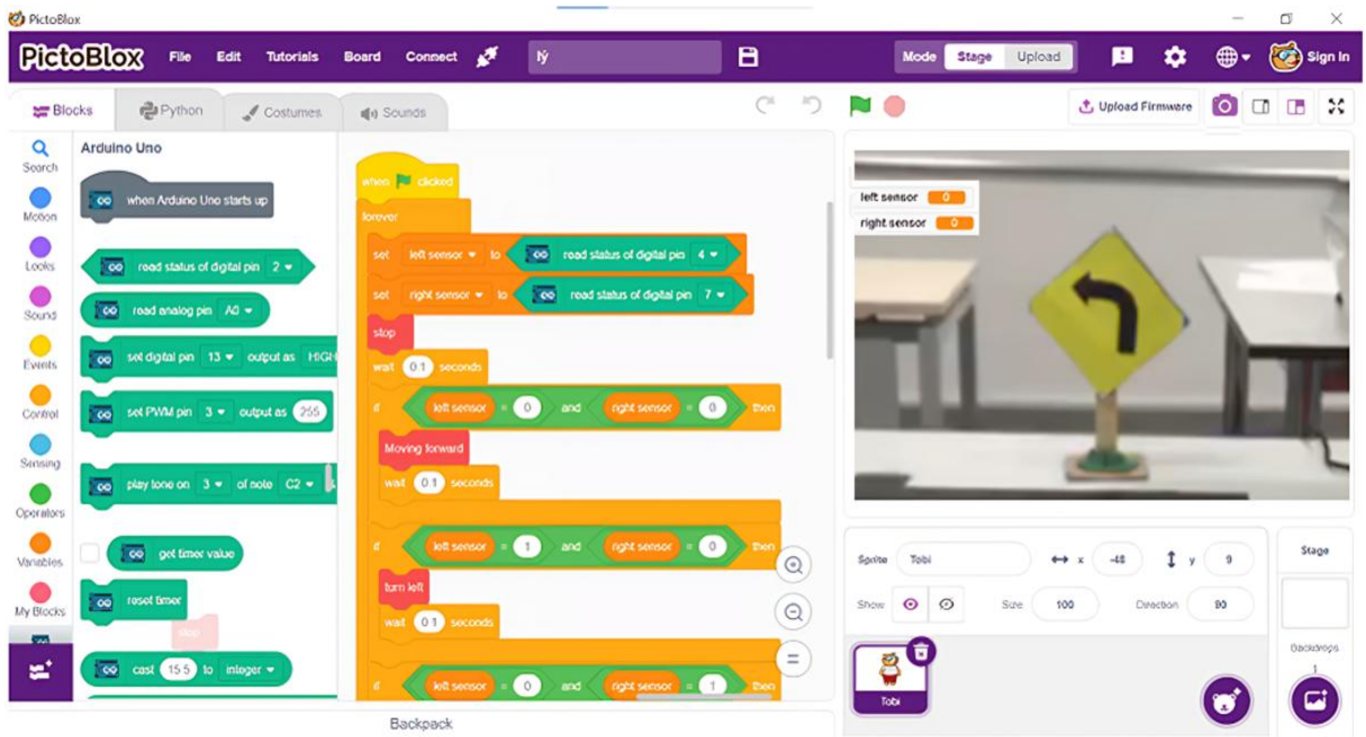

Figure 2. The PictoBlox interface includes a block-based coding area alongside an image recognition window (Source: Field study)

Line following

The robot is equipped with two line-detecting sensors positioned underneath the chassis. These sensors continuously monitor the surface for black lines on a white background (or vice versa). By detecting the contrast between the line and the floor, the sensors guide the robot to follow the black line. The left and right sensors work together: if one sensor detects the line while the other does not, the robot adjusts its movement to stay on course, ensuring it stays centered on the path.

Traffic signal classification

The robot uses the ML extension of PictoBlox to classify and respond to traffic signals. Students train an ML model using PictoBlox's image classifier module (**Figure 2**). They collect images of four traffic signals–left, right, straight, and stop–and label them. After uploading and labeling the images on the ML extension, the image classifier trains the model to recognize these signals. Students then test the model by showing it new images, and once the model correctly classifies them, it will be deployed to the robot. The robot's camera will detect traffic signs in real-time, and the trained model will classify them, guiding the robot to turn left, right, go straight, or stop accordingly.

Materials

The teachers prepared all necessary tools and equipment ahead of time. This included Arduino boards, sensors, various electronic components, connectors, fomex sheets (for building the robot chassis), motors and wheels, and batteries with holders. Due to the students' limited economic conditions, most did not have their laptops, so the teachers prepared computers pre-installed with the PictoBlox software. This preparation ensured that students had everything they needed to focus fully on designing and building their robots.

Research Methods and Tools

CT scale

The CT scale by Korkmaz et al. (2019) was used, including 20 items measuring students' CT skill levels, from strongly disagree (1) to strongly agree (5). It is a five factors CT scale: creativity (3 items), algorithmic thinking (4 items), critical thinking (4 items), cooperativity (4 items), problem-solving (5 items), involving structured approaches to identify and overcome obstacles effectively. Sample items are: "I can digitize a mathematical problem expressed verbally," and "I am good at preparing regular plans regarding the solution of complex problems." For the problem-solving factor, all five items were phrased negatively (e.g., "I cannot apply the solution methods I plan step by step"), so they were reverse-coded during the analysis. The exploratory factor analysis (EFA) result of the scale in the study by Korkmaz and Bai (2019) is 0.83, with factor-specific values ranging from 0.613 to 0.805, indicating that it is a reliable scale to test students' CT skills. The scale was also used in studies by Ince and Koc (2021) and Martín-Núñez et al. (2023).

Table 4. Test results for CT skills

Dimensions	Pre-/post-test	n	Mean rank	Rank sum	z	p-value
Creativity	Negative rank	11	8.00	16.00	-0.932	0.351
	Positive rank	11	15.52	419.00		
	Equal	7				
Algorithmic thinking	Negative rank	8	9.94	79.50	-2.441	0.015
	Positive rank	18	15.08	271.50		
	Equal	3				
Cooperation	Negative rank	8	14.00	112.00	-2.089	0.037
	Positive rank	20	14.70	294.00		
	Equal	1				
Critical thinking	Negative rank	3	10.33	31.00	-2.978	0.003
	Positive rank	18	11.11	200.00		
	Equal	8				
Problem-solving	Negative rank	27	3.00	6.00	-4.588	0.000
	Positive rank	2	15.89	429.00		
	Equal	0				
CT (average score)	Negative rank	2	8.91	98.99	-4.357	0.000
	Positive rank	27	14.09	155.00		
	Equal	0				

STEM career interests scale

The STEM career interests scale by Oh et al. (2013) was used in this study. It is a 9-item scale, measuring students' STEM career interests through three distinct factors: interest in science, interest in technology, and interest in mathematics, three items each. The original scale was a 7-point Likert scale, from strongly disagree (1) to strongly agree (7). To align the scale with the CT skills scale, it was adjusted to a 5 Likert scale. This instrument was used for the pre- and post-tests. Sample questions were: "I am interested in taking courses that help me learn more about SCIENCE," and "I am interested in working in a career that allows me to use TECHNOLOGY related skills or knowledge." Oh et al. (2013) found high school students viewed technology and engineering as interconnected, not separate, due to limited engineering familiarity. The EFA result of this study with 92 students identified three factors with a total scale reliability of 0.88, indicating that it is a reliable scale to test students' STEM career interests.

Semi-Structured Interview

Interviews were used to determine the students' experiences, career orientation, and attitudes towards the course with eight questions. These questions asked students about their experiences after the robotics course (three questions), career orientation (three questions), attitude toward robotics (one question), and students' suggestions for the course improvements (one question) (**Appendix B**). Cell phones were used to record interviews with each student.

Data Analysis

In this study, data obtained from the CT scale and the STEM career interest scale were analyzed with SPSS 26. As the scores obtained from these scales did not distribute normally and the number of data was less than 30, the Wilcoxon signed rankings test was used to compare the pre- and post-test mean scores. The effect size (r) was interpreted as follows: 0.10 to 0.29 small effect, 0.30 to 0.49 moderate effect, 0.50 to 1.0 large effect (Cohen, 1988). Audio recordings obtained from semi-structured interviews were transcribed verbatim and coded into themes, then input into Excel for analysis. These analyses are used as part of the qualitative assessment of CT.

FINDINGS

Effects of the Robotics Course on CT Skills

Table 4 displays the results of pre- and post-tests for CT skills.

It was found that students' algorithmic thinking, cooperativity, critical thinking, and problem-solving significantly increased from after the course ($z_{\text{Algorithmic thinking}} = -2.441$, $z_{\text{Cooperativity}} = -2.089$, $z_{\text{Critical thinking}} = -2.978$, $z_{\text{Problem-solving}} = -4.588$, $z_{\text{Computational thinking}} = -4.357$, $p < 0.05$). When considering the effect size, critical thinking, problem-solving, and average CT show large effects ($r_{\text{Critical thinking}} = 0.553$, $r_{\text{Problem-solving}} = 0.852$, $r_{\text{Computational thinking}} = 0.809$), while algorithmic thinking and cooperativity demonstrate moderate effects ($r_{\text{Algorithmic thinking}} = 0.453$, $r_{\text{Cooperativity}} = 0.388$). On the contrary, students' creativity remained the same, with no significant changes ($z_{\text{Creativity}} = -0.932$, $p = 0.351$). Overall, the robotics course has a positive impact on most aspects of CT skills, except for creativity.

Effects of the Robotics Course on the STEM Career Interests

Table 5 shows the results of pre-post tests on students' STEM career interests.

Table 5. Test results for STEM career interests

Factors	Pre-/post-test	n	Mean rank	Rank sum	z	p-value
Interest in science	Negative rank	6	6.67	40.00	-2.827	0.005
	Positive rank	16	13.31	213.00		
	Equal	7				
Interest in technology	Negative rank	1	14.50	14.50	-3.395	0.001
	Positive rank	19	10.29	195.50		
	Equal	9				
Interest in mathematics	Negative rank	4	7.50	30.00	-1.971	0.049
	Positive rank	12	8.83	106.00		
	Equal	13				
STEM career interest (average score)	Negative rank	2	6.75	13.50	-3.788	0.000
	Positive rank	21	12.50	262.50		
	Equal	6				

Table 6. What students learned

Knowledge	Skills	Qualities
Programming (all)	Technical skills (all)	Meticulousness (S1, S2, S3, and S5)
AI (S3, S4)	Designing (S1, S2, S4, and S5)	Cooperation (S3)
	Teamwork (S3)	Diligence (S2)
	Creativity (S2, S5, and S6)	
	Observation (S6)	

It was found that students' interests in STEM careers (science, technology, engineering, and mathematics) as well as average STEM career interest changed significantly after the robotics course ($z_{Science} = -2.827$, $z_{Technology} = -3.395$, $z_{Mathematics} = -1.971$, $z_{STEM\ career} = -3.788$, $p < 0.05$). When considering the effect size, science, technology, and the average STEM career interest demonstrate large effects ($r_{Science} = 0.525$, $r_{Technology} = 0.630$, $r_{Mathematics} = 0.366$, $z_{STEM\ career} = 0.703$), while mathematics shows a moderate effect. The difference between the pre- and post-test is most evident in interest in technology. This can be explained by the fact that robotics activities in the course tend to emphasize technical and science aspects more than mathematics. The effect sizes of the average score of STEM career interest were found to be high ($r = 0.876$). It can be concluded that the robotics course had a significant effect on students' interest in science, interest in technology, and interest in mathematics.

Students' Perceptions of the Block-Based Arduino Course

The interview data were reported based on four aspects: what they learned, challenges they faced, their career intentions, attitudes towards robotics, and students' suggestions for course improvements.

What students learned

Table 6 summarizes students' responses to questions about what they learned during the course.

When asked about what they gained or learned from the project and after the course, students reported different aspects of knowledge, skills, and qualities, as shown in **Table 6**. All students thought that they had a better understanding of programming and their technical skills improved.

As regards skills, designing and creativity were the ones many students claimed that they developed during the course. Two of them said:

> Carefulness, creativity, meticulousness, and diligence. I learned these through designing posters and building the car (S2).

> In my opinion, the knowledge and skills most important to me are in the robot assembly process. It helps me become more meticulous and fosters creative thinking in designing and constructing robot models (S5).

For qualities, four students believed that the project helped them to become more meticulous. Two of them said:

> Designing the robot requires meticulousness and carefulness; just one slip can ruin the entire line. You also need to know how to connect the electrical wires properly (S1).

> In my opinion, the knowledge and skills most important to me are in the robot assembly process. It helps me become more meticulous and fosters creative thinking in designing and constructing robot models (S5).

Besides these common aspects of things they learned after the course, the interviewing students also reported other aspects of knowledge, skills, and qualities: AI (2 students), teamwork (1), observation (1), and cooperation and diligence (1). For AI, one student mentioned that the program helped them understand how AI is applied in traffic systems, guiding robots to follow routes and turn left or right (S4), and another noted that AI could read visual information and convert it into data to help vehicles navigate (S3).

Overall, the students' interview data highlighted significant learning outcomes from the project, including improved programming knowledge and technical skills, as well as emphasizing the value of designing, creativity, and meticulousness in engineering tasks as well as the benefits of teamwork, cooperation, and diligence.

Perceived challenges

Regarding the difficulties encountered during the project, four students (S1, S2, S6, and S7) reported challenges with assembly, two students (S3 and S5) found coding difficult, and one (S7) mentioned challenges in training the ML model to recognize traffic signs. Two of them said:

> The hardest part was wiring the circuits to connect the robot and make it move (S2).

> Coding was the hardest because it was quite difficult for me (S5).

Given that only 4 out of the 29 students had previous experience with robotics, and only 2 of the 7 interviewees had engaged with it before and the project spanned only 12 sessions, it is easy to understand why students found it challenging to grasp a wide range of new knowledge and skills in this unfamiliar field.

When asked about how they overcame difficulties, five out of seven students said they sought assistance from the teachers (S1, S2, S4, S5, and S7), while three students mentioned help from peers (S1, S3, and S4). Students were not able to articulate clearly what specific challenges or solutions their group implemented, indicating a level of dependence on teacher support and a lack of confidence in independently solving problems during the project.

Career intentions

Three out of seven students (S2, S6, and S7) felt that STEM careers were not suitable for them, while four students (S1, S3, S4, and S5) believed the course positively influenced their STEM career orientation. Of these, two students (S1 and S5) confirmed they would pursue a STEM career, while two others (S3 and S4) remained undecided. Students cited career orientation benefits such as clearer career paths (S5), more job options (S3), and the applicability of knowledge to fields like IT (S1), as well as recognizing the importance of science and technology (S4).

On the contrary, one student believed that the course was not able to guide him to any STEM career. He said,

> Learning to code only helped me type faster and did not guide me toward any career. For those passionate about this subject, it might seem easy. For those who find it boring and uninteresting, with all the numbers and coding involved, it won't seem easy at all (S2).

It is important to note that the technical and mathematical nature of STEM robotics may not appeal to all students. Realizing that they are not suited for STEM careers after participating in the project can also be considered a valuable outcome in career orientation.

For the two students who expressed a desire to pursue STEM careers, they were asked about their future study and training plans. S1 said,

> "I should learn more things, watch videos on assembling, and designing electrical circuits."

S5 mentioned,

> "I think I need a clear plan and focus on science subjects like IT, math, physics, and chemistry."

These responses suggest that the students are beginning to form ideas about their career paths and the steps they need to take to achieve their career goals.

Attitudes and suggestions for future robotics courses

When being asked about how students' understanding and perception of robotics changed after participating in the program, some found robotics very interesting (S1, S2, and S3), noted rapid progress in the field (S5 and S6), and considered it beneficial (S5). After the project, students expressed more interest in robotics (S6), felt they learned more about it (S7), found it easier to understand and more intriguing (S1), and gained a broader perspective on its applications (S2). Overall, the project provided students with direct learning and practice with the basic aspects of robotics, sparking curiosity and enthusiasm for this relatively new subject.

As regards students' suggestions for course improvement, the responses are quite varied and somehow contradictory. Some students suggested lengthening the course and adding more small activities (S1, S4, and S6), increasing the focus on circuit assembly (S1 and S3), coding (S3 and S4), teamwork (S1), organizing more frequent robotics programs to provide students with the necessary experience and knowledge (S5 and S7). S1 and S2 suggested reducing the amount of coding, while two others (S4 and S6) felt that all activities were useful and none should be removed. One student (S2) said that the program should start with easier concepts and gradually increase in difficulty.

Based on these responses, it is clear that while most students found the robotics course engaging and beneficial, they were still apprehensive about the challenges, particularly coding. Providing more detailed guidance and individualized support in future iterations of the course is essential for addressing these concerns.

In sum, the interviews revealed that the robotics project had a positive impact on students' learning, with gains in programming, technical skills, soft skills (creativity and teamwork), and qualities such as meticulousness. The hands-on activities, including assembly, coding, and AI applications, sparked interest in engineering for some, while others appreciated the exposure to real-world applications of technology. However, students faced notable challenges, particularly with coding and circuit assembly, given their limited prior experience and the project's 12-session duration. The reliance on teacher support to overcome these difficulties indicated a need for more confidence-building in problem-solving. In terms of career orientation, the project influenced some students toward STEM fields, providing clearer career paths and highlighting the relevance of science and technology while a few students realized that STEM might not suit them. Suggestions for course improvements, such as lengthening the duration, starting with simpler concepts, and increasing focus on certain skills, indicate a desire for a more gradual learning curve. The varied yet contradictory suggestions for course improvement are also meaningful for STEM teachers to pay attention to individualized learning.

DISCUSSION

The study found that the robotics course improved students' self-reported CT skills, specifically in almost all measured CT factors: algorithmic thinking, cooperation, critical thinking, and problem-solving. This improvement aligns with the growing body of literature supporting the role of robotics and hands-on, project-based learning in CT development (Chen & Chang, 2018; Ince & Koc, 2021; Karaahmetoğlu & Korkmaz, 2019; Yin et al., 2022). Our study's findings resonate with findings from Karaahmetoğlu and Korkmaz (2019), as both studies demonstrate the efficacy of Block-based Arduino robotics projects in enhancing problem-solving skills over more abstract or non-physical programming activities. Korkmaz's observation that physical interaction with robotics tools strengthens CT development aligns with our findings on the positive impact of physical robotics on algorithmic thinking and engineering skills (Karaahmetoğlu & Korkmaz, 2019).

While some of the seven students mentioned in interviews that their creativity improved during the course, the pre-/post-test results indicated no significant changes in creativity after completing the robotics course. This inconsistency arises from the differing groups involved in the interviews and tests, as well as the nature of participants' subjective self-assessments in both methods. Our results align with findings by Ince and Koc (2021), which found that creativity, along with cooperation and problem-solving, did not show notable gains. One explanation proposed in Ince and Koc's (2021) study is that the short duration of the course may have limited opportunities for students to develop comprehensive CT skills. Time constraints hinder students' ability to fully develop CT skills and engage deeply with complex robotics topics like coding and troubleshooting (Ching & Hsu, 2024; Kopcha et al., 2017; Sarı et al., 2018). Students in this study faced challenges due to limited prior experience in programming and robotics, compounded by time constraints, leading to heavy reliance on teacher guidance and reduced opportunities for creative, independent learning. Another explanation is that task-specific activities like robotics projects may not promote creativity because they focus on achieving specific technical goals and limit open-ended exploration, which is essential for fostering creativity (Yin et al., 2022). The robotics project has primarily centered around a single product with a fixed operating principle, limiting opportunities for students to experiment with diverse robotics models and ideas. This narrow focus restricts creativity and innovation. However, more objective methods of assessment are needed to assess these CT skill factors more accurately, such as detailed observation of the learning process of CT skills.

This study also found that the block-based Arduino robotics course significantly increased students' interest in STEM careers, particularly in technology, followed by science and mathematics. This aligns with prior research, which underscores the role of robotics and hands-on engineering activities in motivating students toward STEM careers. The results align well with the affective gains reported by Ince and Koc (2021), where students engaging in similar robotics activities expressed increased enjoyment, interest in programming, and self-confidence in project development, all of which contribute to career orientation. This suggests that both structured robotics programs and hands-on, real-world applications can enhance students' motivation and perceived relevance of STEM fields. The significant increase in students' interest in technology, driven by their exposure to technical tasks such as coding, sensor integration, and ML, resonates with Chiang et al.'s (2022) that task value is critical in shaping students' attitudes and career intentions in STEM. The study's use of Arduino to introduce students to technical skills made these tasks feel highly relevant, reinforcing students' motivation to pursue technology-related careers. Our course engaged students in R&D role-playing tasks, bridging academic learning with real-world applications, thus helping students better understand diverse STEM professions, from engineering design to software development. This practical exposure may have contributed to the heightened interest in STEM, as students could envision how technology and science skills apply to real-world challenges. The emphasis on role-playing as R&D teams allows students to gain a broader perspective on STEM career paths and responsibilities. This approach, highlighted by Eguchi (2010) helps students develop goal-oriented thinking and understand how STEM fields contribute to meaningful, real-world outcomes. However, it should be noted that the above results only reflect students' temporary interest immediately after the course. To truly help students pursue STEM fields in the future, it is essential to cultivate their long-term and sustainable interests, which requires longitudinal studies.

While some students discovered a newfound interest in STEM, not all students were equally enthusiastic about robotics and STEM careers, with some feeling that STEM was not suited to their long-term interests. This result is also entirely consistent with the social cognitive theory of career development, which posits that providing more opportunities through career-related learning experiences helps students assess their suitability for a particular profession and make informed decisions about whether to pursue a STEM career (Lent et al., 1994).

Students' perceptions of robotics activities were diverse. Most interviewed students recognized the benefits of robotics in enhancing programming, technical skills, teamwork, and creativity. These results demonstrate that the robotics course delivered effects beyond our study's objectives and theoretical framework; however, they remain consistent with previous research findings. Ince and Koc (2021) and Yin et al. (2022) noted that active, collaborative robotics activities not only increase technical skills but also enhance students' confidence, critical thinking, and interest in STEM. The collaborative structure of the course was another key factor positively influencing students' perceptions. Many students noted the importance of teamwork, as they relied on each other's strengths to overcome obstacles and enhance group productivity. This collaborative dynamic aligns with findings from Badeleh (2021) which showed that robotics fosters social skills, communication, and leadership as students work together to bring projects to completion. This experience also resonated with teacher candidates in a study by Sarı et al. (2018), who viewed hands-on STEM activities as effective for enhancing collaboration skills. The course also sparked genuine curiosity about robotics, with students expressing excitement about real-world applications like autonomous vehicles and smart technologies, a finding echoed by Pérez and López (2019). However, these are only preliminary findings based on interviews with a small number of students, and further in-depth studies are needed to explore these effects on larger student samples in Vietnam.

A key challenge in implementing robotics activities is the cost of equipment and materials. Many schools in Vietnam and other developing countries operate with limited resources, and advanced equipment like robotics kits may be unaffordable for most institutions (Le et al., 2023). This challenge is echoed in previous studies (Chen & Chang, 2018; Pérez & López, 2019) where high costs hinder the integration of robotics in schools, particularly in developing regions. In our course, we addressed budget constraints by using Arduino boards combined with affordable materials like foam boards and open-source components, making the course more accessible. This approach aligns with Chen and Chang (2018) who advocate for low-cost, adaptable materials in educational robotics. However, our research still faced challenges in preparation as boarding students could not take equipment home or buy extra materials, and most lacked personal laptops due to limited economic conditions.

Compared to other previous studies (Chen & Chang, 2018; Yin et al., 2022), this research lacks formal assessments of knowledge gains and detailed individual assessments, which limits a closer examination of each student's unique learning process. Additionally, the course has not effectively integrated robotics instruction with teaching core concepts from Vietnam's physics or technology curriculum, which can restrict the potential for incorporating robotics into high school education.

Recommendations for Further Research

To enhance the effectiveness and depth of robotics courses, extending the course duration is essential. A longer timeframe would allow students to move from basic concepts to more advanced robotics applications, promoting a deeper mastery of programming, mechanical assembly, and design skills. With a structured curriculum that builds progressively in complexity, students could gain both foundational and advanced knowledge, enabling them to approach projects with greater independence and creativity. This extended time would also provide opportunities for iterative learning, allowing students to apply feedback and refine their solutions, fostering a richer understanding of robotics concepts. Furthermore, integrating longitudinal studies into these extended courses could track and nurture students' sustained interest in STEM careers, ensuring that their engagement evolves into a long-term commitment through practical experiences, career-oriented projects, and continuous skill development.

To effectively implement STEM robotics education, a general understanding of robotics is essential for teachers apart from the subject's content knowledge (Le et al., 2023). Regular teacher professional development programs should prioritize supporting STEM teachers to meet the need for education for change for students (Le, 2021). STEM resources and robotics competitions should be strongly supported (Nguyen et al., 2019). Science teachers should use teaching approaches of the "applications of science" and "hands-on/practical activities" in their lessons to improve their performances of career-orientation teaching which enhances students' aspirations toward STEM careers as found by Ho and Dinh (2018) and our study as well as significantly improves students' CT skills.

Another important recommendation is to broaden the sample size and diversity of participants, including students from multiple classes or backgrounds. This diversity would improve the generalizability of the findings and offer insights into how different demographics respond to robotics education. Including a control group would allow for more rigorous comparisons, helping to isolate the specific effects of the robotics course on students' learning outcomes (Chen & Chang, 2018; Karaahmetoğlu & Korkmaz, 2019). Furthermore, integrating more open-ended, creative projects would provide students with opportunities to design their solutions rather than strictly following preset instructions. Such an approach could significantly enhance critical thinking, problem-solving, and creativity, as students would be encouraged to experiment and make decisions independently.

Lastly, it is suggested to incorporate interdisciplinary concepts and formal assessments of student learning. By integrating subjects like physics and technology, students can see how robotics applies across STEM fields, deepening their understanding and engagement. Formal pre- and post-course assessments could provide valuable data on students' knowledge gains and skill development, tracking growth in both theoretical and practical competencies. Individual assessments during activities would also allow educators to observe each student's progress and tailor instruction to meet their unique learning needs.

CONCLUSIONS

This study indicates that a block-based Arduino robotics course can substantially enhance CT skills and stimulate interest in STEM among Vietnamese upper secondary students, with broader implications for other developing nations. Robotics education, even when constrained by budgetary and resource limitations, demonstrates the potential to bridge the technological divide and equip students for careers in high-tech industries. Quantitative analyses reveal significant improvements in key CT skills, including creativity, algorithmic thinking, cooperation, critical thinking, and problem-solving. Students also showed a heightened interest in STEM–particularly in technology–suggesting that hands-on robotics education may effectively nurture career aspirations in science and engineering as well as offer students valuable experiences to explore their suitability for STEM careers. The course's practical, collaborative, and applied robotics projects not only engaged students but also allowed them to envision tangible STEM career pathways, underscoring the value of experiential learning. These findings are essential for fostering a skilled, technologically adept workforce, particularly in economies like Vietnam, which are increasingly focused on cultivating high-tech industries.

To optimize these benefits, future robotics programs in Vietnam and other developing countries should consider extended course durations, diverse project types, and interdisciplinary integration. Expanding teacher training and access to cost-effective, open-source resources will be crucial in supporting students and ensuring that robotics education remains inclusive. By addressing these challenges, developing countries such as Vietnam can leverage robotics education to empower the next generation, equipping students with the skills and curiosity needed to excel in an increasingly technology-driven global landscape.

Author contributions: LCD: conceptualization, data curation, formal analysis, investigation, writing – original draft, writing - review & editing; **HTP:** supervision, methodology, validation, writing - review & editing; **NTN:** project administration, conceptualization, supervision, resources. All authors agreed with the results and conclusions.

Funding: This study was funded by the Vingroup Innovation Foundation.

Acknowledgments: The authors would like to thank the Vingroup Innovation Foundation for their funding through this paper with code VINIF.2023.ThS.032.

Ethical statement: The authors stated that the study was approved by the institutional ethics committee of Ho Chi Minh City University of Education on 10th January, 2024 (Approval code: ECSH-2024-004). All participants were informed about the research aims and all permissions for data collection were requested. Codes were used to ensure participants' anonymity.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Altin, H., & Pedate, M. (2013). Learning approaches to applying robotics in science education. *Journal of Baltic Science Education, 3*, 365-377. https://doi.org/10.33225/jbse/13.12.365

Arís, N., & Orcos, L. (2019). Educational robotics in the stage of secondary education: Empirical study on motivation and STEM skills. *Education Sciences, 9*(2), Article 73. https://doi.org/10.3390/educsci9020073

Badeleh, A. (2021). The effects of robotics training on students' creativity and learning in physics. *Education and Information Technologies, 26*(2), 1353-1365. https://doi.org/10.1007/s10639-019-09972-6

Barak, M., & Zadok, Y. (2009). Robotics projects and learning concepts in science, technology and problem solving. *International Journal of Technology and Design Education, 19*(3), 289-307. https://doi.org/10.1007/s10798-007-9043-3

Barger, M. (2015). Do K12 robotics activities lead to engineering and technology career choices? In *Proceedings of the 122nd ASEE Annual Conference & Exposition*. ASEE.

Budiyanto, C. W., Fenyvesi, K., Lathifah, A., & Yuana, R. A. (2022). Computational thinking development: Benefiting from educational robotics in STEM teaching. *European Journal of Educational Research, 11*(4), 1997-2012. https://doi.org/10.12973/eu-jer.11.4.1997

Bybee, R. W. (1997). Achieving scientific literacy: From purposes to practices. *ERIC*. https://eric.ed.gov/?id=ED461491

Bybee, R. W. (2019). Using the BSCS 5E instructional model to introduce STEM disciplines. *Science and Children, 56*(6), 8-12. https://doi.org/10.2505/4/sc19_056_06_8

Chen, Y., & Chang, C.-C. (2018). The impact of an integrated robotics STEM course with a sailboat topic on high school students' perceptions of integrative STEM, interest, and career orientation. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(12), Article em1614. https://doi.org/10.29333/ejmste/94314

Chevalier, M., Giang, C., Piatti, A., & Mondada, F. (2020). Fostering computational thinking through educational robotics: A model for creative computational problem solving. *International Journal of STEM Education, 7*(1), Article 39. https://doi.org/10.1186/s40594-020-00238-z

Chiang, F.-K., Zhang, Y., Zhu, D., Shang, X., & Jiang, Z. (2022). The influence of online STEM education camps on students' self-efficacy, computational thinking, and task value. *Journal of Science Education and Technology, 31*(4), 461-472. https://doi.org/10.1007/s10956-022-09967-y

Ching, Y.-H., & Hsu, Y.-C. (2024). Educational robotics for developing computational thinking in young learners: A systematic review. *TechTrends, 68*(3), 423-434. https://doi.org/10.1007/s11528-023-00841-1

Church, W., Ford, T., Perova, N., & Rogers, C. (2010). Physics with robotics using LEGO® MINDSTORMS® in high school education. In *Proceedings of the 2010 AAAI Spring Symposium Series on Educational Robotics and Beyond*. AAAI.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Routledge.

Cruz, S., Bento, M., & Lencastre, J. A. (2021). Computational thinking training using PictoBlox: Exploratory study with students of primary degree. In *Proceedings of the International Conferences Internet Technologies & Society 2021, Applied Management Advances in the 21st Century 2021 and Sustainability, Technology and Education 2021* (pp. 53-60).

Eguchi, A. (2010). What is educational robotics? Theories behind it and practical implementation. In D. Gibson, & B. Dodge (Eds.), *Proceedings of SITE 2010–Society for Information Technology & Teacher Education International Conference* (pp. 4006-4014).

Ertugrul-Akyol, B. (2019). Development of computational thinking scale: Validity and reliability study. *International Journal of Educational Methodology, 5*(3), 421-432. https://doi.org/10.12973/ijem.5.3.421

Fidai, A., Capraro, M. M., & Capraro, R. M. (2020). "Scratch"-ing computational thinking with Arduino: A meta-analysis. *Thinking Skills and Creativity, 38*, Article 100726. https://doi.org/10.1016/j.tsc.2020.100726

Fleger, C.-B., Amanuel, Y., & Krugel, J. (2023). Learning tools using block-based programming for AI education. In *Proceedings of the 2023 IEEE Global Engineering Education Conference* (pp. 1-5). IEEE. https://doi.org/10.1109/EDUCON54358.2023.10125154

García, J. D. R., Moreno-León, J., Román-González, M., & Robles, G. (2020). LearningML: A tool to foster computational thinking skills through practical artificial intelligence projects. *Revista de Educación a Distancia, 20*(63), Article 7. https://doi.org/10.6018/red.410121

Gavrilas, L., & Kotsis, K. T. (2024). Investigating perceptions of primary and preschool educators regarding incorporation of educational robotics into STEM education. *Contemporary Mathematics and Science Education, 5*(1), Article ep24003. https://doi.org/10.30935/conmaths/14384

Guven, G., Kozcu Cakir, N., Sulun, Y., Cetin, G., & Guven, E. (2022). Arduino-assisted robotics coding applications integrated into the 5E learning model in science teaching. *Journal of Research on Technology in Education, 54*(1), 108-126. https://doi.org/10.1080/15391523.2020.1812136

Hieu, N. T., Huy, L. M., Phat, H. M., Anh, N. N. P., & Wong, W.-K. (2020). Decision sciences in education: The STEMtech model to create stem products at high schools in Vietnam. *Advances in Decision Sciences, 24*(2), 1-50. https://doi.org/10.47654/v24y2020i2p15-65

Ho, T. H. V., & Dinh, Q. B. (2018). Effective science teaching approaches to teaching STEM career orientation of upper secondary school teachers: A case study in Vietnam. *Rangsit Journal of Educational Studies, 5*(2), 64-75. https://doi.org/10.14456/rjes.2018.11

Hsu, T.-C., & Chen, M.-S. (2022). The engagement of students when learning to use a personal audio classifier to control robot cars in a computational thinking board game. *Research and Practice in*

Technology Enhanced Learning, 17(1), Article 27. https://doi.org/10.1186/s41039-022-00202-1

Ince, E. Y., & Koc, M. (2021). The consequences of robotics programming education on computational thinking skills: An intervention of the Young Engineer's Workshop (YEW). *Computer Applications in Engineering Education, 29*(1), 191-208. https://doi.org/10.1002/cae.22321

International Labor Organization Country Office for Vietnam. (2020). *Career research book*. International Labor Organization Country Office for Vietnam.

Karaahmetoğlu, K., & Korkmaz, Ö. (2019). The effect of project-based Arduino educational robot applications on students' computational thinking skills and their perception of basic stem skill levels. *Participatory Educational Research, 6*(2), 1-14. https://doi.org/10.17275/per.19.8.6.2

Khanlari, A. (2013). Effects of educational robots on learning STEM and on students' attitude toward STEM. In *Proceedings of the 2013 IEEE 5th Conference on Engineering Education* (pp. 62-66). https://doi.org/10.1109/ICEED.2013.6908304

Koorn, J. J., Leopold, H., & Reijers, H. A. (2018). A task framework for predicting the effects of automation. *AIS*. https://aisel.aisnet.org/ecis2018_rp/141

Kopcha, T. J., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R., Mativo, J., & Choi, I. (2017). Developing an integrative STEM curriculum for robotics education through educational design research. *Journal of Formative Design in Learning, 1*(1), 31-44. https://doi.org/10.1007/s41686-017-0005-1

Korkmaz, Ö., & Bai, X. (2019). Adapting computational thinking scale (CTS) for Chinese high school students and their thinking scale skills level. *Participatory Educational Research, 6*(1), 10-26. https://doi.org/10.17275/per.19.2.6.1

Le, H. M. N., Dang, N. K., Tran, N. A.-K., Nguyen, T. K.-A., & Nguyen, V. B. (2023). Exploring perspective of teachers on STEM robotics education in some high schools in Ho Chi Minh City–Vietnam. AIP Conference Proceedings, 2685(1), Article 030021. https://doi.org/10.1063/5.0114781

Le, T. C. T., & Nguyen, K. P. (2023). Implementing project-based teaching in physics 10 to develop career orientation competencies for students. *Vietnam Journal of Education, 2023*, 6-11. https://tcgd.tapchigiaoduc.edu.vn/index.php/tapchi/article/view/679

Le, T. Q. T. (2021). Principles for integrating career education into technology teaching in high schools to meet the requirements of the new general education curriculum. *Vietnam Journal of Education, 500*(2), 16-19. https://tcgd.tapchigiaoduc.edu.vn/index.php/tapchi/article/view/105

Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior, 45*(1), 79-122. https://doi.org/10.1006/jvbe.1994.1027

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2020). Computational thinking is more about thinking than computing. *Journal for STEM Education Research, 3*, 1-18. https://doi.org/10.1007/s41979-020-00030-2

Luo, T., So, W. W. M., Wan, Z. H., & Li, W. C. (2021). STEM stereotypes predict students' STEM career interest via self-efficacy and outcome expectations. *International Journal of STEM Education, 8*(1), Article 36. https://doi.org/10.1186/s40594-021-00295-y

Maltese, A. V., Melki, C. S., & Wiebke, H. L. (2014). The nature of experiences responsible for the generation and maintenance of interest in STEM. *Science Education, 98*(6), 937-962. https://doi.org/10.1002/sce.21132

Martín-Núñez, J. L., Ar, A. Y., Fernández, R. P., Abbas, A., & Radovanović, D. (2023). Does intrinsic motivation mediate perceived artificial intelligence (AI) learning and computational thinking of students during the COVID-19 pandemic? *Computers and Education: Artificial Intelligence, 4*, Article 100128. https://doi.org/10.1016/j.caeai.2023.100128

Ministry of Education and Training. (2018a). General education curriculum. *Ministry of Education and Training*. https://en.moet.gov.vn/

Ministry of Education and Training. (2018b). Informatics education curriculum. *Ministry of Education and Training*. https://en.moet.gov.vn/

Mitchell, T. M. (1997). *Machine learning*. McGraw-Hill.

Nguyen, D. D., Nguyen, V. B., Nguyen, T. T. K., Nguyen, T. V. H., Hoang, T. T. A., & Ngo, T. P. A. (2024). Arduino-based experiments: Leveraging engineering design and scientific inquiry in STEM lessons. *International Journal of STEM Education for Sustainability, 4*(1), 38-53. https://doi.org/10.53889/ijses.v4i1.317

Nguyen, M. D., Nguyen, Q. L., & Yuenyong, C. (2019). Situation of organizing STEM activities in Vietnamese schools. *Journal of Physics: Conference Series, 1340*, Article 012030. https://doi.org/10.1088/1742-6596/1340/1/012030

Nugent, G., Barker, B., Grandgenett, N., & Welch, G. (2016). Robotics camps, clubs, and competitions: Results from a US robotics project. *Robotics and Autonomous Systems, 75*, 686-691. https://doi.org/10.1016/j.robot.2015.07.011

Oh, Y. J., Jia, Y., Lorentson, M., & LaBanca, F. (2013). Development of the educational and career interest scale in science, technology, and mathematics for high school students. *Journal of Science Education and*

Technology, 22(5), 780-790. https://doi.org/10.1007/s10956-012-9430-8

Omotayo, S. A., & Adeleke, J. O. (2017). The 5E instructional model: A constructivist approach for enhancing students' learning outcomes in mathematics. *Journal of the International Society for Teacher Education, 21*(2), 15-26. https://files.eric.ed.gov/fulltext/EJ1176946.pdf

Pérez, E. S., & López, F. J. (2019). An ultra-low cost line follower robot as educational tool for teaching programming and circuit's foundations. *Computer Applications in Engineering Education, 27*(2), 288-302. https://doi.org/10.1002/cae.22074

Pham, T. H., & Nguyen, T. H. (2023). Developing career-oriented competencies in high school students through biology teaching. *Vietnam Journal of Educational Sciences, 2023*, 44-50. http://vjes.vnies.edu.vn/sites/default/files/khdgvn_-_tap_19_-_so_01_-_no_08_-44-50.pdf

Quan, G. M., & Gupta, A. (2020). Tensions in the productivity of design task tinkering. *Journal of Engineering Education, 109*(1), 88-106. https://doi.org/10.1002/jee.20303

Ribeirinha, T., Baptista, M., & Correia, M. (2025). The impact of STEM activities on the interest and aspirations in STEM careers of 12th-grade Portuguese students in science and technology curriculum. *European Journal of STEM Education, 9*(1), Article 21. https://doi.org/10.20897/ejsteme/15830

Sarı, U., Alıcı, M., & Şen, Ö. F. (2018). The effect of STEM instruction on attitude, career perception and career interest in a problem-based learning environment and student opinions. *The Electronic Journal for Research in Science & Mathematics Education, 22*(1), 1-21. https://ejrsme.icrsme.com/article/view/17861

Sheldrake, R., Mujtaba, T., & Reiss, M. J. (2017). Science teaching and students' attitudes and aspirations: The importance of conveying the applications and relevance of science. *International Journal of Educational Research, 85*, 167-183. https://doi.org/10.1016/j.ijer.2017.08.002

Ta, T. T., & Le, C. D. (2024). Applying latent profile analysis (LPA) to group students based on academic performance and self-assessment of STEM competencies. *Ho Chi Minh City Open University Journal of Science, 19*(2), 28-44. https://doi.org/10.46223/HCMCOUJS.soci.vi.19.2.3070.1014

Taasoobshirazi, G., Peifer, J., Duncan, L., Ajuebor, A., & Sneha, S. (2024). An interdisciplinary approach to studying academic success in STEM. *Contemporary Mathematics and Science Education, 5*(2), Article ep24013. https://doi.org/10.30935/conmaths/14791

Tran, D. T., Truong, D. H., Le, H. S., & Huh, J.-H. (2023). Mobile robot: Automatic speech recognition application for automation and STEM education. *Soft Computing, 27*(15), 10789-10805. https://doi.org/10.1007/s00500-023-07824-7

Tran, K. M., & Nguyen, N. T. (2023). Developing computational thinking: An unplugged problem-solving approach. In *Proceedings of the 13th Congress of the European Society for Research in Mathematics Education*. https://hal.science/hal-04420633/

Trieu, N. S., Dang, H. M., & Nguyen, T. H. T. (2021). Designing experiential and career-oriented activities in mathematics teaching at middle schools. *Vietnam Journal of Education, 1*(515), 19-22. https://tcgd.tapchigiaoduc.edu.vn/index.php/tapchi/article/view/292

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. *Journal of Technology and Teacher Education, 18*(2), 345-368. https://www.learntechlib.org/primary/p/32311

US Bureau of Labor Statistics. (2019). Occupational outlook handbook 2019. *US Bureau of Labor Statistics*. https://www.bls.gov/ooh/

Wangenheim, C. G. von, Hauck, J. C. R., Pacheco, F. S., & Bertonceli Bueno, M. F. (2021). Visual tools for teaching machine learning in K-12: A ten-year systematic mapping. *Education and Information Technologies, 26*(5), 5733-5778. https://doi.org/10.1007/s10639-021-10570-8

Wanzala, J. N., Robson Atim, M., Wanzala, J., & Atim, M. (2021). AI based wireless traffic light detector using image classification in machine learning to reduce road traffic accidents: A case study of Uganda's road traffic. *International Journal of Electronics Communication and Computer Engineering, 12*(3), 85-93. https://ijecce.org/administrator/components/com_jresearch/files/publications/IJECCE_4403_FINAL.pdf

Williams, R., Ali, S., Devasia, N., DiPaola, D., Hong, J., Kaputsos, S. P., Jordan, B., & Breazeal, C. (2023). AI + ethics curricula for middle school youth: Lessons learned from three project-based curricula. *International Journal of Artificial Intelligence in Education, 33*(2), 325-383. https://doi.org/10.1007/s40593-022-00298-y

Yang, K., Liu, X., & Chen, G. (2020). The influence of robots on students' computational thinking: A literature review. *International Journal of Information and Education Technology, 10*(8), 627-631. https://doi.org/10.18178/ijiet.2020.10.8.1435

Yin, Y., Khaleghi, S., Hadad, R., & Zhai, X. (2022). Developing effective and accessible activities to improve and assess computational thinking and engineering learning. *Educational Technology*

Research and Development, 70(3), 951-988. https://doi.org/10.1007/s11423-022-10097-w

Yoon, J., & Ryu, J. H. (2024). STEM talk: Cultivating students' STEM affinity and careers. *Contemporary Mathematics and Science Education, 5*(1), Article ep24006. https://doi.org/10.30935/conmaths/14473

Zainal, N. F. A., Din, R., Abd Majid, N. A., Nasrudin, M. F., & Abd Rahman, A. H. (2018). Primary and secondary school students perspective on Kolb-based STEM module and robotic prototype. *International Journal on Advanced Science, Engineering and Information Technology, 8*(4-2), 1394-1401. https://doi.org/10.18517/ijaseit.8.4-2.6794

APPENDIX A: DETAILED LESSON PLAN & PROGRESSION OF STUDENTS' ACTIVITY

Table A1. Detailed lesson plan and progression of students' activity

Phase	Lesson plan	Progression
1. Engage	The course introduces students to the R&D process. This phase covers essential stages such as identifying project objectives, conducting market and technology research, selecting solutions, and testing and marketing products. Students are presented with a practical challenge in which they act as an R&D team within an automotive company (e.g., Tesla or Vinfast), tasked with designing a self-driving car. They are asked to divide into groups and assign roles in each group (e.g., project manager, technical specialists). Through brainstorming, students identify the key tasks and technical requirements for the car, such as line-tracking, sensor usage, ML integration, and aesthetic design. The concept of STEM careers, some notable STEM professions, STEM careers related to this robotics project was also introduced at this stage, and the subjects necessary for pursuing STEM careers.	- Students proposed some applications for autonomous vehicle systems, ranging from self-driving taxis (group 1) to industrial and delivery vehicles (group 2-group 5). - Key features identified included collision sensors, accurate GPS, and speed adjustment capabilities. Additional suggestions included remote control (group 4) and traffic sign recognition (group 5). - Product evaluation criteria emphasized safety, energy efficiency, durability, and navigation accuracy, with added focus on system upgrades (group 1) and operational stability (group 2 and group 3).
2. Explore	Students are introduced to the technical tools and components they will use throughout the project. This includes Pictoblox, the software used for programming and training ML models, and hardware components including Arduino microcontroller, sensors, and motor controllers. They then move to workstations, where they undertake specific tasks related to building their self-driving car. At station A, they control motors using an L298N motor driver circuit, while at station B, they connect and interpret signals from line-tracking sensors. At station C and station D, they engage in ML by training image recognition models to help the robot detect road signs.	**- Station A**: Groups encountered challenges such as loose connections, coding errors, and unstable power but resolved them with teamwork and teacher guidance. **- Station B**: Groups adjusted sensor sensitivity and motor response to enhance functionality. **- Station C and station D**: Groups faced data collection and diversity issues but improved their models through adjustments and teacher support.
3.Explain	Students share their findings and exchange knowledge gained with other groups, solidify their understanding of key concepts such as motor control, sensor integration, Arduino programming, and ML algorithms for line-tracking.	Students' discussions focused on enhancing line-following algorithms, optimizing response times, and expanding ML datasets for better traffic sign recognition. testing and optimization. They also worked together to debug coding errors, ensure more reliable performance
4. Elaborate	In this phase, students apply their newly acquired knowledge to design and build their self-driving car. They are tasked with developing the car's schematic, algorithm, and design blueprint. The design must include all the basic components of the car, such as sensors, motors, and control systems. Students assembled and programmed their robots based on the design.	Students completed diagrams outlining the self-driving car's functionality and signals. Most groups required guidance to finalize **c**omponent placement and signal pathways. Groups created detailed project plans, including task assignments, tool lists, cost estimates, and timelines. The assembling and programming process was filled with challenges, especially for team 2 and team 4, who struggled with wiring, Arduino issues, and coding errors, requiring teacher support. Team 5 faced difficulties in training their ML model, while team 1 had to refine its line-following code.
5. Evaluate	The final phase involves evaluating the students' work through a project exhibition. Teams present their self-driving robots in a simulated exhibition environment, where the robots are tested, and the best designs are recognized. After that, students will evaluate their own group's product and receive feedback from other groups based on the following criteria: strengths, weaknesses, and suggested improvements. In addition, students are also required to create and present a career-oriented poster (each group will present on one of the STEM careers listed in **Table 1**), including describing the career, the required qualities and competencies for the profession, employment demand, and educational institutions offering the training.	Students evaluated their vehicles through self- and peer-assessment, identifying strengths and proposing practical improvements. Feedback highlighted students' critical thinking, observation, and analytical skills, contributing to refining the car's performance and design.

APPENDIX B: INTERVIEW QUESTIONS

1. What role or task did you take on in your group?
2. What is the most important knowledge or skill you learned in the program? Through which activities did you acquire this skill?
3. Which activities were the most challenging for you? How did you (or your group) overcome these difficulties?
4. How do you think this program will benefit your future career?
5. After participating in the program, how has your perception of technical and scientific careers changed?
6. After this course, do you want to pursue a STEM-related career in the future? What personal development plans do you think you need to make to achieve your career goals? (for students considering a STEM career path).
7. After completing the program, how has your understanding and perception of robotics changed?
8. What would you like to be added or removed from the program? What improvements would you suggest?

https://www.ejmste.com