

Evaluating the effectiveness of a STEM education programme for at-risk migrant children via a car project

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Abstract

In this study we evaluated the effectiveness of a science, technology, engineering and mathematics (STEM) education programme for at-risk migrant in Northern Cyprus. The study involved 4 at-risk middle school learners from diverse backgrounds, selected based on specific socio-economic and educational disadvantage criteria. A single-subject, multiple-baseline design was employed to assess the impact of the intervention. In this article we report on an intervention through which the children were taught essential skills such as reading electrical circuit diagrams and artificial intelligence (AI)-supported Internet of Things (IoT) coding, through a remote-controlled car project. Data on participant performance were collected throughout the instructional phases using a structured observational checklist designed to measure acquisition of skills. The results indicate that participants gained significant technical skills because of this intervention. These results strongly suggest that when properly targeted, STEM programmes provide a valuable avenue to help close the educational gap for nondominant groups and present a model for use by educators and policymakers. This study is noteworthy for its focus on innovative educational interventions that attend to equity and technological proficiency, suggesting that STEM education may improve future career opportunities for at-risk migrant children.

Keywords: AI-assisted coding; at-risk migrant children; STEM education

Introduction

Education systems increasingly recognise that learning risks stemming from socio-economic deprivation, disrupted schooling, or language barriers should be addressed proactively before they calcify into chronic academic under-performance (Tubele, 2021). The concept of inclusive education, which aims to provide equitable and quality learning opportunities for all learners, is central to this effort. For children labelled at-risk, inclusive practices are not about remediation but about creating supportive learning environments that accommodate diverse needs and backgrounds. The group is heterogeneous, yet they often share exposure to stressors such as poverty, unstable family structures, or forced migration that can undermine cognitive development and school engagement (McClelland, Morrison & Holmes, 2000; Porche, Costello & Rosen-Reynoso, 2016). Among these, recently arrived migrant learners represent a particularly vulnerable sub-population: They must master a new language, navigate unfamiliar cultural norms, and adapt to differing pedagogical expectations, all while often lacking consistent social support. Although policy initiatives and international partnerships have expanded access to schooling for migrant children in Türkiye, and more acutely in the Turkish Republic of Northern Cyprus (TRNC), achievement data indicate persistent disparities in literacy, numeracy, and science outcomes. Evidence from comparative education suggests that these gaps cannot be closed by access alone; targeted interventions must cultivate higher-order competencies that underpin long-term academic success and labour-market resilience (Cavadova, 2023; Ni, Chui, Ji, Jordan & Chan, 2016).

One promising pathway is the integration of science, technology, engineering and mathematics (STEM) curricula with artificial-intelligence (AI)-supported learning tools. Unlike traditional, rote-learning models, project-based STEM activities nurture inquiry, iterative design thinking and data-driven problem-solving – skills aligned with tomorrow's workforce needs (Chen & Chen, 2021). Embedding AI-assisted coding environments further personalises feedback, automates error-checking and elevates learner motivation, thereby lowering entry barriers for novices (Mijwil, Ali & Sadıkoğlu, 2023). However, systematic investigations of AI-enhanced STEM programmers for migrant learners remain scarce, particularly in small-island contexts such as the TRNC (Xu & Ouyang, 2022). When implemented in an inclusive framework, such hands-on approaches can be particularly empowering for migrant learners as they transcend language barriers and allow learners to demonstrate competence through tangible outcomes.

This study is significant because it concentrates on a critical intersection of educational equity and technological advancement. By focusing on a hands-on, project-based learning model, it moves beyond “cookbook-style” instruction, where learners merely follow a list of prescribed steps. Instead, the intervention was designed to foster genuine problem-solving skills, creativity, and engineering design thinking. Evaluating such an approach for at-risk migrant children, a population often excluded from advanced technological learning, provides a vital evidence base for educators and policymakers seeking to develop more inclusive and effective educational strategies for the 21st century.

Research Problem

Despite expanded access to schooling in Türkiye and the TRNC, migrant and socio-economically disadvantaged learners continue to demonstrate persistent gaps in science literacy and problem-solving skills. Many existing educational programmes implicitly assume that learners already possess representational fluency and sufficient language proficiency. Consequently, learners often struggle with interpreting circuit diagrams, executing accurate wiring, and integrating systems effectively. Prior research shows that targeted instructional support, particularly those using visual displays and systematically sequenced multiple representations, can significantly enhance diagram comprehension (Cromley & Chen, 2024). Similarly, active and hands-on learning experiences have been found to yield substantial improvements in STEM achievement (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt & Wenderoth, 2014). However, in small-island and resource-constrained contexts, empirical evidence on the effectiveness of a staged, component-wise STEM pathway that also incorporates AI-assisted coding and IoT-based remote control for at-risk migrant youth remains scarce (Al-Emran, Malik & Al-Kabi, 2019; Xu & Ouyang, 2022).

Research Aim

The primary aim of this study was to evaluate the effectiveness of a comprehensive STEM education programme designed for at-risk migrant children living in Northern Cyprus. The TRNC was selected due to its unique context as a small-island state with a growing and diverse migrant population. This setting presents distinct challenges, including limited resources and specific social integration dynamics, making it a critical environment for examining the impact and adaptability of targeted educational interventions. While the intervention aimed to enhance technological proficiency and provide a strong foundation in STEM disciplines, its broader goal was to help close the educational gap that at-risk migrant children face. This was done by fostering critical thinking, problem-solving, creativity, and collaboration, which are essential skills for academic success and long-term career development. Our research is important as it examines an innovative educational intervention that focuses on equity and technological proficiency, thereby contributing a model that educators and policymakers can use in supporting at-risk populations.

Research Questions

How effective is the five-phase STEM-based remote-controlled car project in teaching identified skills to at-risk migrant children?

- 1) What are the effects of the first instructional phase on learners' ability to recognise circuit elements and

interpret diagrams, and how does this foundational knowledge influence subsequent wiring tasks?

- 2) To what extent does the second phase develop learners' proficiency in translating circuit diagrams into correct physical connections, and what challenges commonly arise during this translation process?
- 3) How does the third phase that focus on electromechanical assembly affect learners' ability to integrate components into a functional prototype, and what does this reveal about their applied engineering thinking?
- 4) What competency levels do learners achieve in using a mobile application for IoT control and data transmission in the fourth phase, and how does this digital interaction impact their understanding of system connectivity?
- 5) To what degree are the AI-assisted coding skills acquired in the fifth phase retained over time, and can learners generalise the electromechanical assembly skills to a novel context?

Conceptual Framework

This study is grounded in the principles of scaffolded learning in a STEM context. Scaffolding, a concept introduced by Wood, Bruner and Ross (1976) and widely applied in educational psychology, refers to a process through which a teacher or more knowledgeable peer provides temporary support to learners to help them achieve a task that they would be unable to complete on their own. This support is gradually withdrawn as the learners' competence increases. In this study, the five-phase structure of the remote-controlled car project acted as a scaffold. Each phase built on the skills acquired in the previous one, starting from foundational knowledge like recognising circuit elements and progressing to more complex tasks such as AI-assisted coding. This structured, incremental approach is particularly beneficial for at-risk learners who may lack prior knowledge and confidence in STEM subjects (Quintana, Reiser, Davis, Krajik, Fretz, Duncan, Kyza, Edelson & Soloway, 2004). The use of various instructional aids such as visual cards, video modelling, and direct instruction at each stage represents specific scaffolding techniques designed to support the learners at their point of need. By systematically building skills and providing targeted support, the aims with the programme was to foster not only technical proficiency but also learner autonomy and self-efficacy in STEM.

Literature Review

An increasing number of studies highlight the unique benefits of culturally responsive STEM enrichment for migrant and refugee youth, emphasising its role in enhancing learner engagement, self-efficacy, and long-term academic outcomes (Damoah, 2022; *Syracuse University Today*, 2024). For instance, Master and Meltzoff (2020) suggests that project-based STEM activities can foster a sense of belonging and academic

identity among learners from non-dominant backgrounds. Despite these benefits, migrant and economically disadvantaged learners often face a dual challenge: limited prior exposure to technical representations and persistent systemic resource gaps. To remove these barriers, the instructional process in this study was intentionally structured to begin with foundational concepts, – specifically the identification of basic circuit components and the interpretation of schematic diagrams. According to Ainsworth (2006), the approach is supported by research showing that multiple-representation scaffolds significantly improve learners' ability to interpret diagrams. Cromley and Chen (2024) demonstrate that visual cues and signalling strategies enhance comprehension across K-12 learning environments.

After gaining the ability to read a circuit, learners transitioned to physically constructing it. Research has found that guided, hands-on activities with electronics significantly improved learners' retention and problem-solving abilities. Crudu and the MoldStud Research Team (2025) state that guided breadboarding in Arduino lessons improved learners' retention and problem-solving abilities by as much as 60%. These results are supported by Heradio, De la Torre, Galán, Cabrerizo and Dormido (2016), who conclude that physical prototyping offers deeper conceptual understanding compared to virtual simulations alone. Building on this procedural knowledge, learners then moved on to integrating electronic components such as motors, wheels, and controller boards into a functional vehicle chassis. Research by Coufal (2022) shows that such electromechanical assembly tasks, particularly in contexts like LEGO-Mindstorms design challenges, significantly enhance learners' problem-solving skills and their ability to apply theoretical knowledge to practical situations (Jaipal-Jamani & Angeli, 2017). This aligns with earlier meta-analyses by Benitti (2012), emphasising the cognitive benefits of hands-on construction in STEM education.

Once the vehicle assembly was complete, the focus shifted from physical construction to remote operation and digital interaction. A comprehensive review by Al-Emran et al. (2019) found that authentic data-driven tasks, such as real-time sensor monitoring and dashboarding, consistently increased learners' engagement and confidence. The final stage of the learning sequence introduced AI-supported debugging using large language models. Adhikari, Dhakal and Jha (2024) reported that learners who received real-time error explanations during coding tasks were able to reduce their troubleshooting time by half, while also strengthening their understanding of both programming structures and circuit logic.

Taken together, these sequential and interconnected instructional phases create a

progressive learning pathway. Each stage builds on the previous: visual literacy in circuit design enables accurate wiring; hands-on wiring solidifies mechanical and electrical integration; system assembly sets the foundation for IoT-based control; and AI-supported coding consolidates the entire experience. This carefully scaffolded approach supports the development of resilient, transferable engineering skills particularly valuable for at-risk migrant learners navigating educational challenges.

However, a significant gap exists between the theoretical promise of STEM education and its practical implementation for at-risk migrant learners. While many studies advocate for hands-on learning, they often fail to address the initial barriers related to technical literacy and language proficiency. The reality is that simply providing a kit of parts without foundational scaffolding can lead to frustration and reinforce feelings of inadequacy. This study presents a novelty by integrating a multi-phase, scaffolded approach that begins with basic diagrammatic literacy and culminates in advanced, AI-assisted coding. It connects discrete bodies of research on diagram comprehension, hands-on construction, and AI in education into a single, cohesive intervention. This carefully structured pathway, designed specifically for a resource-constrained and culturally diverse context, addresses the gap between expectation and reality in STEM education for vulnerable populations.

Research Methodology

We used a quantitative single-subject experimental design, specifically a multiple-baseline approach across participants, to examine the effectiveness of a five-phase STEM-based remote-controlled car project designed for at-risk migrant middle school learners in Northern Cyprus. The multiple-baseline design enabled the intervention to be introduced in a staggered manner for individuals, allowing for the assessment of whether observable changes in skill development occurred only after the intervention was implemented. This methodological approach strengthens the internal validity of the study by facilitating the identification of a functional relationship between the intervention and the observed outcomes (Simonsen & Little, 2011). Given the small size and specific characteristics of the sample, this design was chosen for its ability to yield accurate, repeated, and contextually grounded assessment of individual performance over time.

Population and Sampling

The target population for this study comprised at-risk migrant middle school learners in Northern Cyprus (see Table 1). The sample consisted of four male learners who were selected through criterion-based purposive sampling. The inclusion criteria were: being of middle-school age, having no prior

experience with STEM-related activities, demonstrating an interest in technology, and experiencing challenges in adjustment such as language acquisition difficulties and social adaptation issues. The fact that all participants were

male was coincidental and reflected the pool of eligible volunteers available during recruitment. All learners participated voluntarily, and pseudonyms were used to protect their identities.

Table 1 Varied information of participants

Participant	Age	Grade	Country of origin	Language proficiency	Daily technology access	Observed difficulties
Ali	12	Sixth	Sudan	Limited Turkish/English	Parents' phone	Bullying, academic low performance
Ahmed	13	Seventh	Sudan	Limited Turkish/English	Parents' phone	Social withdrawal, discrimination
Elnur	14	Eighth	Azerbaijan	Fluent Turkish	Own computer	Limited peer interaction
Emir	15	Eighth	Pakistan	Limited Turkish	No computer	Isolation, adaptation issues

The four participants were selected from diverse economic backgrounds and countries. The children selected had no previous experience with STEM education but were interested in this field. Their educational background was evaluated. The aim of the introduction of these participants to the programme was to help them successfully develop their academic and social learning skills via STEM education.

Instrument and Procedures

The primary instrument for data collection was a structured performance observation form developed by us. This tool is a type of observational checklist, a method recognised for its utility in systematically recording the presence, frequency, and accuracy of specific, predetermined behaviour or skills. The checklist was designed to provide objective, quantifiable data on each participant's ability to complete the steps within each phase of the project, from component identification to final assembly and coding (see Appendix A).

Baseline phase

During the baseline phase, participants were provided with a standardised kit and, without any prior instruction, were asked to assemble a remote-controlled car. Their performance was recorded using the observation form.

Intervention phase

The intervention was delivered in five structured instructional phases:

- 1) Reading circuit diagrams and recognising circuit elements: Participants were introduced to circuit diagrams and electrical components through direct instruction, visual cards, and physical models.
- 2) Reading circuit diagrams and connecting wires: video modelling was used to teach participants how to read circuit diagrams and connect wires accurately.
- 3) Assembling the electrical and chassis sections of the remote-controlled car: Participants physically assembled the electronic parts onto the car chassis.
- 4) Blynk application skills: Participants learned to use the Blynk app for IoT device control through guided presentations.

- 5) AI-assisted coding: Participants learned to identify and correct coding errors using AI tools through video-based training.

Maintenance and generalisation phases

They were conducted to evaluate long-term retention of coding skills, assessment was conducted at 1, 3, and 5 weeks following the intervention. To assess generalisation, participants were asked to build a car with a smaller chassis and different wheels.

Data Analysis

In this study, data from the structured checklists were analysed using methods appropriate to single-subject research designs. The primary method was the visual analysis of graphed data, a foundational technique in single-subject research for determining the effectiveness of an intervention (Kratochwill, Horner, Levin, Machalicek, Ferron & Johnson, 2023). This process involved plotting the performance data such as the percentage of correct steps for each participant across all the baseline, intervention, maintenance, and generalisation phases. The graphs were then examined to identify changes in level, trend, and variability between the baseline and intervention phases. This indicates whether a functional relationship exists between the intervention and the observed outcomes.

To complement the visual analysis, the percentage of non-overlapping data (PND) was calculated to provide a quantitative measure of the intervention's impact. PND is determined by the proportion of data points in the intervention phase that exceed the highest score recorded during the baseline phase. To ensure reliability, inter-observer agreement (IOA) was calculated for 30% of the sessions using the point-by-point method, with two independent raters achieving 90% agreement during the intervention phase.

The checklist scores were analysed using a multi-tiered strategy consistent with established best practices in single-subject research. Firstly, individual scores were graphed across the baseline, intervention, maintenance, and generalisation phases. Visual analysis was then conducted to

examine changes in performance levels, trends, variability, and overlaps between phases each of which provides insight into the presence and strength of functional relationships between the intervention and participant outcomes.

Secondly, the PND was calculated to offer a quantitative measure of intervention impact. This involved determining the proportion of data points in the intervention phase that exceeded the highest score recorded during the baseline phase, thereby providing a clear index of improvement.

Together, these analytic procedures, supported by validated instruments, high IOA, and the transparent inclusion of checklist samples in tabular form, offered a strong foundation for interpreting participant progress. As a result, the quantitative findings in the study can be considered valid and reliable.

Preparation of Teaching Material

Before the preparation of the STEM programme, expert opinions were sought to ensure the quality and effectiveness of the intervention items. These opinions were used to develop the material, including video prompts and PowerPoint presentations. All the video content was recorded via a smartphone and then edited with Vegas Pro 21 software to be instructional. After the initial version was completed, it underwent further revisions of additional expert reviews to meet educational standards. For sections that required more in-depth analysis, video prompts were used.

STEM Programme

The primary components of the STEM education programme provided to the participants, in this regard, are as follows: baseline sessions, Phase 1, Phase 2, Phase 3, Phase 4, Phase 5, maintenance, and generalisation sessions. Each component had been developed to enhance the participant's ability to read electrical circuits and program AI-supported IoT devices in creating a remote-controlled car.

The first stage of research involved providing participants with the ability to read electrical circuit diagrams and learn to identify the circuit components. Here, some basic physical principles at the core of electronics were taught. Understanding and applying the functions of circuit components truly allows for laying a strong STEM foundation (Sabogal Guerrero, 2023). The second stage involved reading and connecting electrical circuit diagrams. This gave the participants full knowledge of the electric current and circuit theory. Properly connecting the components of a circuit aids in learning the principle of operation for an electronic device, which enhances engineering design or application competencies (Meehan & Fritz, 2011). The third phase involved the assembly processes for the electrical and chassis sections. During this stage, the participants put into practice

the theoretical knowledge consolidated in classes through the experiences of what was learned during practical applications regarding electrical circuits. The combination of electronic components and mechanical parts helped develop participants' technological knowledge and assembly skills (Karahoca, Karahoca & Uzunboylu, 2011). The processes of assembly, engineering design, and problem solving were taught, whereas measurements and calculations allowed for the practical use of mathematic skills (English, Hudson & Dawes, 2013). The fourth phase was intended to provide the necessary skills used in the working functioning of IoT technology and to extend the knowledge of science. It showed how the method involved in managing IoT devices via a Blynk application would improve technological knowledge and application competencies. Additionally, the integration and management of IoT devices taught engineering design and application processes (Alharbi, 2024). The fifth phase involved AI-based coding skills. In this phase, the participants enhanced their knowledge of science by being introduced to AI and the various principles of coding. Coding via AI develops advanced technology and programming skills and enhances engineering problem-solving and application competencies. Algorithm development and debugging processes involved in coding significantly advanced participants' mathematical thinking and problem-solving skills (Moraiti, Fotoglou & Drigas, 2022). These phases provided the participants with comprehensive STEM education, and each stage helped the participants to gain knowledge and skills in various fields of STEM. This process is one way in which the theoretical knowledge of the participants becomes practical for application and success in the field of STEM. The remote-controlled car project used in this research is an important part of the designed STEM programme because these stages provided participants with many learning experiences.

Phase 1: Reading circuit diagrams and recognising circuit elements

These sessions familiarised the participants with essential electrical circuit components using direct intervention methods and outlined cards containing the necessary information. Essential elements in the given tasks included batteries, motors, Wi-Fi modules, motor drivers, wheels, breadboards, wires, and switches. The functions of these components in the circuit and how they are used, were explained in detail. During the introduction of the circuit components to the participants, step-by-step instructions were given using visual cards for each component. For example, the function and ports of a battery were explained in detail via PowerPoint presentations and physical models. The participants progressed with feedback

on identifying these components and understanding their functions. One-on-one interventions were provided to correct misunderstandings. Phase-related measurements were made after each

teaching session. Tables and visuals regarding the contents of Phase 1 are given below (see Table 2, Figure 1).

Table 2 Phase 1: Reading circuit diagrams and recognising circuit elements

Step	Skill	Description
1	Showing the battery	Identify and demonstrate the battery
2	Showing the motors	Recognise and place the motors in the correct locations
3	Showing the Wi-Fi module	Identify and demonstrate the Wi-Fi module
4	Showing the motor driver	Identify and demonstrate the motor driver
5	Showing the wheels	Identify and place the wheels
6	Showing the breadboard	Identify and demonstrate the breadboard
7	Showing the wires and connection points	Identify and demonstrate the wires and connection points
8	Showing the switch	Identify and demonstrate the switch

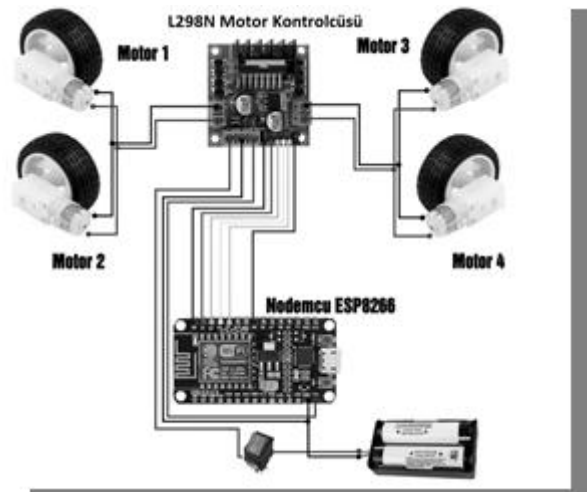


Figure 1 Wiring diagram for the remote-controlled car project

Phase 2: Reading circuit diagrams and connecting wires

The participants were shown how to wire the points shown in the diagrams that went with the reading of the circuit diagrams. In this exercise, participants learned how to connect ENA to D0, IN1 to D1, IN2 to D2, IN3 to D3, IN4 to D4, ENB to D5, the ground pin (GND) to the corresponding GND, and the voltage input pin (VIN) to 5 Volts (V). The battery's negative terminal (-) must be connected to the GND, whereas the positive terminal (+) must be connected to the switch's input and then the output

of the switch to 12 V. During the teaching phase of cable connections, participants were given step-by-step instructions with a video model. For example, how to connect ENA to D0 was supported by visual and auditory instructions. Incorrect connections were immediately detected and corrected, and participants were provided feedback when the correct connection was made. Phase-related measurements were made after each teaching session. Tables and visuals regarding the contents of Phase 2 are given below (see Table 3, Figure 2).

Table 3 Phase 2: Reading circuit diagrams and connecting wires

Step	Skill
1	Connecting ENA to D0
2	Connecting IN1 to D1
3	Connecting IN2 to D2
4	Connecting IN3 to D3
5	Connecting IN4 to D4
6	Connecting ENB to D5
7	Connecting GND to GND
8	Connecting VIN to 5 V
9	Connecting the negative (-) terminal of the battery to GND
10	Connecting the positive (+) terminal of the battery to the input of the switch
11	Connecting the output of the switch to 12 V

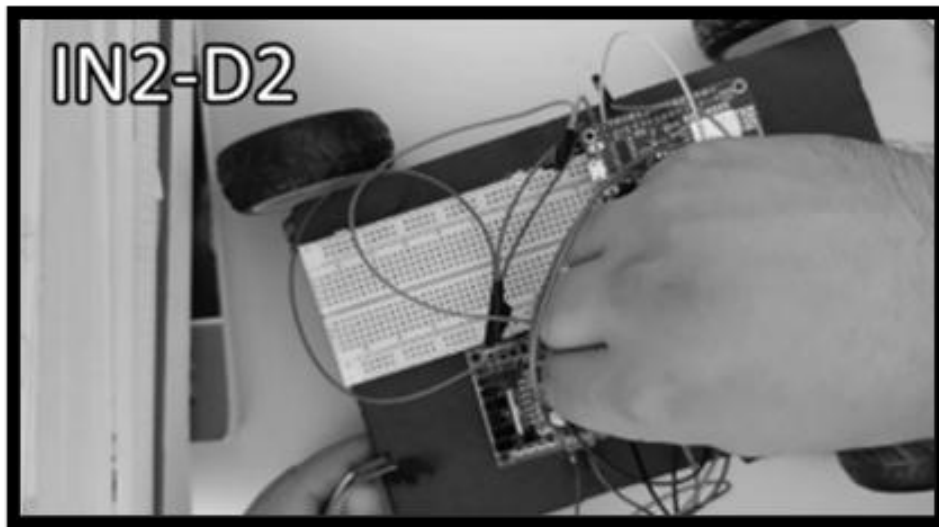


Figure 2 An image from the video prompt for Phase 2 of the remote-controlled car project

Phase 3: Assembling the electrical and chassis sections of the remote-controlled car

Phase 3 was designed to test the participants on the application of the reading of circuit diagrams and model construction taught in real-world conditions. The practitioner developed electrical and chassis modules for a radio-controlled vehicle by using existing models and developed circuit diagrams. During the assembly of the electrical and chassis sections, detailed diagrams and photographs were

provided to the participants. Each assembly step was demonstrated by the instructor via the modelling technique, and the participants repeated these steps. When necessary, physical assistance and interventions were provided to ensure that the participants learned the correct assembly. Phase-related measurements were made after each teaching session. Tables and visuals regarding the contents of Phase 3 are given below (see Table 4, Figure 3).

Table 4 Assembling the electrical and chassis sections of the remote-controlled car

Step	Skill	Description
1	Placing the motors on the chassis	Mounting the motors on the chassis correctly by referring to the diagram and photos
2	Placing the wheels on the chassis	Mounting the wheels on the chassis according to the diagram
3	Connecting the motors to the motor controller	Connecting the motors to the controller correctly
4	Placing the breadboard on the chassis	Mounting the breadboard on the chassis according to the diagram
5	Placing the motor controller on the chassis	Correctly mounting the motor controller
6	Placing the battery on the chassis	Mounting the battery correctly
7	Placing the Wi-Fi module on the chassis	Correctly mounting the Wi-Fi module
8	Placing the circuit switch on the chassis	Correctly mounting the switch
9	Establishing connections between the battery and the motor controller	Making the correct connections
10	Establishing connections between the Wi-Fi module and the motor controller	Making the correct connections

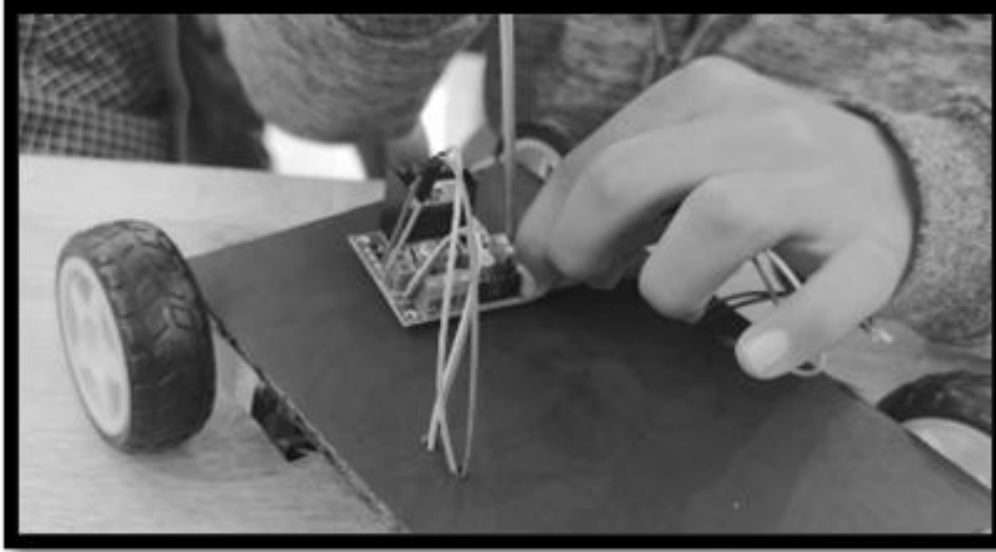


Figure 3 Assembling the electrical and chassis sections of the remote-controlled car

Phase 4: Blynk application skills

This section introduced the participants to the basics of the Internet of Things (IoT). It involved training on interaction with the basic concept via Blynk. The stage involved step-by-step navigation through the Blynk Console to manage the IoT device. The participants learned how to copy the authorisation key, see devices that are already connected, connect a new device, choose the relevant hardware and connection, view the device status, and use movement buttons and sliders. Such essential learning placed the participants on good ground towards deploying IoT technologies well in their projects. The participants were asked how to

accomplish the tasks when collecting data for computers and phones. The participants were taught how to use the Blynk application step by step. After the application was introduced, the process of adding a new device and establishing a connection was explained in detail to each participant. Video prompt techniques were used to create action buttons, and assigning functions was demonstrated. The participants progressed by receiving feedback at each step of the application. Phase-related measurements were made after each teaching session. Tables and visuals regarding the contents of Phase 4 are given below (see Table 5, Figure 4).

Table 5 Blynk application skills

Step	Skill	Description
1	Copying the authorisation key	Acquire the skill to copy the authorisation key from the Blynk console
2	Viewing existing devices	View existing devices on the main screen
3	Adding a device	Add a new device by clicking the “+” icon in the top right corner
4	Selecting hardware and connection type for device linkage	Select the hardware (ESP8266) and connection type (Wi-Fi) for device linkage
5	Checking device status	Check the device status and information (e.g., “offline”)
6	Touching movement buttons	Learn the functions of the forward, backward, right, and left buttons by touching them in the Blynk application
7	Moving the slider	Move the slider to the right and left in the Blynk application

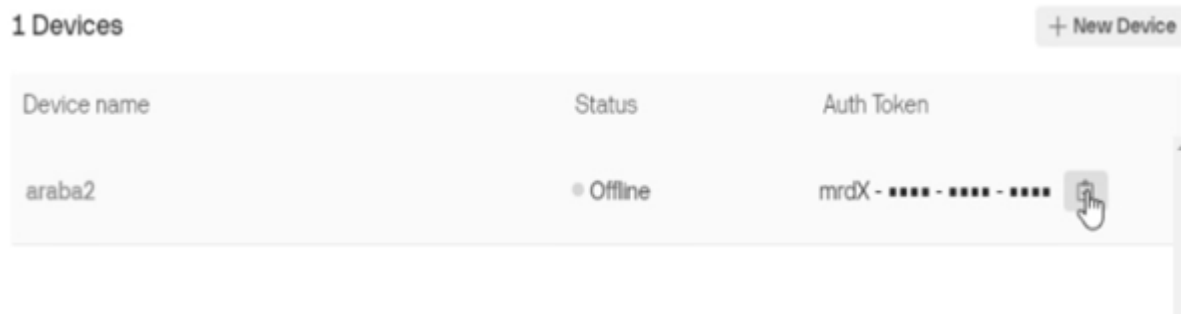


Figure 4 Copying the authorisation key

Phase 5: AI-assisted coding

During the coding process, in which artificial intelligence (AI) was used, participants created movement buttons on the Blynk application and added such buttons to the necessary functions. The errors in the codes were corrected via AI so that the codes ran smoothly. The authorisation key required for the phone's communication with the Blynk servers, Wi-Fi name, and password were added to the code by AI. These AI-assisted modifications were then integrated into the application of the Arduino IDE, after which the accuracy of the code was tested before it was uploaded to the car. Finally, tests were conducted by running the

vehicle to confirm that the coding and connections were performed correctly. The participants were taught AI-supported coding processes step by step. How to fix coding errors with AI tools was shown with a video prompt. The creation of movement buttons in the Blynk application, correction of code errors and upload of the software to the Arduino IDE are explained step by step. The participants progressed by receiving feedback at each step of the application. Phase-related measurements were made after each teaching session. Tables and visuals regarding the contents of Phase 5 are given below (see Table 6, Figure 5 and Figure 6).

Table 6 AI-assisted coding steps

Step	Skill	Description
1	Creating movement buttons	Creating movement buttons in the Blynk application
2	Adding function activities to buttons	Adding functions to the buttons
3	Correcting code errors with AI	Correcting code errors using AI
4	Adding the authorisation key to the code	Adding the authorisation key to the code
5	Adding Wi-Fi name and password to the code	Adding the Wi-Fi name and password to the code
6	Incorporating changes into Arduino IDE	Adding code changes to Arduino IDE
7	Testing the code's accuracy	Testing the written code
8	Connecting the Wi-Fi controller to the personal computer (PC)	Connecting the Wi-Fi controller to the computer
9	Uploading the code to the car	Uploading the written code to the car
10	Testing the car by running it	Testing the car by running it

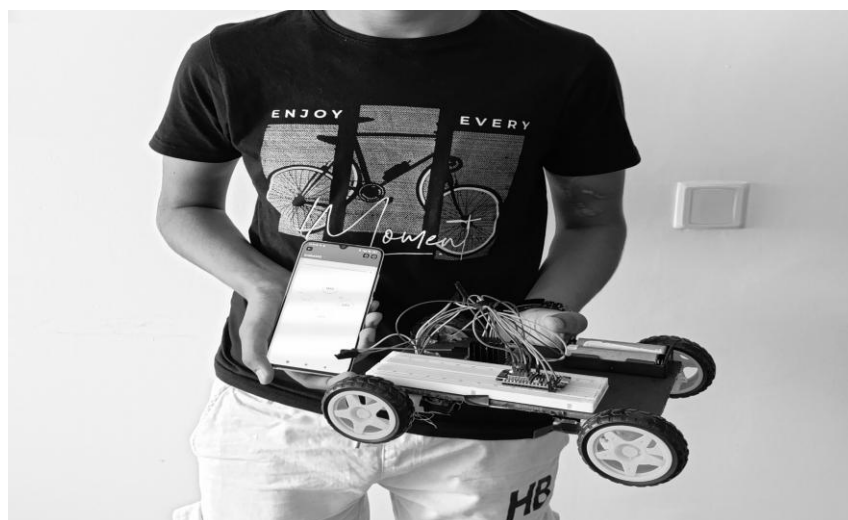


Figure 5 Adding the authorisation key to the code

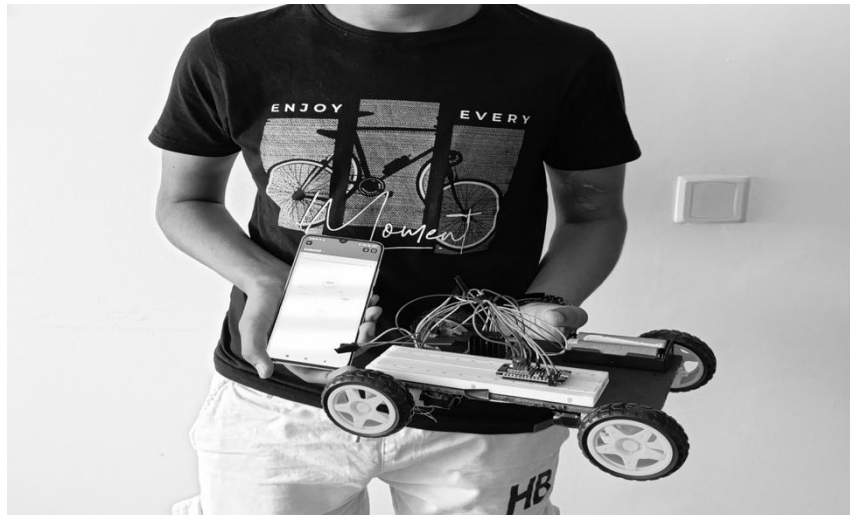


Figure 6 Testing the remote-controlled car

Maintenance Sessions

Maintenance sessions were conducted in the first, third, and fifth weeks to assess the retention of acquired skills from Phase 5. Maintenance data were collected because of the importance of acquiring coding skills utilising the natural language processing capabilities of AI, which participants can use in the future.

Generalisation Sessions

The generalisation sessions involved testing whether the learners could apply the learned skills in Phase 3 across new but similar situations. In this learning phase, participants were required to make the mechanical parts and wiring layout of the remote-controlled car using different parts of the wheels and a smaller chassis.

Inter-observer Reliability

To ensure inter-observer reliability, the practitioner reviewed video recordings of all the sessions to verify that the instructions collected for internal validity were followed as intended. These sessions were videotaped primarily for coding purposes. The second author trained two coders with prior knowledge of STEM education, two doctoral students, until they achieved 90% agreement on two consecutive videos, which was reached after three videos were reviewed. For each participant, 30% of the sessions from each condition were randomly chosen for analysis. Inter-observer reliability was determined by calculating the percentage of agreement between observers, dividing the number of agreements by the total number of observations, and multiplying by 100. IOA was calculated using the point-by-point method. Agreement was 100% during the baseline phase and 90% during the intervention phase, with 30% of sessions scored by two independent observers.

Research Results

In this study, data collection was carried out using structured checklists developed to evaluate participants' acquisition of specific STEM-related skills across five instructional phases. Each phase targeted distinct competencies required for the construction and operation of a remote-controlled car. Maintenance and generalisation probes were also conducted to examine skill retention and transferability.

Baseline Assessment

At the outset, participants were given the necessary materials and asked to independently build a remote-controlled car. These materials included a car chassis, four DC motors with wheels, a Wi-Fi module (ESP8266), a motor driver board, a breadboard, a battery pack, wires, and a switch. None of the four participants, namely Ali, Ahmed, Elnur, and Emir, were able to complete the task, indicating a lack of foundational STEM knowledge and affirming the need for the instructional intervention.

Phase 1 – Reading Circuit Diagrams and Recognising Circuit Elements

Participants received instruction on how to read basic circuit diagrams and identify electronic components. After the intervention, noticeable improvements were observed: Ali and Ahmed each progressed from seven to eight correct steps; Elnur improved from six to eight; and Emir completed all eight steps from the beginning.

Phase 2 – Reading Circuit Diagrams and Connecting Wires

This phase focused on interpreting circuit diagrams and correctly wiring components. All participants demonstrated growth: Ali improved from eight to 11 steps, Ahmed from seven to 11, Elnur from

eight to 11, and Emir from nine to 11.

Phase 3 – Assembling the Electrical and Chassis Sections of the Remote-controlled Car

Participants were taught to mount essential components onto the car chassis. All four participants successfully completed all 10 steps in every session, indicating full mastery.

Phase 4 – Blynk Application Skills

Participants learned to interact with the Blynk app to understand IoT concepts. Performance improvements were evident for all participants, reflecting their growing comfort with digital interfaces.

Phase 5 – AI-assisted Coding

Using video tutorials and the Arduino IDE, participants were guided to develop and debug code with the assistance of AI tools. All participants showed strong progress, demonstrating competence in applying AI to coding tasks.

Maintenance and Generalisation

Maintenance assessment was conducted during the first, third, and fifth weeks after the intervention. All participants maintained consistent performance, indicating successful retention of AI-supported coding skills. In generalisation probes, where participants built a new vehicle with different parts, all participants completed the task successfully, showcasing their ability to adapt learned skills.

Data Analysis Summary

The collected data were examined using visual graphing methods. To measure effectiveness more precisely, PND values were calculated for each participant. Remarkably, all participants achieved a PND score of 100%, demonstrating a strong functional link between the intervention and their observed progress. IOA was assessed for 30% of the sessions, achieving 90% agreement, which supports the credibility and robustness of the study's findings (see Figure 7).

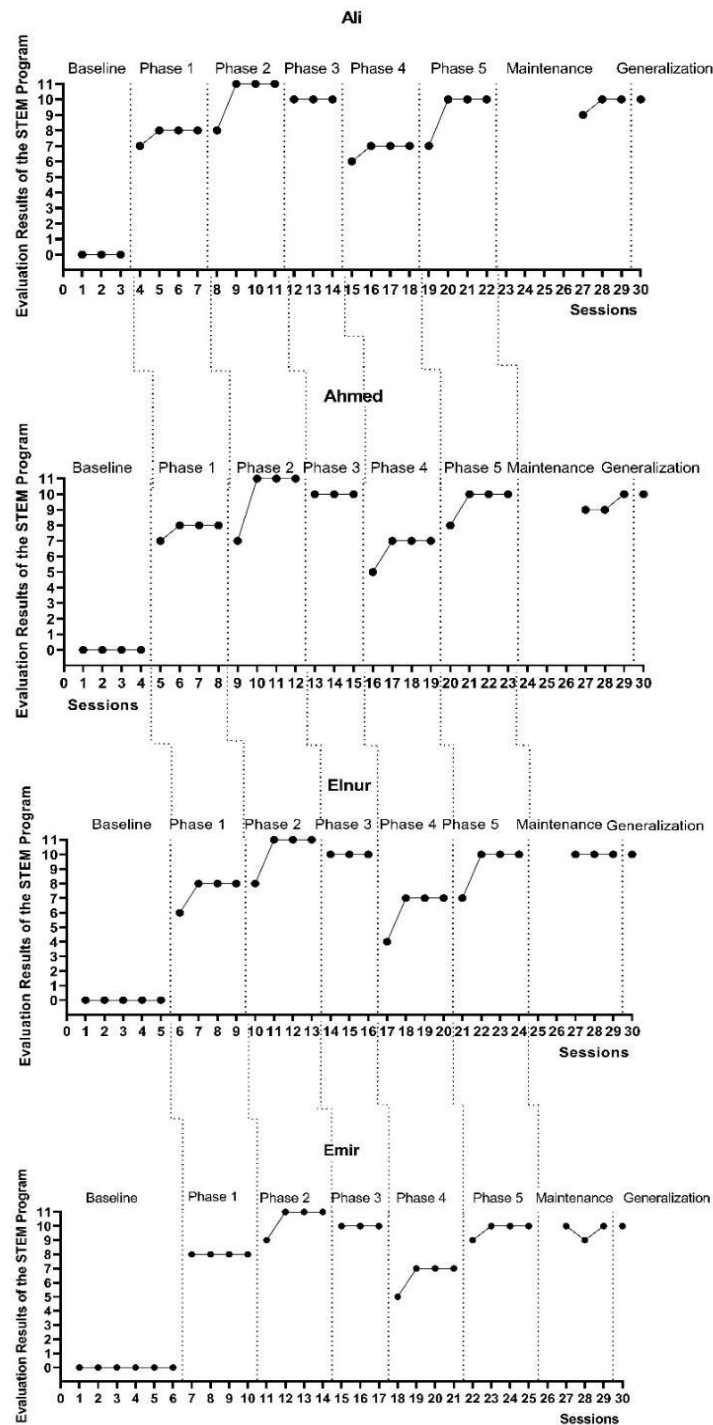


Figure 7 Evaluation results of the STEM programme, highlighting the improvement in participants' skills across various phases, including the baseline, intervention, maintenance, and generalisation sessions

Discussion

The findings of this study demonstrate that a phased, project-based STEM intervention can be highly effective in teaching complex technical skills to at-risk migrant children. The 100% PND score achieved by all four participants provides strong quantitative evidence of a functional relationship between the intervention and skill acquisition. This result aligns with the broader

literature, which consistently finds that active, hands-on learning yields substantial improvements in STEM achievement compared to passive instruction (Freeman et al., 2014).

The scaffolded, multi-phase structure of the project was essential to its success. By breaking down the complex task of building and programming a remote-controlled car into manageable stages, the intervention supported

learners at each step. This approach resonates with the principles of scaffolded learning, which is particularly beneficial for learners who may lack prior knowledge or confidence (Wood et al., 1976). The initial phases, focused on reading circuit diagrams and recognising components, built a necessary foundation of visual and conceptual literacy. This finding is consistent with research by Cromley and Chen (2024) who demonstrate that visual cues and signalling strategies enhance comprehension in K-12 learning environments.

Furthermore, the integration of modern technological tools proved highly effective. The use of video modelling for teaching wiring connections and AI-assisted tools for debugging code lowered entry barriers and enhanced motivation. The successful application of AI-assisted coding, in particular, aligns with emerging research showing that real-time error explanations can significantly reduce troubleshooting time and strengthen conceptual understanding (Kasneci, Sessler, Kücherrmann, Bannert, Dementieva, Fischer, Gasser, Groh, Günnemann, Hüllermeier, Krusche, Kutyniok, Michaeli, Nerdel, Pfeffer, Poquet, Sailer, Schmidt, Seidel, Stadler, Weller, Kuhn & Kasneci, 2023). Our study contributes to this nascent field by demonstrating the feasibility and effectiveness of using such tools with at-risk middle school learners.

The successful maintenance and generalisation of skills are also noteworthy. Participants not only retained their coding abilities weeks after the intervention but were also able to apply their assembly skills to a novel task. This suggests that the learning was not merely procedural but led to a deeper, more flexible understanding of engineering design principles. This outcome supports the argument that project-based learning, when structured properly, fosters transferable, higher-order thinking skills (Maiorca & Stohlmann, 2016).

Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. Firstly, the small sample size of four male learners, while appropriate for a multiple-baseline design, limits the generalisability of the results to a broader population of at-risk migrant children. The all-male sample was a result of voluntary recruitment and was not intentional; future research should aim to include female participants to explore potential gender-based differences in experience and outcomes. Secondly, the study was conducted in the specific socio-cultural context of Northern Cyprus, and the findings may not be directly transferable to other regions with different educational systems or migrant populations. Finally, while the study measured skill acquisition

effectively, it did not include long-term tracking of academic performance or career aspirations, which could provide a more comprehensive understanding of the program's impact.

Conclusions and Implications

STEM education is a part of integration into society for all children (Brenneman, Lange & Nayfeld, 2019). It prepares them for advanced levels, thereby increasing their value due to their sense of organisation, problem-solving skills, and creativity levels. In other words, this study underlines the importance of innovative educational interventions in eliminating educational inequalities and preparing all children, regardless of their background, for future labour market demands. This research demonstrates that a well-structured STEM education programme can be highly effective for at-risk migrant children. This principal result helps create good practices and educational policy options that sustain learners from disadvantaged backgrounds, providing them with opportunities for better social adjustment. The study's primary contribution is its illustration of a holistic and scaffolded approach that integrates foundational skills (reading circuit diagrams), mechanical assembly, IoT device management, and AI-assisted coding. According to Kolne and Lindsay (2020), programmes that promote participation in STEM education for children and young people with disabilities yield positive outcomes in self-efficacy, self-esteem, social skills, and interest in STEM. The process helps transform theoretical knowledge into practical application, fostering success and confidence in STEM. The development of skills in electricity, AI, and IoT provides learners with advantages that can support their academic progress and problem-solving abilities, contributing to their social integration in a new region. Ultimately, this study highlights the profound, multifaceted effects of inclusive STEM education for vulnerable populations.

Recommendations

Grounded in the study's findings, the following summarised recommendations are proposed:

- a) Educational practice: Schools serving migrant and disadvantaged learners should implement modular, project-based STEM programmes that integrate modern tools like AI and IoT. The phased structure used in this study offers an effective model for scaffolding complex skills.
- b) Teacher development: Professional development should be provided to equip educators with the skills to design and deliver inclusive, project-based STEM curricula using AI-assisted tools.
- c) Policy and funding: Education policymakers should allocate dedicated resources to support equity-oriented STEM initiatives in underserved schools. Fostering partnerships with technology companies and non-governmental organizations

(NGOs) can enhance the sustainability and reach of these programmes.

Data Availability

The data and materials can be used with the authors' permission.

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Authors' Contributions

The first author (OA) prepared and implemented the materials and teaching content. The second author (GK) contributed to planning and guidance.

Conflict of Interest

The authors declare that they have no competing financial interests or personal relationships in this manuscript.

Notes

- i. This article is derived from the doctoral (PhD) thesis of Osman Akkuş.
- ii. Published under a Creative Commons Attribution Licence.
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Appendix A: Structured Performance Observation Form

Participant name: _____

Date: _____

Session ID _____

Phase 3 – Assembling the electrical and chassis sections

Instructions: For each step, mark if the participant completed the skill correctly and independently (I) or incorrectly/not at all (N). Add notes for specific errors or observations.

Step	Skill description	Performance (I/P/N)	Notes (e.g. type of error, level of assistance needed)
1.	Placing the motors on the chassis		
2.	Placing the wheels on the chassis		
3.	Connecting the motors to the motor controller		
4.	Placing the breadboard on the chassis		
5.	Placing the motor controller on the chassis		
1.	Placing the battery on the chassis		
2.	Placing the Wi-Fi module on the chassis		
3.	Placing the circuit switch on the chassis		
4.	Establishing connections between the battery and the motor controller		
5.	Establishing connections between the Wi-Fi module and the motor controller		

Summary of the performance

Total steps correct (Independent): ____ / 10

Total steps correct (Prompted) ____ / 10

Overall accuracy (%) ____ %