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Perspectives of Science Teachers on Arduino-Based Robotic Coding Activities

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Abstract

This research will analyze the issues encountered by two science teachers implementing Arduino-based robotic coding projects. This research employed a case study design. This research has used a criterion sampling group. This study used semi-structured observation, interviews, and video observations as data collection tools. The teachers conducted three activities in physics, chemistry, and biology. The data was analyzed through content analysis. The authors have determined that teachers do not fully utilize their time and assessment tools, nor do they effectively promote entrepreneurial skills. The authors propose that teachers incorporate additional Arduino-based robotic coding activities into their curricula.

Introduction

According to constructivism, students construct their learning and actively participate in classes. On the other hand, teachers are in a guiding role (Keengwe et al., 2014). Additionally, constructivism focuses more on cognitive development and deep understanding than behavior and skills in education (Fosnot, 1996). At the same time, constructivism encourages students to work in groups, thereby contributing to developing their communication skills (Schreiber & Valle, 2013). Despite all these gains, the extent to which teachers effectively implement robotic coding practices based on the constructivist approach in their lessons remains a current issue in the educational literature (Jaipal-Jamani et al., 2017).

Additionally, teachers face difficulties guiding students' active participation, research, inquiry, and the ability to relate what they have learned to everyday life when implementing robotic coding activities (García-Carrillo et al., 2021). Therefore, it is essential to investigate the causes of these problems to evaluate the effectiveness of teachers' robotic coding activities. Additionally, it is necessary to examine the teachers' approaches to robotic coding activities from different perspectives, as it is believed that this will contribute to students, the education system, and the literature (Anwar et al., 2019).

Constructivism has integrated STEM (Science, Technology, Engineering, Mathematics) education into curricula, facilitating individuals in obtaining skills for personal development. There is a noted surge in robotics coding activities within STEM education (Curaoğlu & Konyaoğlu, 2023). Nevertheless, the data suggest that science educators inadequately incorporate STEM into their curricula (Kim & Lee, 2016; Sullivan & Heffernan, 2016). Consequently, addressing this issue is crucial as it provides a reference for scholars engaged in this field and enhances the professional development of educators and teacher candidates.

Arslan and Tanel (2021) focused on two crucial robotic coding education programs, Scratch and Arduino. Arduino allows for the production of various projects using sensors due to its ease of understanding and high applicability. Therefore, Arduino, suitable for project development in science courses regarding topics and content, can be associated with various achievements in science courses and applied in different disciplines (Guo et al., 2025). Therefore, Arduino, suitable for project development in science classes regarding topics and content, can be associated with various achievements in science classes and applied in different disciplines (Guo et al., 2025).

Robotic coding is a significant subject in the literature that necessitates emphasis on its scientific relevance, usefulness, and the need for further research. The research has shown a growing interest in the application of robotic coding (Gökçe et al., 2024; Seçkin Kapucu, 2023). The analysis of the findings indicates that Arduino-based robotic coding activities in science education are constrained and have not been extensively explored (Ajay et al., 2025). Incorporating certain technologies into educational settings is challenging, and users encounter difficulties in strategizing the process and connecting the application to education (Merrill & Wilson, 2007).

The utilization of Arduino-based robotic coding activities in science teaching requires thorough examination. It is crucial to comprehend how teachers implementing Arduino-based robotic coding activities, rooted in constructivism, may tackle the aforementioned challenges in scientific education. This research will analyze the issues encountered by two science teachers implementing Arduino-based robotic coding projects. This study seeks to present several viewpoints to educational stakeholders by proposing potential solutions to the challenges faced during the process. The research question of this study is, "How do science educators implement Arduino-based robotic coding activities?"

Method

The Design of The Study

This research employed a case study design. A case study is a research method wherein the investigator gathers data from diverse sources by capturing a specific real-life procedure and analyzing that scenario (Creswell & Creswell, 2018). The researchers selected a case study approach to examine how teachers executed Arduino-based robotic coding activities and the challenges they faced during deployment.

Study Group

This research has used a criterion sampling group. The criterion sample group comprises individuals, events, or circumstances that exhibit the qualities defined regarding the problem (Liff et al., 2024). According to this description, the authors established that teachers must possess experience with Arduino-based robotic coding relevant to the study's objective and included two science teachers who integrate Arduino-based robotic coding activities into their instruction. One teacher is female, while the other is male. The female teacher possesses a master's degree, but the male instructor holds a doctoral degree. The authors designated the female teacher P1 and the male teacher P2.

Data Collection Tools

This study used semi-structured observation, interviews, and video observations as data collection tools. The authors explained the observation first because they initially started with observation during data collection.

Semi-Structured Observation

The researcher may employ observation to acquire a thorough and exhaustive analysis of behavior within a context (Lim, 2024). The authors employed semi-structured observation to elucidate the interview data comprehensively. The primary researcher and two additional observers performed non-participant observation in this study. The observation form was submitted for evaluation by the second researcher and a researcher holding a doctoral degree in scientific education. Table 1 presents the input provided by both experts regarding certain observation items and the amendments implemented by the writers.

Table 1. Items For Observation Forms and Expert Evaluations

Item	Second Researcher	Expert
During Arduino-based robotic coding activities, worksheets were provided to guide the students.	During Arduino-based robotic coding activities, steps related to the process were explained by providing worksheets to guide the students.	During Arduino-based robotic coding activities, steps related to the process were explained by providing worksheets to guide students (worksheet + explanation = sufficient, worksheet/explanation = moderate, neither = insufficient)
The teacher aimed to enhance students' affective characteristics through Arduino-based robotic coding activities.	The teacher aimed to enhance the students' affective characteristics (interest, attitude, motivation, self-confidence, and self-regulation skills) through Arduino-based robotic coding activities.	Items for observation forms and evaluations by experts. The educator sought to improve one of the emotional traits of the pupils (interest, attitude, motivation, self-confidence, self-regulation abilities) through Arduino-based robotic coding activities.

Semi-Structured Interview

Semi-structured interviews allow a study to be conducted within predetermined parameters, thereby providing the opportunity to obtain more systematic and comparable information (Merriam, 2009). Therefore, following the purpose of the study, a semi-structured interview form was developed based on the literature to obtain systematic information within a specific framework for science teachers using Arduino-based robotic coding activities (Bogdan & Biklen, 2007; Patton, 2002). The interview form was presented to the second researcher and a researcher with a doctoral degree in science education for their review. Table 2 shows the feedback given by both experts on some of the interview items and the corrections made by the authors.

Table 2. Exemplary Items and Professional Evaluations of The Interview Questionnaire

Item	Second Researcher	Expert
Did you have difficulty guiding your students in Arduino-based robotic coding activities? Why?	-	What challenges do you face while ensuring students' active participation in Arduino-based robotics coding activities? Please explain.
Would you recommend including Arduino-based robotic coding activities in science classes? Why?	Do you recommend using Arduino-based robotic coding activities in science classes? Why?	-

Data Collection Process

Activity Process

The authors received ethics committee approval, reference number 292. The teachers conducted three Arduino-based robotic coding activities on physics, chemistry, and biology, as determined by the researchers. In the physics category, they conducted an activity called "Planets," in the chemistry category, an activity called "Attention, there is a Gas Leak," and in the biology category, an activity called "Plants Have a Language." Two teachers implemented each activity for at least one hour. Both teachers carried out their activities according to the given activity plans during the implementation. For example, the activity plan for the "Plants Have a Language" activity is presented in Figure 1. Both teachers ensured that the students implemented the activities through group work. For example, photos of P2's sample implementation are presented in Figure 2.

The classroom where the activities were conducted was suitable for group work. Although it was a classroom with fixed tables and stools, it had an atmosphere where the activities could be undertaken efficiently. With the center of the classroom left empty, there were fixed tables on one side and two round tables where groups worked on the other side. Additionally, there was a small section at the back of the classroom, accessible to students, where the necessary tools, equipment, and materials were located. While P2 conducted the activities with a group of eight, P1 conducted them with a group of six. The teachers could move freely between the groups and manage the process during the implementation. Observers positioned themselves in two distinct classroom sections to carry out their observations during the implementation phase.

Course Name: Science

Course Outcomes:

F.8.6.2.1. Recognizes the importance of photosynthesis in food production in plants. a. It is emphasized that carbon dioxide and water are used in photosynthesis, and food and oxygen are produced.

F.8.6.2.2. Makes inferences about the factors affecting the rate of photosynthesis. The color of light, the amount of carbon dioxide, the amount of water, light intensity, and temperature are emphasized.

Course Content:

In this material, the aim is to determine the water requirement of plants, which is one of the necessary substances for photosynthesis. In the material, the soil moisture sensor is immersed in the plant's soil to determine the moisture level in the soil, and in the presence of a certain amount of moisture, a "smiley emoji" is displayed on the dot matrix.is. If the soil moisture level is below a certain threshold or the soil is dry, a "sad emoji" is displayed on the dot matrix.is. Visuals related to the "Plants Speak!" material are provided below.

Figure 1. Activity Plan for the "Plants Have a Language."

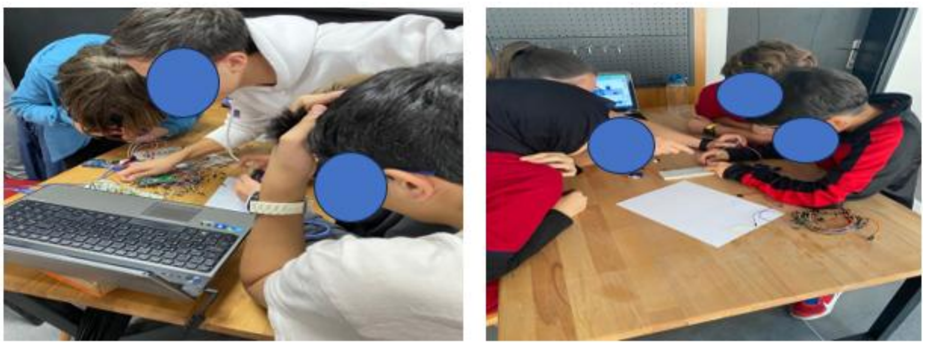

Figure. 2. Photos Related to The Sample Activities

Observation Process

The first researcher and two observers observed the implementation process carried out by the two teachers. While the first researcher was present in all observations, the second observer, a chemistry teacher with a doctoral title, observed for five hours, and the third observer, a science teacher with a doctoral title, observed for one hour. Apart from the researcher, the other observers had classes during the activities, preventing them from being present. The authors used these observations to support and refute the interview data. During the observations, all three observers conducted non-participant observation by remaining at the back of the activity environment and not intervening in the activities. During their observations, they marked using semi-structured observation forms and wrote explanatory notes when necessary.

Interview Process

Both teachers were contacted in advance for the interview, and appointments were made. The first researcher had a meal with both teachers before the interview and gave a relaxation talk. Both interviews were conducted in a Zoom environment with the participation of two researchers. The first researcher explained the purpose of the study to both teachers at the beginning of the interview and stated that their thoughts on the activities they conducted would be collected. He shared the prepared interview form with the teachers and requested permission for an audio recording. The second researcher directed the questions to the teachers. Both researchers carefully listened to the teachers' thoughts and took notes during the interview. The second researcher repeated the teachers' thoughts at the end of each question for confirmation and then moved on to the next question. After the interview, the second researcher reiterated all responses provided to the questions and inquired whether the teachers had any further contributions to offer. The interview lasted an average of 75 minutes for both teachers. At the end of the interview, the first researcher played the audio recordings to both participants and obtained their approval. Similarly, the first researcher sent the transcribed texts to the participants and finally obtained their authorization.

Video Recordings

Video recordings were captured during the practices to corroborate or challenge the observations and interviews in the present investigation. Before the video recording, it was guaranteed that personal information would remain confidential and not be disclosed to any other parties, and consent for the recording was secured from both teachers and students. The camera is positioned to avoid obstructing the action and disturbing the participants.

Data Analysis

The data obtained from the interview were subjected to inductive content analysis. Content analysis aims to reach concepts and the relationships between these concepts. The researcher seeks to transform the data into a systematic and meaningful whole (Creswell & Creswell, 2018). The authors have effectively integrated the data of this research to address the research question. This process began with the first researcher creating a code list for each category in the MAXQDA Pro 2020 program. Secondly, they reached a consensus on the codes with the second researcher. Finally, a chemistry teacher with a doctoral degree reviewed the codes and categories. Based on the received feedback, the research concluded the data analysis. The data were visualized using the MAXQDA Pro2020 program and presented in detail in the findings. Additionally, the authors presented the data obtained from observations during the implementation process in tables in the findings section, categorized appropriately to support or refute the interview data.

Validity and Reliability

The researchers ensured internal validity controls by conducting participant confirmation, data triangulation, direct quotations, prolonged engagement, and expert review (Merriam, 2009; Patton, 2002). The researchers provided detailed descriptions and selected a study group appropriate to their objectives for external validity controls (Bogdan & Biklen, 2007; Patton, 2002). To ensure the internal reliability of the study, in other words, its consistency, the researchers presented the findings without interpretation and reached a consensus on the interview data among themselves. For external validity control, the study's data analysis, findings, conclusion-discussion, and recommendations sections were reviewed by two experts in science education. The experts have approved these sections. Thus, the authors have confirmed that all three study sections are consistent.

Results

Reasons For the Feasibility of The Activities

Figure 3 illustrates that two teachers evaluated the feasibility of Arduino-based robotic coding activities for four reasons. P1 mentioned three of these reasons, while P2 mentioned two. The bold line in Figure 3 shows that both participants possess that code. The thin line suggests that one of the participants holds a viewpoint about that code.

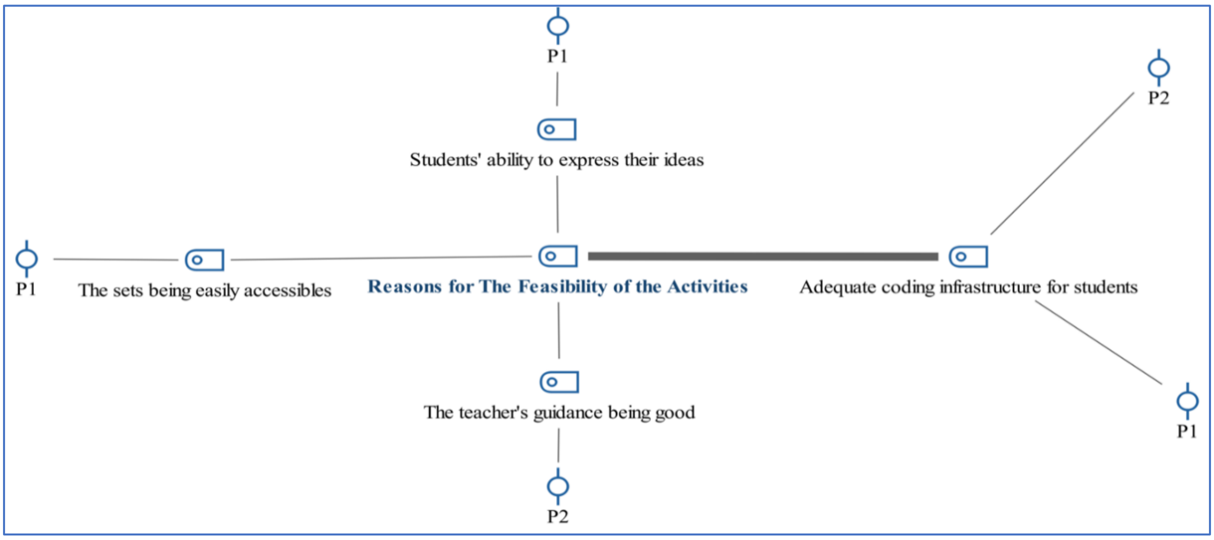

Figure 3. Justifications For Participants Engaging in Activities

Table 3 illustrates the evaluative assessments made by observers on the participants' justifications for the relevance of Arduino-based STEM activities. Observers scrutinized the participants in all three activities. Table 3 delineates the activities that the observers actively monitored.

Table 3. Participant Codes and Observer Scores Related to The Category of Feasibility Reasons

Participants	Codes	Observer	Activity 1	Activity 2	Activity 3
P1	Students' ability to express their ideas	O1	Adequate	Adequate	Moderate
		O2	Adequate	Adequate	Moderate
	The sets being easily accessible	O1	Adequate	Adequate	Moderate
		O2	Adequate	Adequate	Moderate
P2	The teacher's guidance being good	O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-
P1	Adequate coding infrastructure for students	O1	Adequate	Adequate	Moderate
		O2	Adequate	Adequate	Moderate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-

In the pertinent category, we typically included a direct quotation from each participant corresponding to a specific code. P1 indicated that he implemented these activities to facilitate the generation of ideas among students. P1 states: *"The students were able to come up with perfect ideas, and I think it is useful in terms of implementation for education."* Data obtained during the observation corroborated P1's opinion, with both observers reaching a consensus that the students effectively expressed their ideas during the activities. Similarly, the first author analyzed the video recordings and concluded that the students expressed their ideas with considerable ease during the activities. P2 has stated that the quality of his guidance was a factor in implementing the activities. P2 states, *"...Under my guidance, the students could easily practice."* Observers O1, O2, and O3 have collected data corroborating P2's viewpoint. O1 states, *"Students received guidance during the process, and coding errors were identified."*

Integrating Science with Technology, Engineering, and Mathematics

Figure 4 illustrates the reasons teachers connect science with technology, engineering, and mathematics in the context of Arduino-based robotic coding activities. Participants identified four distinct reasons for the science integration with the other three disciplines. P1 offered two reasons, whereas P2 presented three reasons.

Table 4 presents the participant codes alongside the observers' scores. P1 mentioned that she combined science with other disciplines due to the students' use of Arduino and their involvement in design. While P1 claimed to have integrated science into engineering, O1 and O2 assessed this integration as moderate in practice. Similarly, three observers assessed P2 as moderate in science integration with mathematics, noting that the students' use of ratios and proportions in their designs was deemed insufficient. Conversely, the observers remarked that P2 integrated this adequately.

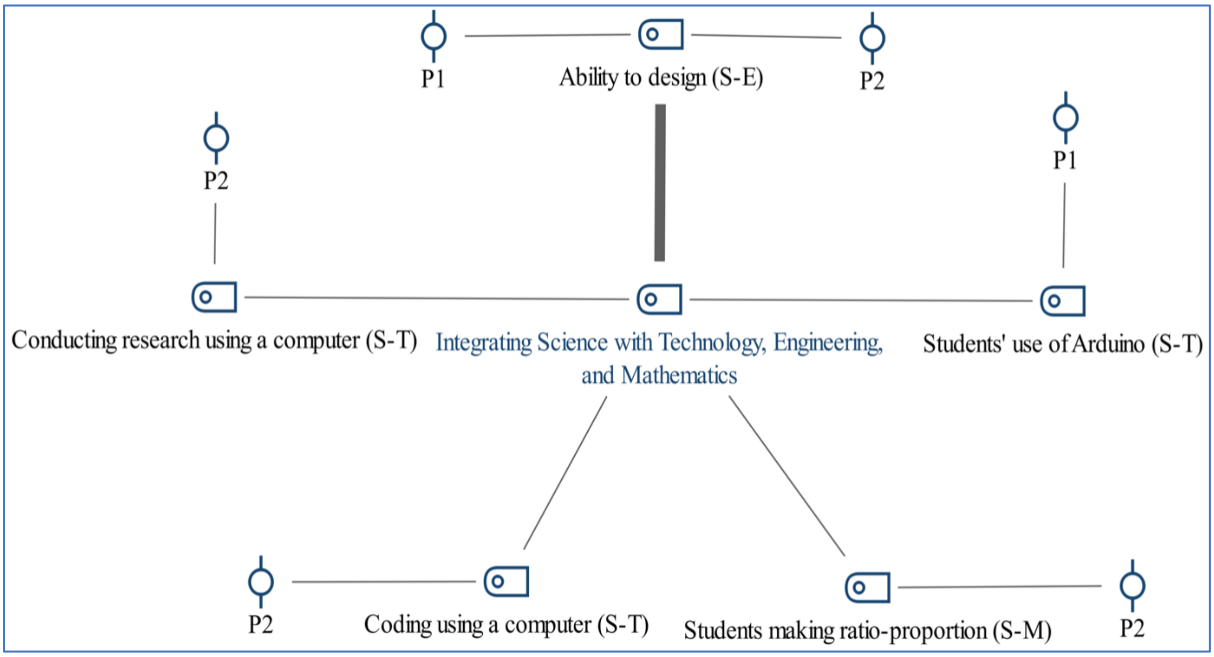

Figure 4. Reasons For Integrating Science with Technology, Engineering, and Mathematics

Table 4. Participant Codes and Observer Scores for The Category of Reasons for Associating Science with Technology, Engineering, and Mathematics

Participants	Codes	Observer	Activity		
			1	2	3
P1	Students' use of Arduino (S-T)	O1	Adequate	Adequate	Adequate
		O2	Adequate	Adequate	Adequate
P2	Students making ratio-proportion (S-M)	O1	Moderate	Moderate	Moderate
		O2	-	-	-
		O3	-	-	-
	Conducting research using a computer (S-T)	O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Unobserved	-	-
	Coding using a computer (S-T)	O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Unobserved	-	-
P1	Ability to design (S-E)	O1	Moderate	Moderate	Moderate
		O2	Moderate	Moderate	Moderate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-

P1 believed that utilizing Arduino allowed the students to merge technology with science. P1 states: *"Arduino lets us smoothly integrate technology into science."* Based on the observations made by O1 and O2, they endorsed P1's idea and considered it adequate. O1 writes: *"Students were tasked with researching the sensors on the computer, concentrating on the features of the sensors, and interaction with the sensors was supported."*

As Arduino-based robotic coding activities allow students to engage in design, P1 and P2 believed they connected the dimensions of science and engineering. For instance, P1 mentions: *"...the engineering aspect is present. They made a design. We have connections between science and engineering."* Conversely, O1 and O2 have assessed the implementation of P1 as moderate regarding students' design capabilities. O1 takes notes: *"After the activity, the students produced a product; however, due to time limitations, they were unable to finalize the design."* Furthermore, three observers remarked that P2 was "sufficient" in connecting science and engineering. For instance, O3 states: *"Students created products by adjusting the values of gas sensors."*

Learning Approaches

Figure 5 illustrates the learning strategies employed by teachers in the context of Arduino-based robotic coding activities. P1 reported employing an inquiry-based learning strategy, whereas P2 noted using a discovery-based. Table 5 presents the learning strategies employed by P1 and P2 during the implementation of activities.

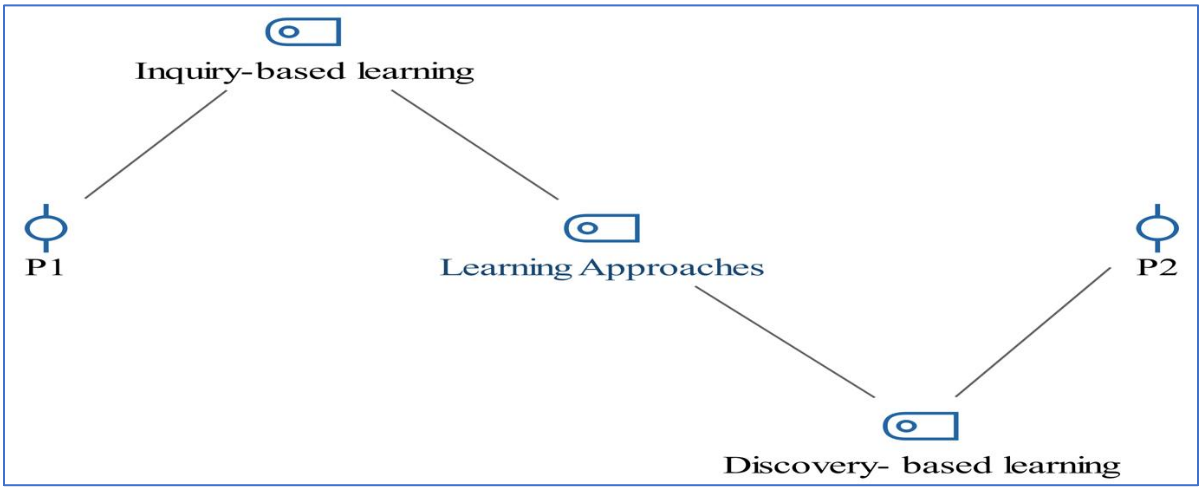

Figure 5. Learning Approaches

P1 claimed she used inquiry-based learning while implementing Arduino-based robotics coding activities. P1 states: *"...I used inquiry-based learning because there were computers in the students' environment."* O1 and O2 observed that P1 used inquiry-based learning during the activities. As evidence for this evaluation, O1 watched video recordings that P1 performed all the steps of inquiry-based learning while conducting the first and third activities but did not give students enough time to conduct research during the second activity.

P2 employed discovery-based learning during the implementation of Arduino-based robotic coding activities. P2 states: *"...my essential approach in Arduino is discovery-based learning. The teacher will guide the child,* *conducting independent research that will lead to learning outcomes. We instruct the child in the skill of fishing. There are numerous advantages associated with it. We facilitate his actions and activities through indirect hints and guidance. When the appropriate environment is provided, learning is observed. Some students exhibit hesitance towards technology. When the cable is improperly connected, individuals may express frustration by stating, "I gave up," yet we offered assistance. The child attempted the task independently and identified his error. Subsequently, we achieved improved outcomes".* During the activities of P2, O1, O2, and O3 observed that the students engaged effectively with Arduino-based robots. O1 stated, *"The student independently executed each phase of the activity,"* while O3 elaborated, *"Arduino sets were distributed to the student groups, the mBlock program was initiated, and the students conducted the coding phases systematically."*

Table 5. Participant Codes and Observer Scores Related to The Category of Learning Approaches

Participants	Codes	Observer	Activity		
			1	2	3
P1	Inquiry-based learning	O1	Adequate	Moderate	Adequate
		O2	Moderate	Adequate	Adequate
P2	Discovery-based learning	O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-

Characteristics of the Environment

Figure 6 illustrates the participant codes related to the characteristics of the environment in Arduino-based robotic coding activities.

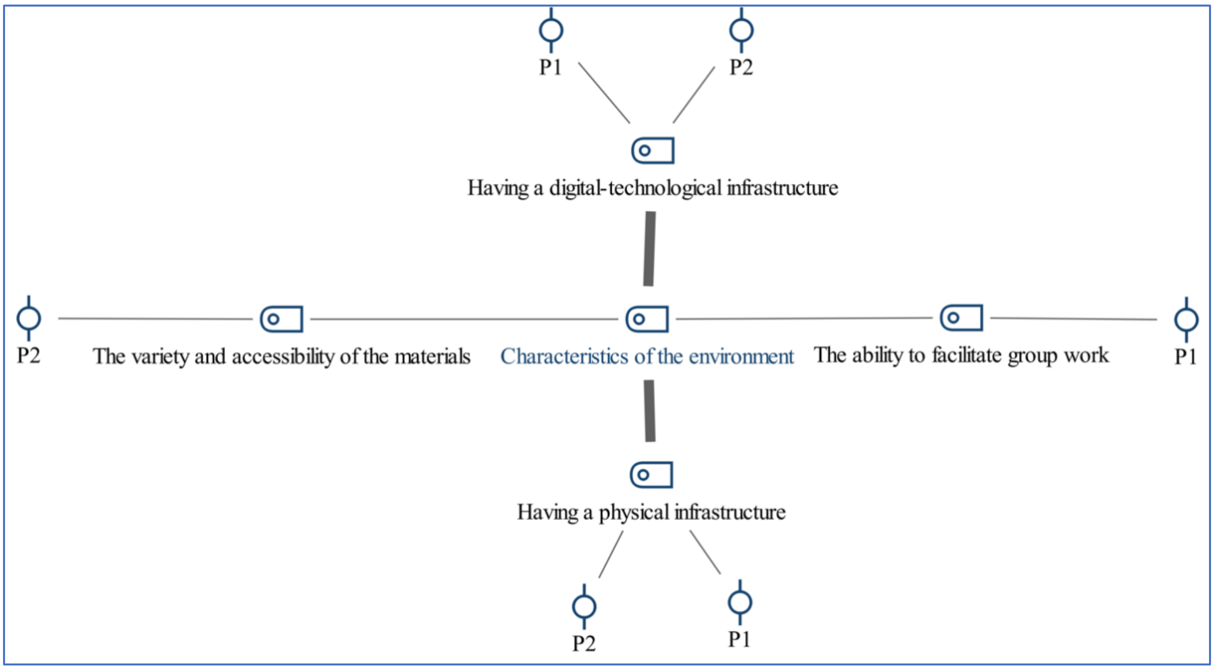

Figure 6. Characteristics of the Environment

Each participant identified three traits associated with the environment. Both participants noted the strong technological and physical infrastructure as one of these features. P1 noted that the setting facilitates collaboration, whereas P2 highlighted the variety and accessibility of materials available during the activities. In contrast to P1's view, three observers observed that the existence of fixed tables in the environment rendered it inappropriate for group work.

Table 6 presents the participants' perceptions reflecting the characteristics of the environment they used during the activities and the observers' scores related to them. P2 stated that the materials were diverse and accessible while implementing Arduino-based robotics coding activities. P2 stated: *"...there were plenty of materials at the school where we conducted the workshop. When I asked the students which materials they would use in the activity, the children could choose the materials themselves—having a variety of materials provided the children with an alternative. Maybe that part would not be there, so he would go and try it himself. For example, the cable did not work, so he got the cable, then took it back."* Three observers supported P2's opinion and noted that the materials were abundant, diverse, and easily accessible to the students. O3 wrote: *"A design skills workshop with ample materials was used for the activities."*

Table 6. Participant Codes and Observer Scores Related to The Category of Environmental Characteristics

Participants	Codes	Observer	Activity		
			1	2	3
P1	The ability to facilitate group work	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2	The variety and accessibility of the materials	O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-
P1	Having a digital-technological infrastructure	O1	Adequate	Adequate	Adequate
		O2	Adequate	Adequate	Adequate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-
P1	Having a physical infrastructure	O1	Moderate	Moderate	Adequate
		O2	Moderate	Moderate	Adequate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-

P1 and P2 stated that the physical infrastructure of the environment was sufficient during the implementation of Arduino-based robotics coding activities. P1 explains, *"...there need to be Arduino materials; otherwise, a normal classroom environment will be sufficient. A table, a row... A set that is very practical to implement, easy to apply, with small materials, and does not require large spaces. Since these are things done by students with fine motor skills, everything can be done in a row."* Three observers rated P1 as "medium" in terms of using the physical infrastructure of the environment in the first two activities. In contrast, they rated P2 as "sufficient" in terms of using the physical infrastructure in all three activities. O1 wrote: *"Before starting the activities, P2 arranged the classroom environment (table, chair) to make it suitable for the activities."*

Evaluation of Time

Figure 7 illustrates the participant codes for assessing time in activities. Both participants indicated that the duration before the design was adequate, whereas the duration after the design was inadequate.

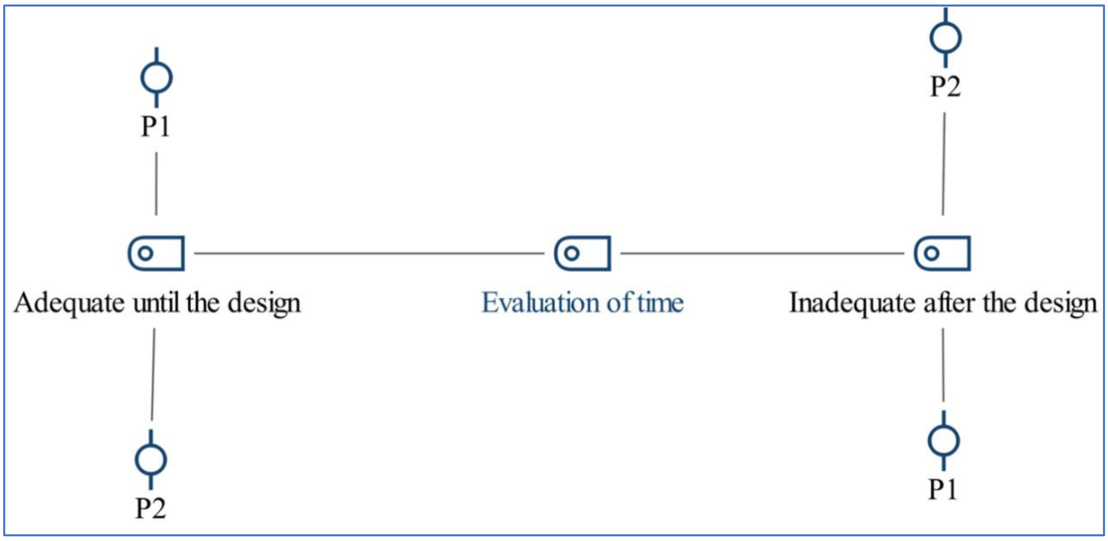

Figure 7. Evaluation of Time

Table 7 presents the participant codes and observer scores associated with the time evaluation category. Neither participant received adequate grades from the observers for time use before and after the design. O1 and O2 evaluated P1 as "inadequate" in time management before and after the design in activities 1 and 3.

Table 7. Participant Codes and Observer Scores for The Category of Time Evaluation

Participants	Codes	Observer	Activity		
			1	2	3
P1	Adequate until the design	O1	Inadequate	Moderate	Inadequate
		O2	Inadequate	Moderate	Inadequate
P2		O1	Moderate	Moderate	Unobserved
		O2	-	Unobserved	-
		O3	Unobserved	-	-
P1	Inadequate after the design	O1	Inadequate	Moderate	Inadequate
		O2	Inadequate	Moderate	Inadequate
P2		O1	Moderate	Moderate	Unobserved
		O2	-	Unobserved	-
		O3	Unobserved	-	-

P1 and P2 stated that the time was sufficient for the design phase while implementing Arduino-based robotics coding activities. P1 states: *"...It was sufficient for the part up to the design. It was sufficient for the students to learn how to use the codes and materials for the activities planned for that day. Therefore, we did not need much time."* While P1 asserted that the duration allocated for the design was enough, observers disagreed with this assessment. P1 and P2 stated that the time was insufficient for design during the implementation of Arduino-based robotics coding activities. P2 said: *"...If we had more time, the designs would have been better."* Observers have noted that the time allocated for design was insufficient, supporting P2's opinion. O1 wrote: *"The design phase of the activity was incomplete; it could not be finished."*

Measurement and Assessment Tools

Figure 8 illustrates the assessment tools used by teachers in activities. Table 8 shows the assessment tools used by the participants during the activities and the observer scores. Accordingly, P1 was evaluated as "insufficient" by two observers before, during, and after the event. On the other hand, three observers rated P2 as "medium" before, during, and after the events.

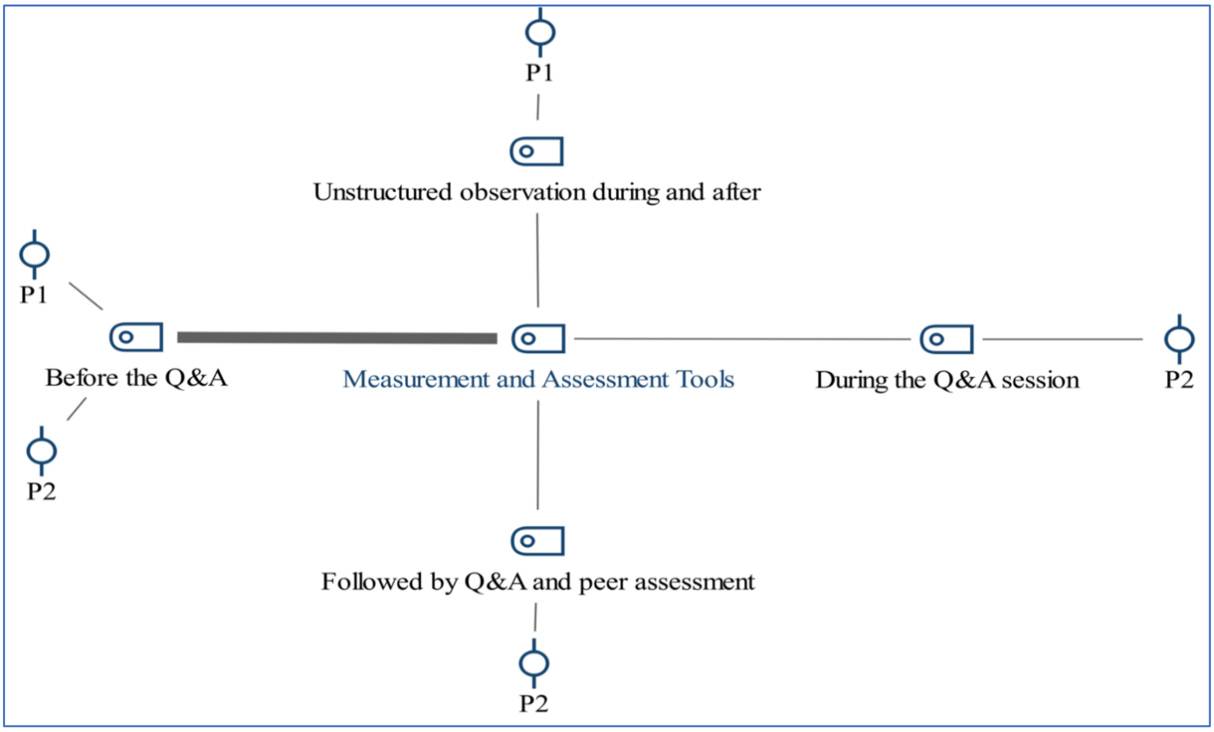

Figure 8. Assessment Tools

P1 used question-answer sessions before the Arduino-based robotic coding activities and unstructured observation during and after the activities. P1 said: *"...I did not apply any extra scale or anything during the activity... I occupied the role of an observer. I intervened at the juncture when they encountered difficulties and endeavored to rectify the deficiencies...."* Two observers noted that P1 was inadequate during the activities. O1 wrote: *"The assessment tool was not used."* Similarly, P1 used unstructured observation after the implementation. P1 stated: *"...after the events, the functioning of the events, everything going smoothly gave us an idea for evaluation."*

Table 8. Participant Codes and Observer Scores Related to The Measurement and Evaluation Tools Category

Participants	Codes	Observer	Activity		
			1	2	3
P1	Unstructured observation during and after	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2	During the Q&A session	O1	Moderate	Moderate	Unobserved
		O2	-	Moderate	-
		O3	Unobserved	-	-
	Followed by Q&A and peer assessment	O1	Moderate	Moderate	Adequate
		O2	-	Unobserved	-
		O3	Unobserved	-	-
P1	Before the Q&A	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Moderate	Moderate	Unobserved
		O2	-	Unobserved	-
		O3	Unobserved	-	-

P2 used question-answer and peer evaluation after Arduino-based robotic coding activities. P2 highlights, *"...after the activity, we initially assessed a material with the students, how it went, what the shortcomings were. Additionally, we evaluated what the students gained, what disadvantages there were, what they learned, etc. The children also conducted a peer evaluation among themselves."* The observers also noted that after the activities, P2 used question-answer and peer evaluation as assessment tools, and the video recordings supported these observations.

Technological Tools

Figure 9 illustrates the participant codes associated with the technological instruments used in Arduino-based robotic coding activities. The teachers' use of technology was deemed distinct from the Arduino set. Both participants employed the computer to take advantage of the internet's benefits.

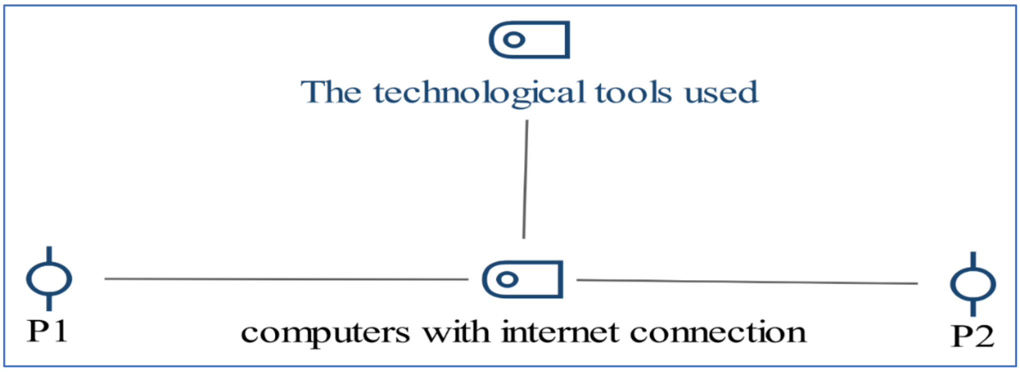

Figure 9. Technological Tools

Table 9 displays the technological tools used by the participants throughout the activities. Furthermore, Table 9 presents the ratings given by observers to teachers concerning their proficiency in using these tools. The observers assessed both individuals as "lacking" in their capacity to use the Internet. P1 stated: *"We used the computer but didn't use the smart board or the projector because our group was small. The PC was positioned in a location that was observable by everyone, so there was no need for a projector…."* However, the observers thought that the computer was not being used effectively. The observers determined that the teachers used the computer for research purposes over the Internet. The observers expected the teachers to use Web 2.0 tools, slides, and other technological tools through the computer.

Table 9. Participant Codes and Observer Scores for The Category of Technological Tools

Participants	Codes	Observer	Activity		
			1	2	3
P1	Computers with internet connection	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Inadequate	Inadequate	Unobserved
		O2	-	Inadequate	-
		O3	Unobserved	-	-

21st-Century Skills

Figure 10 illustrates the participant codes associated with the 21st-century skills addressed by activities.

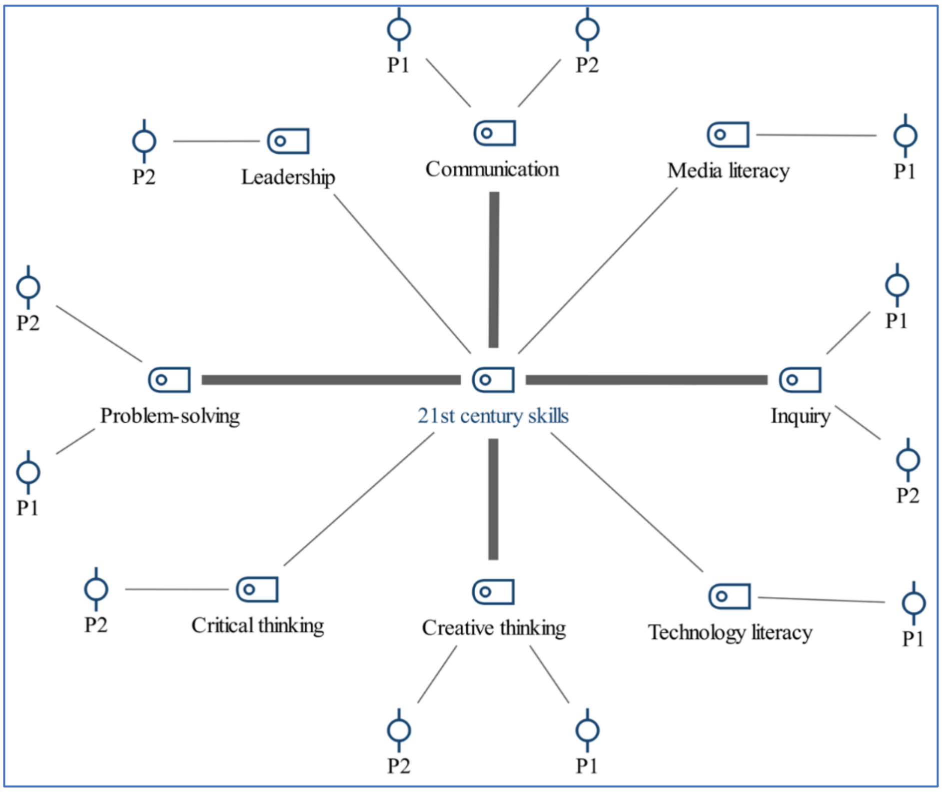

Figure 10. 21st Century Skills

Teachers sought to convey eight distinct 21st-century competencies. The female teacher sought to educate technological and media literacy, whereas the male teacher focused on imparting leadership and critical thinking skills. Both participants sought to cultivate research inquiry, communication, problem-solving, and creativity skills in their students.

Table 10. Participant Codes and Observer Scores Related to the 21st-Century Skills Category

Participants	Codes	Observer	Activity		
			1	2	3
P1	Technology literacy	O1	Adequate	Adequate	Moderate
		O2	Adequate	Adequate	Moderate
	Media literacy	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2	Critical thinking	O1	Adequate	Adequate	Adequate
		O2	-	Unobserved	-
		O3	Adequate	-	-
	Leadership	O1	Adequate	Adequate	Adequate
		O2	-	Unobserved	-
		O3	Adequate	-	-
P1	Creative thinking	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Unobserved	-
		O3	Adequate	-	-
P1	Problem-solving	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Unobserved	-
		O3	Adequate	-	-
P1	Communication	O1	Moderate	Moderate	Adequate
		O2	Moderate	Adequate	Adequate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Moderate	-
		O3	Adequate	-	-
P1	Inquiry	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Adequate	Adequate	Adequate
		O2	-	Unobserved	-
		O3	Adequate	-	-

Table 10 delineates the competencies for the 21st century that the participants aim to cultivate in their students. Furthermore, Table 10 presents the ratings assigned by the observers to the participants in this area. O1 and O2 assessed P1 as deficient due to its inability to convey the essential abilities of media literacy, creative thinking, problem-solving, and research inquiry to students. Conversely, all three evaluators have deemed P2 adequate for the abilities it intends to develop.

P1 asserted that Arduino-based robotic coding activities enhance students' media literacy skills. P1 stated: *"...They consistently searched on media literacy and navigated the internet. They searched and discovered several findings."* P1 claims to enhance students' media literacy skills; nevertheless, O1 and O2 have noted that P1 does not successfully convey the desired media literacy education.

P2 asserted that implementation enhances the development of students' leadership abilities. P2 elucidated: *"...The students in the class exercised control over the situation. All the students were able to articulate themselves with great ease. They were devising plans such as, you will execute this task, and I will manage it. The students assumed leadership roles. These students possess the capability to self-regulate effectively in the classroom."* Three observers have reported that P2 enhanced students' leadership abilities through the exercises. O1 noted: *"Students searched and were allowed to develop and manage their projects."*

P1 and P2 asserted that the activities enhance students' problem-solving abilities. P1 stated, *"I firmly believe it enhanced problem-solving abilities. The students recognized smoking as an issue that required attention. Consequently, they developed a product intended to address the issue."* During the observation, in reaction to P1's comment, O1 and O2 asserted that the implementation was inadequate for fostering students' problem-solving abilities.

Two teachers asserted that Arduino-based robotic coding activities improve students' research inquiry abilities. P1 remarked: *"...They employed research inquiry. Their inquiry focused on the necessity of employing one sensor in a specific location while using a different sensor in another, supposing that the identical device could not be used universally. For instance, we used the mq4, and they inquired and examined our rationale for not employing the four, five, seven, eight, and nine. They attempted to ignite them using a lighter, positioning them in their designated locations, and inhaling carbon dioxide onto them. I believe the activities cultivate the skill of inquiry."* During the observation, O1 and O2 collected data that refuted P1's perspective and assessed P1 as inadequate. O1 reviewed the video recordings and concluded that the students were insufficiently allotted time to complete their research questions. O1 indicated that the students examined the properties of the materials used in this evaluation procedure and did not engage in a thorough study.

Targeted But Unattained 21st-Century Skills

Figure 11 illustrates the participants' codes concerning the 21st-century abilities aimed at but not conveyed to students in Arduino-based activities. Both teachers said they were unable to convey entrepreneurship skills.

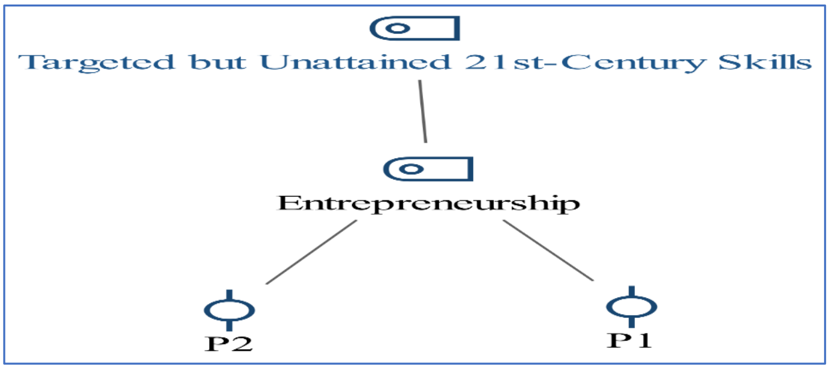

Figure 11. Targeted But Unachieved 21st-Century Skills

Table 11. Participant Codes Related to The Targeted but Unattained 21st-Century Skills Category

Participants	Codes
P1 and P2	Entrepreneurship

P1 and P2 indicated that students exhibited deficiencies in entrepreneurial skills during the Arduino-based activities (Table 11). P2 remarked: *"...there exists entrepreneurial aptitude, yet we failed to integrate it into our activities here; the students were incapable of proficiently promoting the goods... The student states I will create a signal blocker for public buildings. This is an excellent concept; when the student implements this, there should be a competitive advantage. We typically begin with instances of robotic programming; but, if students adopt a marketing-focused viewpoint, they will generate innovative goods. Entrepreneurial skills did not manifest in the activities."*

Affective Characteristics

Figure 12 illustrates the affective qualities that teachers want to cultivate in their students through Arduino-based activities. P1 sought to cultivate four distinct emotive traits, two of which (attitude and motivation) differed from those of P2. P2, conversely, sought to enhance student engagement and elevate self-confidence.

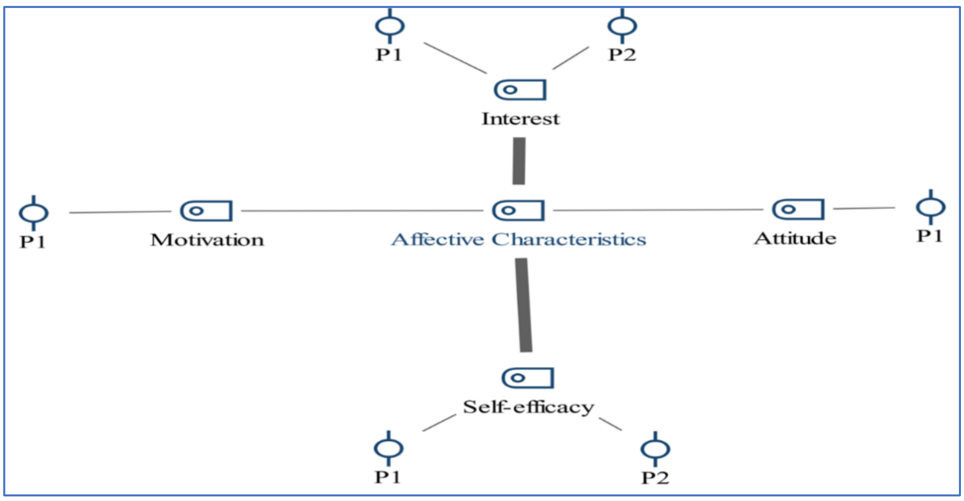

Figure 12. Targeted Affective Attributes

Table 12 shows the affective characteristics that P1 and P2 aimed to address through Arduino-based robotic coding activities. Also, it displays the scores assigned by the observers to the participants based on these objectives. O1 and O2 have assessed P1 as inadequate in conveying the four distinct affective characteristics it intended to impart to the students across all activities. Conversely, all three observers considered P2 to be adequate.

Table 12. Participant Codes and Observer Scores Related to The Targeted Affective Characteristics

Participants	Codes	Observer	Activity 1	Activity 2	Activity 3
P1	Attitude	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
	Motivation	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P1	Interest	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Adequate	Adequate	Unobserved
		O2	-	Unobserved	-
		O3	Adequate	-	-
P1	Self-efficacy	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2		O1	Adequate	Adequate	Unobserved
		O2	-	Unobserved	-
		O3	Adequate	-	-

P1 expressed her intention to enhance their students' attitudes and motivation throughout the activities. P1 states: *"I believe I have enhanced qualities such as attitude, motivation, and interest... The atmosphere was quite enjoyable. During the coffee break, discussions were held concerning robotic coding with the children. One of the students created a robotic coding tool, so we retrieved it from his locker and examined it. This indicates that the student's attitude and motivation are elevated."* While P1 noted that students' motivation rose during the activities, O1 and O2 conveyed that P1 fell short in enhancing students' motivation.

P1 and P2 stated that they aim to increase their students' interest during Arduino-based robotics coding activities. For example, P2 identified, *"In our activity, there were no students with low interest. They were all very focused."* Three observers have obtained data that support P2's opinion. At the same time, during the activities, O1 stated that P2 effectively enhanced interest levels.: *"He created an environment to enhance students' interest and motivation."* Conversely, O3 asserted that P2 was adequate for generating interest, referencing the initial activity.: *"One of the students expressed their change in the affective domain by saying they enjoyed spending time here."*

Challenges Faced While Actively Participating

Figure 13 illustrates the participant codes associated with the difficulties faced during active participation. P1 noted that the student faced problems during the activities due to a lack of focus. P2 highlighted challenges in managing the process because of the varying proficiency levels among the students.

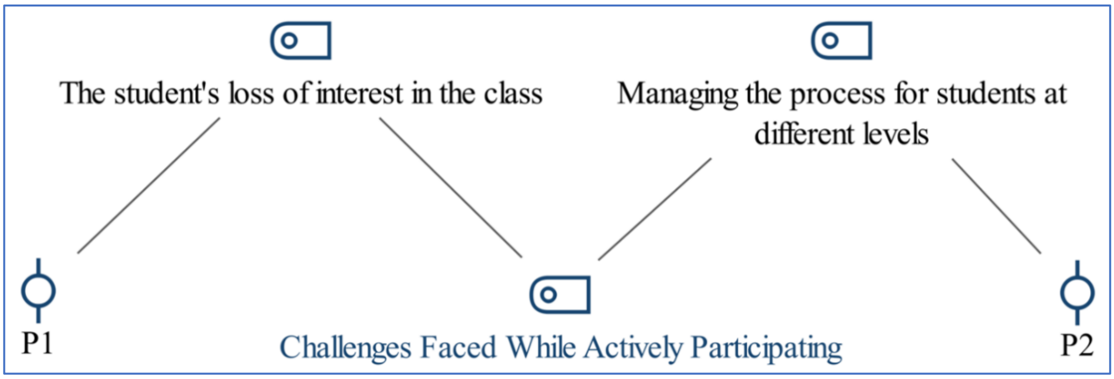

Figure 13. Challenges Faced While Ensuring Active Participation

Table 13 illustrates the challenges P1 and P2 in facilitating students' active engagement during the events. O1 and O2 noted that P1 failed to enhance students' engagement during the activities. Conversely, three observers remarked that P2 motivated students of varying levels to engage actively.

Table 13. Participant Codes and Observer Scores Related to The Category of Difficulties Experienced While Actively Participating

Participants	Codes	Observer	Activity		
			1	2	3
P1	The student's loss of interest in the class	O1	Inadequate	Inadequate	Inadequate
		O2	Inadequate	Inadequate	Inadequate
P2	Managing the process for students at different levels	O1	Adequate	Adequate	Adequate
		O2	-	Adequate	-
		O3	Adequate	-	-

P1 stated that she had difficulty ensuring active participation from the students during the activities due to their lack of focus. P1 expressed her opinion during a dialogue with the researcher;

P1: One student was engaged, but they were not interested in the activity at a particular moment. There was a moment when he was focused on his phone. I did not tell the student, "You are looking at your phone; this is unacceptable; go outside." I think communication is important. It's a significant occasion; I told you to join us and included the student in the group.

Second researcher: What could be the reason for the student’s use of his/her phone during these activities?

P1: I think it is due to the group work. If it were individual, that child would not look at his/her phone; they would focus on their work. In the group, two students were much better. Those students were already managing the work. S/he thought, "I do not need to be there."

Although P1 stated that it regained the students' scattered attention during the activities, O1 and O2 observed that P1 did not effectively enhance student interest. On the other hand, P2 stated that while ensuring active participation from students during the activities, he had difficulty managing the process for students at different levels. P2 said: *"I want every student to participate and experience it. When I do not give the code ready, the student tries to do it. Instead of providing the codes immediately, I allow the child some time. The successful student finishes early; if they have connected two LEDs, they connect the third one. Then, he changes the time, and the successful student thinks of his alternatives for a while. Unfortunately, the unsuccessful student also tries to do that; if a failed LED is lit, they increase the number of successful LEDs, add another sensor, and increase or decrease the time. A balance is achieved in the classroom."* Three observers have obtained data that support P2's opinion. O1 wrote in their note: *"During the process, students with different academic achievements were guided, and errors in the codes were identified."*

Discussion

Reasons For the Feasibility of The Activities

This study concluded that teachers are inclined to implement Arduino-based robotic coding activities due to their alignment with a constructivist approach. The authors conclude that P1 aids students in idea generation, while P2 underscores the importance of teacher guidance within the constructivist framework. Kim et al. (2017) highlighted the significance of teacher guidance in robotic coding education, a point corroborated by our findings and other studies in the literature (Chevalier et al., 2022). The activities conducted by our participants in alignment with the constructivist approach highlight the challenge of its limited adoption by teachers, a significant issue in our study, and illustrate that contemporary science teachers have embraced this approach (Driver, 2012). This study is important as it proposes student-centered activities for educators and highlights the importance of the constructivist approach for learners.

Integrating Science with Technology, Engineering, and Mathematics

This study concluded that science teachers integrate science with the other three STEM disciplines in the context of Arduino-based robotic coding activities. P2 employed ratios and proportions to integrate science with mathematics throughout the activities. Eroğlu and Bektaş (2022) have incorporated ratios and proportions into scientific disciplines. Brown and Bogiages (2019) integrated science and mathematics through the topic of functions. Consequently, it is anticipated that science teachers must possess proficiency in mathematics to effectively integrate mathematical concepts into science curricula (Niess, 2005). This study is noteworthy as it highlights teachers' need to enhance their mathematical skills.

Teachers' presentation of three distinct perspectives during Arduino-based robotic coding activities demonstrates their acceptance of science and technology integration. The effectiveness of contemporary technology and the preparedness of educators regarding technological literacy may stem from the successful integration of science and technology (Ertmer et al., 2012; Rafi et al., 2019).

Teachers have ensured the integration of science and engineering by having students engage in design during their implementation. Similarly, the literature shows design-oriented activities as evidence for the integration of science and engineering (Küçükaydın & Ulum, 2024). Therefore, this study considers the integration of science and engineering important for students to develop creativity skills, which are among the 21st-century skills (Fajrina et al., 2020). Additionally, this study is important in emphasizing the need for science teachers to incorporate design-related activities during their lessons (Capobianco et al., 2022). Finally, this study raises awareness among science teachers about the importance of Arduino-based robotic coding activities in integrating science with other disciplines.

Learning Approaches

This study concluded that science teachers prefer student-centered learning approaches when implementing activities. Teachers believe that these activities are conducive to inquiry-based and discovery learning. Therefore, this study is important because it emphasizes the need for such approaches to support meaningful learning (Fyrenius et al., 2005). Student-centered approaches facilitate a better understanding of the subject and enable the student to construct knowledge in a way that moves away from rote memorization (Ekiz, 2018). Many studies argue for the use of student-centered approaches like this one. For example, Applefield et al. (2000) state that students feel more active and independent during the process due to the use of constructivist approach practices, and they emphasize that their success level increases due to structuring knowledge. Woods and Copur-Gencturk (2024). asserted that student-centered lessons effectively address knowledge gaps and mitigate potential misconceptions. It can be said that more positive results are obtained in classes and practices where the constructivist approach is adopted compared to traditional methods (Ayaz & Şekerci, 2015). Based on all this, this study sheds light on science teachers by indicating that Arduino-based robotic coding activities are compatible with constructivist, student-centered learning approaches (Amo et al., 2021).

Characteristics of the Environment

The study concluded that activities must be conducted in an environment conducive to group work, with accessible materials and adequate digital and physical infrastructure. The study's introduction highlights the issues of student passivity, a lack of research inquiry skills, and insufficient technological infrastructure in the environment (Araújo et al., 2015). From this perspective, it is noted that teachers seek to create an environment that facilitates student interaction with one another and the activity materials while implementing Arduino-based robotic coding activities, allowing them to engage in both technological and physical aspects of the activities. Conversely, our participants regarded the classroom as an activity environment. Ceylan and Kesici (2017) asserted that robotic coding activities should be implemented in a blended learning environment. This study demonstrates how science teachers can effectively implement Arduino-based robotic coding activities in a suitable environment.

Evaluation of Time

This study concluded that teachers believe Arduino-based robotic coding activities provide adequate time for the initial phases but are inadequate during the design process. The study's introduction highlighted those teachers encountered challenges in managing the process as an issue (Cakir & Guven, 2019). Eroğlu and Bektaş (2016) noted that teachers encountered time-related challenges while implementing STEM-based activities. This study identifies negative time-related issues in Arduino-based robotic coding activities and considers these findings for future training sessions. This study is significant for teachers to implement activities more effectively in science classes and to execute the science education program without time constraints (Siew et al., 2015).

Measurement and Assessment Tools

The authors concluded that the measurement and evaluation process of Arduino-based robotic coding activities in science classes could utilize scales, interviews, and surveys before the implementation; scales, structured observations, and journals during the activities; and scales, surveys, question-answer sessions, and self-assessment following the implementation. The conclusion indicates that participants appreciate using assessment tools and the availability of self-evaluation opportunities in robotic coding activities (Norton et al., 2022). The literature emphasizes the importance of evaluating the process in robotic coding education, indicating that assessment tools should fulfill this role (Grover, 2014; Kotini & Tzelepi, 2015). This study highlights the necessity of increasing teacher awareness about the assessment tools employed to evaluate the effectiveness of robotic coding activities in science education.

Technological Tools

The study concluded that science teachers need computers with internet access to implement Arduino-based robotic coding activities (Pan et al., 2012). The literature supports this situation (Kasalak, 2017). This study is significant for educators implementing Arduino-based robotic coding activities, as it addresses essential evaluations of technological infrastructure and appropriate technological conditions (Cook & Ellaway, 2015).

21st-Century Skills

Arduino-based robotic coding activities provide students with a variety of skills. The identified skills include technology literacy (Chung & Lou, 2021), media literacy (Cakir & Guven, 2019), critical thinking (Dwyer et al., 2014), leadership (Tupac-Yupanqui et al., 2022), creative thinking (Chou, 2018), problem-solving (Plaza et al., 2018), communication (Sefein et al., 2021), and research inquiry (Chou, 2018). These skills will enhance the qualifications of teachers and students in STEM competencies (Hancock & Walsh, 2016). Conversely, teachers aiming to impart these skills to students in STEM activities must be adequately prepared. The number of participants in this study was inadequate. The authors argue that teachers need skill training to impart these skills to their students. P2's assertion that it does not impart entrepreneurial skills reinforces our argument.

Affective Characteristics

Arduino-based robotic coding activities enhance students' attitudes, motivation, interest, and self-confidence.

Research demonstrates that robotic coding activities have a beneficial impact on students' affective characteristics, including attitude (Tiryaki & Adigüzel, 2021), motivation (McGill, 2012), self-confidence (Dorotea et al., 2021), interest (Turan & Aydoğdu, 2020), and self-regulation (Yang et al., 2022). The use of Arduino-based robotic coding activities is important as it promotes the affective characteristics of students. However, the authors concluded that P1 was inadequate in fostering students' affective characteristics. Consequently, teachers need to receive training in these skills.

Challenges Faced While Actively Participating

Participants reported that students exhibit distracted attention in class and encounter challenges in managing the learning process for individuals at varying levels. The literature indicates that teachers encounter challenges related to active participation in Arduino-based robotic coding activities, including time-consuming setup, sensor detection issues, and difficulties in assembling and utilizing components (Kılınç, 2014; Yavuz-Konokman & Cukurbasi, 2019). This study sets itself apart from current literature by providing two new viewpoints on teachers' difficulties concerning active participation. The authors emphasize that curriculum developers must prioritize personalized learning in the preparation of science programs.

Recommendations

A more suitable environment should be provided for the activities. Since internet connectivity and infrastructure support are important in such activities, schools' physical facilities should be improved. More Arduino-based robotic coding activities can be organized to develop students' 21st-century skills. These skills can be addressed individually within these activities. Teachers should incorporate more Arduino-based robotic coding activities into their lessons. This study employed interviews, observations, and video recordings as tools for data collection. Future researchers may enhance data variety by utilizing teachers' documents. The limited number and duration of the activities, coupled with the inability of teachers to implement them in their classes and the absence of planned long-term activities with their students, resulted in the exclusion of teachers' documents from this study. This research involved two science teachers as participants. This situation arises from the inadequate number of science teachers conducting Arduino-based robotic coding activities in the province where the study was conducted. Consequently, researchers can engage teachers to perform a comprehensive qualitative study, implement a quantitative study for broader generalizability, and undertake a mixed-methods study to capture a more functional and pluralistic viewpoint. Based on the suggestions and experiences of the participants in this study, we argue that teachers need training in STEM. Qualitative research can be conducted to examine in-depth the technological pedagogical content knowledge, digital competence, reluctance to update oneself, attitudes, and understanding of teachers using Arduino-based robotic coding activities.

Notes

[*]This study comes from the first author's master's thesis under the second's supervision.

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