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Drivers and Barriers of Science Teacher Development Program on STEM Learning Using Arduino

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Abstract: The science teacher development program on STEM Learning using Arduino was conducted to enhance science teacher competencies in designing and implementing a 21st-century skills-based teaching approach. This study implemented research evaluation with Context, Input, Process, and Product (CIPP) to determine the drivers that supported and enhanced the program's effectiveness and address the barriers that obstruct teachers' competencies. The methodology employed in this study is both qualitative and quantitative methods. Qualitative methods gather data through observations, interviews, and document analysis. In addition, quantitative methods involve calculating the percentage of participants who complete the training program. Interviews and document studies in context evaluation help determine if program objectives are relevant to teachers' needs and aligned with the curriculum. Observation, interview, and document study were employed to evaluate input, process, and product and complement with quantitative data. The result shows that the science teacher development program is highly relevant today in enhancing teachers' competencies to design 21st-century skills-based teaching. However, some improvements are still needed to support the drivers and eliminate the barriers to make the program more effective. Some drivers, such as participants' motivation, well-organized content, competent facilitators, and sufficient resources, are assets to continue the program. However, the revision of the indicator objectives program, the selection process of participants, the time to conduct the workshop session, guidance, and content representation are essential to note.

Keywords: Arduino Project; Science Teacher Development; STEM Learning.

Introduction

The development of the Fourth Industrial Revolution has significantly affected many aspects of human life, including the nature of jobs. In 2017, the Swiss Federal Council reported that 350,000 jobs had disappeared in Switzerland due to infrastructural changes, yet during the same period, 850,000 new types of jobs emerged [1]. This transformation is not confined to Switzerland; the effects of the Fourth Industrial Revolution have been felt globally [2]. To tackle these challenges, the education sector should become adaptable. Education should help students understand concepts and equip them with the skills needed to face these challenges. The World Economic Forum (WEF) has identified key skills for future job preparedness, including problem-solving, critical thinking, creative thinking, decision-making, coordination flexibility, and negotiation [2]. Science education, in particular, should aim to develop these students' skills. One effective approach to promote these 21st-century skills is STEM education. STEM, an acronym for Science, Technology, Engineering, and Mathematics, was introduced by the National Science Foundation (NSF) in the United States in the 1990s [3]. The STEM curriculum was launched in response to concerns about decreasing interest in STEM careers and the performance of American high school students in Trends in International Mathematics and Science Study (TIMSS) and Program for International Student Assessment (PISA), where they ranked 24th in science literacy and 27th in mathematics out of 57 participating countries[3].

Meanwhile, Indonesia's PISA results have not shown significant improvement over the years, although there was an increase in ranking of 5-6 positions in 2022 from 2018. The average performance of Indonesia remains less than that of other countries, as illustrated in Figure 1**.** According to the PISA result, the science classroom learning process must adapt to the new paradigm and trend, such as STEM Learning.

The STEM approach is an interdisciplinary method that enables students to apply mathematics, technology, science, and engineering to design and conduct investigations, analyze and interpret data, and communicate findings [4]. STEM learning is an approach that can improve 21st-century skills, including computational thinking skills [5].

When used in group learning, STEM provides a robust environment for social interaction, which is crucial for the learning process. STEM activities are reported to impact communication and collaboration [7] positively. Additionally, Bybee (2018) argued that STEM education develops opportunities for students to be aware of things beyond the traditional disciplines. Bybee (2018) mentioned that some competencies in STEM education that students would have the chance to enhance are [8] understanding the nature of science, using evidence and developing arguments, engaging in civil discourse, and enhancing 21st-century skills.

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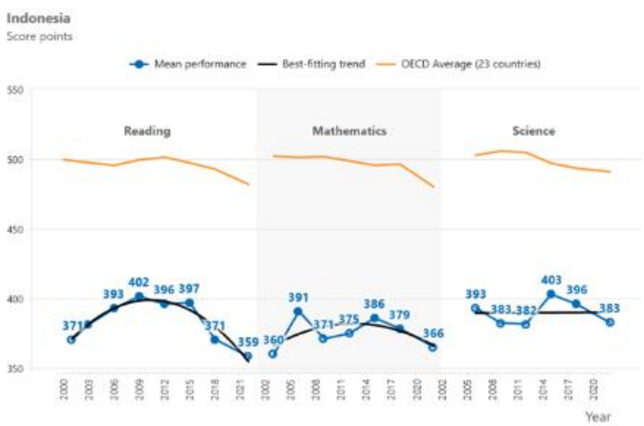

Figure 1. Indonesia PISA Result [6]

The characteristics of the STEM approach are similar to those outlined in the Next Generation Science Standards (NGSS), which include Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The steps of Engineering Design Practices (EDP) as proposed by James R. Morgan et al. include identifying problems (Identify Problem), researching (Research), developing ideas (Ideate), analyzing ideas (Analyze Ideas), building products (Build), testing and refining (Test and Refine), and communicating and reflect (Communicate and Reflection) [5].

Technology in STEM learning implementation is essential and can't be ignored. However, the technology skills of the science teacher in Indonesia still need improvement. According to the ICT director of the Ministry of Education, Indonesia stated that only 40% of Indonesian teachers in 2018 had competencies to integrate digital technology in the classroom [9]. Therefore, the science teacher professional development program in STEM learning should continue to be pursued.

One technology that is valuable for STEM education is Arduino [10]. Arduino is a highly popular technology with a large user community [11]. An Arduino can be integrated with six sensors at once [12]. It is a microcontroller capable of controlling various sensors, such as temperature, distance, pressure, magnetic, light, and humidity, making it a valuable tool for scientific experiments [12] or project-based learning [13]. Arduino is easy to use [11], open-source [14], affordable, low-cost [15][16] and widely available on the market. Its programming system can be based on block programming [17] or procedural programming [18], allowing independent experiments and active learning [17]. Using Arduino vocational education improves students' logical thinking [19]. Using Arduino with Engineering Design Process (EDP) in science classes can enhance students' problem-solving skills [20], thus significantly improving their 21st-century skills.

Utilizing Arduino as a multifunctional tool for STEM education, initial questionnaire results of junior and senior high school teachers in West Java indicate that over 80% of 50 teachers who take the survey are not yet familiar with Arduino technology. This condition also appears to occur in other regions, such as in Purworejo, Central Java, as indicated in research that highlights the low competency of teachers in implementing microcontroller-based learning, both in terms of software and hardware [21]. However, Arduino technology is an inexpensive and practical alternative tool because it can be integrated with various sensors for measurements in scientific investigation, such as experiments of temperature dependence resistance [22], speed of sound [23], Malus' Law [24], pH and temperature measurement [25].

To enhance teacher competence and integrate Arduino in science classrooms, STEM learning workshops have been organized by teacher communities and practitioners, with institutional support and funding. One such initiative is the *belajarstem.id* program received funding from the Seameo Australia Education Link Award in 2021. The workshop on STEM Learning using Arduino has been conducted continuously since 2021. In 2023, the workshop targeted teachers from Bandung and Cimahi, West Java. Since the program was undertaken constantly, it needs evaluation to determine the drivers and barriers to improve its quality and achieve its goals.

Based on the backgrounds, this study's purpose is to evaluate the context, input, process, and product of the science teacher training program on STEM learning using Arduino conducted in 2023. To comprehensively assess the program, this study employed the CIPP (Context, Input, Process, Product) evaluation model [26]. The findings from this evaluation are expected to provide recommendations to policymakers regarding the driver factors that need to be addressed to enhance the effectiveness of workshops on STEM Learning using Arduino and to identify and mitigate potential barriers.

Research Methods

The research approach in this study used an evaluation program using The CIPP (Context Input Process Product) model, a decision-oriented evaluation approach aimed at assisting administrators in making informed decisions [26]. The CIPP model highlights the importance of value, meaningfulness, accountability, dissemination, and understanding. Context evaluation is employed to determine the needs of a program and existing programs to aid in setting program objectives.

Meanwhile, input evaluation is utilized to serve decision-making in planning, considering assets, and addressing problems regarding the implementation. In addition, process evaluation aims to determine and analyze how to modify implementation to achieve the training objectives. Finally, the last is a product evaluation that assesses teacher skills in implementing STEM learning in the classroom and their product. The main questions for each step of the evaluation can be seen in Table 1.

The method employed in this research combines both qualitative and quantitative approaches. Qualitative methods are utilized to obtain the data to answer the main questions through a series of descriptive data collection techniques: interviews, questionnaires, observation, and documents. The collection data techniques and the sources can be seen in Table 2.

Table 1. Main Questions of Evaluation Research (Adapted from Fitzpatrick, 2010)

Evaluation	Main Questions	CODE
Context	What are the program objectives?	Q1A
	Does the program's objectives align with the prevailing curriculum?	Q1B
Input	How are the resources to support the training?	Q2A
	How is the demography of participants?	Q2B
	How is the experience of the participant in using Arduino for STEM Learning?	Q2C
	How is the apparatus (experimental setup) available to support training?	Q2D
Process	How are the facilitator's competencies?	Q3A
	How are the teachers performing during the training?	Q3B
	What obstacles threaten its success?	Q3C
	How are the participants' perceptions of the program?	Q3D
Product	How are the results of the training?	Q4A
	Are the STEM Learning implemented in the classroom activities after the training?	Q4B

Table 2. Collection Data Techniques

CODE	Collection Data Techniques	Data Sources
Q1A	Interview	Head of the program
Q1B	Interview	Head of the program
Q1C	Interview	Head of the program
Q2A	Resources Analysis	Database program
Q2B	Document Analysis	Database program
Q2C	Interview	Head of the program
Q2D	Interview	Head of the program
Q3A	Questionnaire	Participants
Q3B	Observation	Participants
Q3C	Interviews	Participants
Q4A	Document Analysis	Report of Participants' Project
Q4B	Interviews	Participants

Data collection techniques began from the preparation phase utilizing qualitative methods such as participant interviews. All participants in the program are secondary school teachers in junior (13^{th} – 16^{th}) and senior (16^{th} – 19^{th}) high schools. The program committee selected the participants for this study. Qualitative methods are also employed during training by observing participants' interactions with web-based instructional materials. Apart from interviews, data collection techniques include observation and performance analysis of the website as training materials using website performance tools GTMetrix. This application is a free web performance tool that provides a free analytical process for single users. This tool is a trusted and popular tool to evaluate the performance of a website based on loading speed -related files, rating of the webpage, optimization power, and search engine algorithm [27].

In addition, quantitative methods are used to determine program effectiveness based on the percentage of participants who complete all training activities. Quantitative methods were also used to obtain the percentage of participants who attended the training. In the quantitative phase, data collection involves assessing the outcomes of products/projects submitted by participants, calculating the percentage of participant attendance, and program completion.

With both qualitative and quantitative data collected, data analysis techniques are tailored to the data type. Qualitative data analysis techniques are employed for interviews, questionnaires, and observation. This analysis began with transcribing interview results and providing descriptive analysis. Similarly, observation data is analyzed based on descriptive analysis.

The procedure of this evaluation process refers to the Stufflebeam (1973) framework, as depicted in Figure 1.

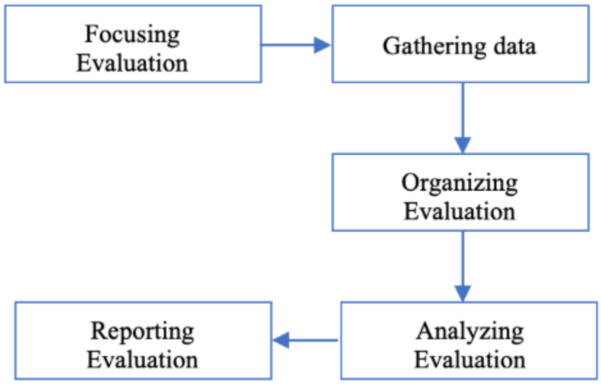

Figure 1. Research Procedure [26]

The evaluation research involves directing the evaluation towards assessing context, input, output, and process. The evaluation focus was guided by the questions outlined in Table 1. Subsequently, data collection occurs following the data collection techniques delineated in Table 2, followed by organization, analysis, synthesis, and the formulation of an evaluation report.

Table 3. Science and Technology Curriculum Objectives Related to Arduino Programming

Curriculum	Junior High School	Senior High School
Science	Students can create simple electrical circuits to understand the phenomena of magnetism and electricity and solve challenges or problems faced in everyday life.	Students can apply the concepts and principles of electricity (static and dynamic) and magnetism in solving various problems and technological products.

		Students can understand the principles of logic gates and their use in computer systems and other digital calculations.
Technology	Students can understand objects and instructions in a block (visual) programming environment to develop simple visual programs based on the examples provided, produce creative digital works (games, animations, or presentations), apply concept translation rules from one visual language to other visual languages, and get to know simple textual programming.	Students can apply good practice procedural programming concepts in one of the procedural programming languages. They can develop programs structured in algorithmic or other notation based on appropriate algorithmic strategies.

Result and Discussion

Context Evaluation

The science-teachers program on STEM Learning using Arduino aims to improve science teachers' skills in designing STEM learning using Arduino. The program's outcome is based on two indicators: 1) teachers can develop lesson plans based on the STEM approach, and 2) teachers can develop STEM projects using Arduino.

To determine whether the program's objectives align with the current curriculum that students need today, a curriculum analysis at the secondary school level was conducted, considering that all participants in the program are secondary school teachers, both from junior high (SMP) and senior high schools (SMA).

Based on the curriculum review, using Arduino in science learning at the junior high and senior high school levels is still in line with the learning outcomes. **Table 3** shows science and technology curriculum objectives for junior and senior high school related to technology and Arduino.

Table 3 shows that junior and senior high school students should already be familiar with digital technology and basic programming. Given this essential material, Arduino is not a new technology for students. Instead, using Arduino as a teaching apparatus at the junior and senior high school levels offers an alternative solution to classic problems such as limited experimental tools or project-based learning materials. Several research findings indicate that using Arduino in learning can enhance computational thinking skills, especially in abstraction, pattern recognition, and decomposition [5]. Embedded Arduino activities also improve problem-solving abilities and creativity, positively impacting the learning process [28] and algorithmic thinking skills [29]. These skills are crucial for students in the 21st century [30] and are measured internationally in PISA. By improving skills continuously and practicing these thinking skills continuously and continuously, increasing PISA scores can be achieved. However, the emphasis on integrated programming in junior and senior high school needs to be differentiated. Block programming is the primary method of introducing technology at the junior high school level.

In contrast, at the senior high school level, they are already familiar with programming languages such as Python. Therefore, the program indicators for teacher training need to be adjusted accordingly. An alternative for the second indicator workshop program recommended can be structured as shown in **Table 4.**

Table 4. Recommended Alternative Indicator

Level	Indicator
Junior High School	Teachers can develop project-based STEM using Arduino with block programming.
Senior High School	Teachers can develop project-based STEM using Arduino with procedural programming.

Block programming, such as Scratch for Arduino, allows beginner users to create Arduino projects without writing procedural programming (text-based coding). Instead, they can use drag-and-drop techniques [31]. This contrasts with text-based coding, which is more abstract and often perceived as difficult for beginner programmers [31]. Therefore, the success indicators of the program also need to be redefined according to the grade levels of the students taught by the participants.

Input Evaluation

The input evaluation began with observing and evaluating training supporting resources. Two main resources support the training program, namely the training material website and the Arduino kit. Teaching materials for STEM learning and using Arduino to implement project-based learning are available on an open-access website at the https://belajarstem.id. The performance test results of the website presented using GTMetrix are shown in Figure 2.

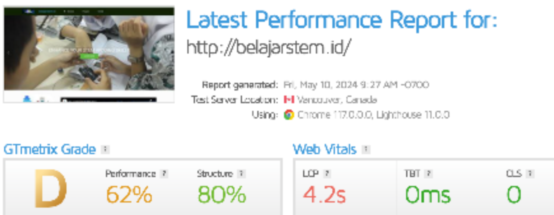

Figure 2. GTMetrix Evaluation Result

According to the criteria, GTMetrix grades range from A (very good) to F (very poor) [27]. Based on Figure 2, the website's performance scored 62%, falling into grade D, indicating that the educational resource website is categorized as relatively weak (suboptimal). The primary deficiency of the website lies in its image loading speed. A more detailed GTMetrix analysis reveals that the website uses images with substantial memory sizes, which causes the page load time to be slower than recommended. This is also reflected in the Large Content Performance

(LCP) score, with the website's loading duration reaching 4.2 seconds. This is considered subpar as it exceeds the recommended 1.2 to 2.4 seconds[27]. However, the content structure and layout shift presentation are rated very well, indicated by green markers for the Total Block Time (TBT) and Cumulative Layout Shift indicators. Based on the questionnaire, participants' perceptions of the educational materials on the website are illustrated in the graph structure in Figure 3.

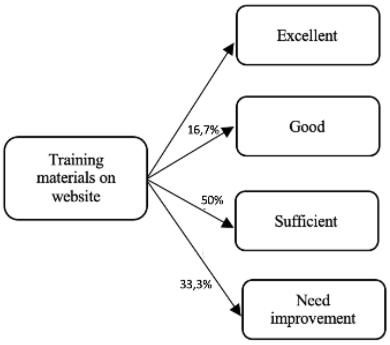

Figure 3. Participants' Perception of Training Materials

Based on feedback from several participants, it would be beneficial if the website included tutorial videos, allowing participants to learn independently when an instructor is unavailable. The website needs improvements, particularly in presenting the material menu to make it easier to navigate, such as adding category features and a content search function.

Regarding the Arduino kits, the equipment provided is adequate. There are 10 Arduino kits available for participants to use during the training, allowing every two participants to take turns or collaborate in practicing with the Arduino kits. For information, these Arduino kits were acquired through the Seameo Australia Education Link Award program in 2021. The condition of the Arduino kits is still suitable for use. Another supporting factor contributing to the training's success is the participants' ownership of laptops and their ability to operate them.

The following input evaluation concerns the participants' demographics. The STEM Learning Arduino training program participants consist of science teachers from junior high schools (SMP) and physics, chemistry, and biology teachers from senior high schools (SMA). The demographics of participants who attended the training in September 2023 are shown in Table 5.

The selection process of participants for the training program is not based on specific criteria. Registration for the training is conducted openly, allowing junior and high school science teachers to enroll. Once the quota is filled, registration is closed. The training program includes 18 participants who are science teachers from Bandung and Cimahi, West Java. Experience with Arduino or developing STEM learning is not a prerequisite for joining this training. The participant selection system, which does not require prerequisite skills, is one of the barriers to the program's success. Teachers with no computer skills or essential skills about wiring diagram on the breadboard will find it challenging to complete the project.

Table 5. Participants Demography

Participant	Gender	Level	Experience on Arduino
Participant 1	Female	Senior High	No
Participant 2	Male	Senior High	Yes
Participant 3	Male	Senior High	Yes
Participant 4	Female	Senior High	No
Participant 5	Female	Senior High	No
Participant 6	Female	Senior High	No
Participant 7	Male	Senior High	No
Participant 8	Male	Senior High	No
Participant 9	Female	Senior High	No
Participant 10	Female	Senior High	No
Participant 11	Female	Senior High	No
Participant 12	Female	Junior High	No
Participant 13	Male	Junior High	No
Participant 14	Female	Junior High	No
Participant 15	Female	Junior High	No
Participant 16	Female	Junior High	No
Participant 17	Male	Junior High	No
Participant 18	Male	Junior High	No

Process and Product Evaluation

Process evaluation began with exploring and analyzing the steps of the training activities. Based on interviews and document studies from program reports, the training activities are divided into three sessions, with the material for each session depicted in Figure 4.

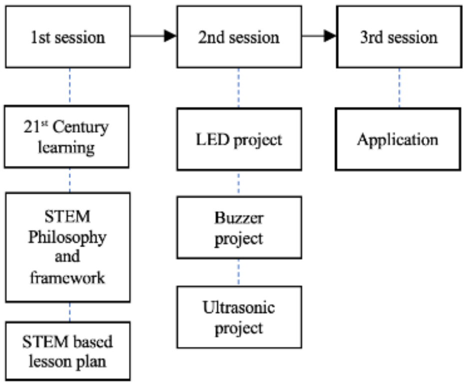

Figure 4. Training session

The first session of the training began with understanding 21st-century learning, the philosophy and framework of STEM education, and principles for developing STEM-based lesson plans. All participants were able to complete this session. Three quizzes were given for each topic after the session concluded. The percentage of participants who successfully wrote reflective essays on the training materials is shown in Table 6.

Table 6. Quiz Submission Percentage for Session 1

Topic	Percentage
21st-century learning	100%
Philosophy and Framework of STEM Education	100%
STEM-based lesson plan	100%

In the second session, participants learned about using Arduino, starting with installation and creating simple projects with LEDs, buzzers, and ultrasonic sensors. In this session, 2 out of 18 participants had difficulty installing because their laptops used illegal operating systems. Another barrier in the Arduino training was the participant's ability to read and implement diagrams into electronic circuits on a breadboard. This issue was revealed in interviews with representative teachers both from junior and senior high schools, who mentioned:

> *"The most challenging part is placing electronic components on the breadboard."*

Another difficulty faced by participants was debugging errors in their programs. Although the project guide on the website outlined the steps for simple projects like the LED program, some coding errors required corrections. Participants without prior programming experience found this extremely challenging. In line with other research, this barrier is related to the difficulty of implementing microcontrollers in the classroom, which is related to knowledge of the board and how to program it correctly [32].

In the second session, one of the participants could not complete the Arduino exercises, starting with the LED programming exercise. Interviews revealed that this participant believed the material would be challenging to implement in the classroom because students had not yet learned programming. This perception became a barrier to their success in completing the program. As noted in another study, a relationship exists between preservice teachers' learning motivation and their self-efficacy perception towards teaching [33]. Therefore, if teachers perceive the training topic as complex, their motivation to master the content will decrease.

Based on the prior skills self-assessment of participants' abilities, two individuals with experience using Arduino showed high proficiency in programming and assembling components on the Arduino board. However, by the end of the second session, 17 out of 18 participants, or approximately 94.4%, could complete the basic Arduino projects as per the guide, including the LED and buzzer projects.

The third session focused on applying concepts. Participants were tasked with creating STEM-Arduino-based lesson plans after understanding the basics of STEM education and Arduino utilization. In this session, not all participants succeeded in designing STEM lessons. Out of 18 participants, 5 did not create a lesson plan, 5 modified an example lesson plan involving a blind stick, and 8 successfully designed lesson plans with different themes. The themes of STEM-based lesson plans developed by participants using Arduino are listed in Table 7.

Based on the number of participants who submitted lesson plans, 8 out of 18 (44.4%) created new themes, and 5 out of 18 participants (27.8%) successfully modified existing lesson plans on the theme of distance sensors and blind sticks, as provided in the guide. Thus, the percentage of participants who achieved the program's objective on the first indicator is 72.2%.

Table 7. STEM-based Lesson Theme Product

Participant	Theme	Category
1	Determine the soil degree of acidity of the project	New
2	Smart home project	New
3	Smart watering system	New
4	Soil moisture measurement	New
5	Parking Sensor	New
6	Distance Sensor	Modify
7	Flood Notification System	New
8	Automatic Electricity Home System	New
9	Blind Stick Project	Modify
10	-	
11	-	
12	-	
13	Parking Sensor	New
14	Blind Stick Project	Modify
15	-	
16	Blind Stick Project	Modify
17	Blind Stick Project	Modify
18	-	

Interviews with a junior high school teacher participant revealed that one of the difficulties in designing STEM-based lesson plans using Arduino was the lack of mastery over the Arduino training session, leading to concerns about implementing it in classroom teaching after the training ended. Additionally, the worksheet format was a barrier in developing the lesson plan, which required incorporating science, technology, engineering, and mathematics elements separately, taking considerable time to develop. In contrast, the task completion time was limited.

Interviews with teachers who successfully developed lesson plans indicated that the theme ideas were designed through initial discussions with colleagues, mainly discussing the potential use of Arduino technology in STEM project-based learning activities. It can be synthesized that discussion and collaboration among peers were key drivers of the success of the STEM Arduino training implementation. This aligns with the literature, which explains that successful teacher professional development programs are related to collaborative contexts among teachers [34]. A culture of collaboration is a critical factor in effective teacher-professional development programs [34].

After the lesson plan submission session, participants were divided into four groups, each consisting of 4-5 members. Each group discussed and decided on a STEM project to create and simulate during the training. The four projects chosen for simulation were smart watering systems, parking sensors, flood notifications, and blind sticks.

The smart watering system project involved using a soil moisture sensor, which activates when the sensor detects reduced soil moisture. The Arduino then sends an electrical signal to the water pump to water the soil. This project was new for participants, who independently learned to design the component circuit and its programming. In the second training session, participants only learned to program ultrasonic sensors; in this project, they independently learned to program soil moisture sensors.

The parking sensor and flood notification projects were applications of the ultrasonic sensor project learned previously in the second session. For these projects, participant creativity was evident in designing the model or prototype of the tool. In contrast, the circuit design and programming were nearly identical to the training session, with only a few additional features like modifying buzzer sounds for different distances. In this project, participants demonstrated pattern recognition skills in programming, writing similar program patterns for several electronic components, such as adding LEDs and buzzers.

For the blind stick project, all the program and circuit diagrams were already provided in the guide, and participants only demonstrated their new skill of using Arduino gained from the training.

Interviews with training participants revealed that one of the barriers to completing the Arduino project was the implementation of circuit diagrams into electronic circuits on the breadboard, as the program sometimes did not run correctly. The Arduino board also became overheated after prolonged use, preventing optimal functioning. Technical factors were crucial to the success of the training program. Nonetheless, interviews also revealed that using Arduino in STEM learning was new and highly inspiring for teachers, motivating them to follow the training through to the final session. Another factor driving participants' success in training was the effective grouping to complete the projects. Influential groups combined middle and high school science teachers and balanced male and female participants. However, the combination was more based on mixing participants with higher abilities with those with moderate or lower abilities.

Participant perceptions of the program's implementation are shown in Figure 5. Based on perceptions shown in Figure 5, thirteen participants felt that the training activities lacked sufficient time, indicating a need for extended training duration. The mentoring activities also require attention. Interviews with representatives from junior high schools suggested additional instructors should be involved in the training process to facilitate immediate assistance with programming issues. Other aspects of the program implementation were considered satisfactory, with 83.3% of participants finding the training activities engaging and providing new insights. These results indicate that the science teacher training program on STEM learning using Arduino has a positive influence in developing motivational involvement and interest in learning using new technology.

Regarding the products developed, additional training sessions are necessary to ensure the creation of new products. The blind stick project in the guide should be used as a practice session, followed by assigning a new project as a challenge not covered in the training materials. This activity serves as the application step of the concept in a new situation for the participants.

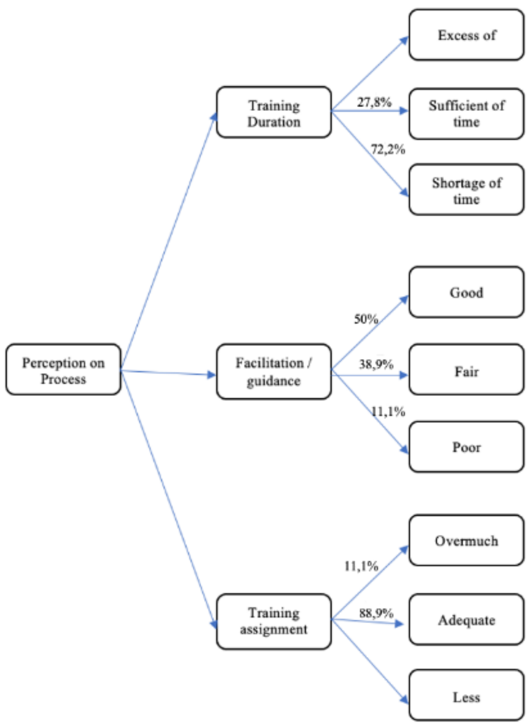

Figure 5. Participants' perception of the training process

Conclusion

The evaluation of the community-based science teacher training program on STEM learning using Arduino conducted in 2023, encompassing context, input, process, and product evaluations, underscores the need to address barriers and support drivers to enhance training effectiveness. Several drivers contributed to optimizing the training, including introducing new insight that increased participant enthusiasm, well-organized content, competent facilitators, and sufficient resources. Conversely, barriers included participants' initial skill levels, static content delivery, technical challenges in programming and wiring, and insufficient time for practicing new skills. The context evaluation recommends aligning achievement indicators with the school levels of the teachers. For input evaluation, revising the participant selection process to ensure the necessary prior skills are met is crucial. Process evaluation should focus on the training activities and mentoring sessions, suggesting additional training time. Lastly, from product evaluation, modification tasks distinct from the projects in the training modules need to be clearly defined. Despite the challenges, this science teacher professional development program on STEM learning Arduino is essential for teachers and should be continued sustainably.

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