CHAPTER I
INTRODUCTION

This chapter discusses the initial foundation of the research, encompassing the background of the problems underlying the development of a multifunctional educational mobile robot based on ESP32, the problem formulations identified from these issues, the research objectives to be achieved, the research benefits both theoretically and practically, as well as the scope limitations established to clarify the research boundaries.

1.1 Background

In general, STEM (Science, Technology, Engineering, and Mathematics) education in Indonesia has experienced positive development alongside the efforts of the government and various related stakeholders to improve education in this field. In the current era of development, the global economy is undergoing significant changes. Many existing jobs have disappeared due to automation, and new jobs emerge every day as a result of technological advancement. Moreover, technological development also influences the way students learn, relate, and interact. Skills in STEM provide a strong foundation for individuals to succeed at the school level and beyond. The global demand for STEM qualifications and skills is currently high and is expected to continue increasing in the future. This literature review was compiled to examine the development of STEM learning in Indonesia over recent years, from 2019 to 2022. The observed developments were focused on STEM learning based on variations in subjects, teaching materials, and assessment aspects utilized [1].

The STEM approach supports the learning process and facilitates the achievement of 21st-century competencies as well as the advancement of science and technology. These activities were conducted using lecture, discussion, and question-and-answer methods. The socialization and training materials consisted of: (1) the STEM approach for Science-Chemistry learning in the context of wetlands, (2) the design of learning tools including syllabi, lesson plans, student worksheets, and evaluation instruments, and (3) sample videos or simulations of the implementation of STEM Science-Chemistry learning in the context of wetlands.

Through these socialization and training activities, participants were expected to be able to employ STEM Science-Chemistry learning as a chemistry teaching strategy in the classroom [2]. Furthermore, computational-based STEM learning has been proven to be an effective approach for developing computational thinking skills when integrated into various disciplines in primary education. The following are several examples: (1) Scratch has been used to enhance mathematical understanding among sixth-grade students, where students who received Scratch training demonstrated improvements in understanding mathematical processes, reasoning, problem formulation, and problem-solving. (2) Scratch can be used to develop storytelling skills through the creation of interactive stories. (3) Scratch can be used to teach science concepts such as the water cycle by creating interactive simulations. (4) Scratch can be used to teach language arts concepts such as grammar and vocabulary by creating interactive games and quizzes. (5) Scratch has been used to develop computational thinking through live music coding [3]. These examples demonstrate the versatility of Scratch programming and its potential to enhance learning across various disciplines in primary education.

The results of a multilevel meta-analysis indicate that educational robotics has a significant positive impact on student learning outcomes in the context of STEM education, including improvements in academic performance, learning attitudes, and computational thinking skills [4]. In line with these findings, a systematic review of trends and research focuses in STEM-based robotics reveals that the use of robotics has played a crucial role in STEM learning design across various educational levels, with a primary focus on enhancing the engagement and perceptions of both learners and teachers [5]. A structurally designed STEM-based curriculum has been proven capable of improving creative thinking skills among senior high school students [6]. The Problem-Based Learning (PBL) approach integrated with STEM has also demonstrated positive results in enhancing students' problem-solving and collaboration skills [7]. On a broader scale, a meta-analysis of 66 experimental studies indicates that STEM education has a moderate positive impact on student learning outcomes across various educational levels and disciplines [8].

In the implementation of educational robotics, the selection of a microcontroller becomes a critical factor. The ESP32 is a microcontroller featuring a Tensilica

Xtensa 32-bit LX6 dual-core processor with a clock frequency ranging from 80 to 240 MHz, equipped with integrated WiFi 802.11b/g/n and Bluetooth 4.0 dual-mode connectivity, as well as 448 KB of ROM, 520 KB of SRAM, and 4 MB of Flash memory, which are sufficient for running various IoT applications [9]. Previous research has demonstrated that the design of an ESP32-based mobile robot with a Scratch coding platform is capable of effectively supporting STEM education through visual programming that is easily understood by students [10]. Additionally, a comparative study between Scratch and LEGO robots in programming education indicates that block-based visual programming is capable of significantly enhancing student engagement and learning motivation [11].

The development of ESP32-based mobile robots has also been applied in various contexts, including IoT-based surveillance robots capable of performing real-time monitoring through ESP32 cameras [12], ESP32-based educational robot control systems that integrate various sensors and actuators to enhance the learning experience [13], as well as line follower robots with obstacle avoidance capabilities that utilize ESP32-based architecture for autonomous navigation [14]. Other research has shown that the construction of mobile educational robots using a practical approach with microcontrollers is capable of improving students' understanding of integrated STEM concepts [15].

Nevertheless, several issues have emerged in the implementation of educational robotics in Indonesia. First, the currently available STEM learning media are generally still conventional and lack interactivity, rendering them unable to accommodate the needs of project-based learning that integrates the concepts of science, technology, engineering, and mathematics in a unified manner [16]. Second, commercially available educational robotics platforms on the market, such as LEGO Mindstorm, are relatively expensive, making them difficult to afford for most schools in Indonesia, particularly those in rural areas [17]. Third, the use of text-based programming languages for robot control poses a significant barrier for students who do not yet have a programming background, thereby reducing their interest and learning motivation [18]. Fourth, existing educational robots generally possess only a single operational function, making them less flexible for use in various different STEM learning scenarios [19]. Fifth, robot control systems generally have not yet implemented decision-making methods that are structured and formally documented, making them difficult to analyze and further develop. One approach that can be utilized to address this issue is the Finite State Machine (FSM), a system behavior modeling method that defines a finite number of states along with transition rules between states based on specific inputs [20].

Based on the background and issues described above, the researcher intends to propose a study on the development of a mobile robot with multiple functions that can be programmed using a visual programming language (visual coding) based on Scratch by implementing the Finite State Machine (FSM) method as the decision-making mechanism for each robot operation mode. This mobile robot is expected to serve as a learning tool for STEM education for elementary, junior high, senior high, and vocational high school students. By using Scratch visual coding, students are no longer required to have prior experience in learning programming languages. The mobile robot to be developed utilizes the ESP32 as its main component, which is already integrated with WiFi and Bluetooth modules and is relatively affordable in price.

1.2 Problem Statement

Based on the background that has been described, several problems will arise in this research, which are formulated as follows:

1. How to design and construction a multifunctional educational mobile robot based on ESP32 by implementing the Finite State Machine (FSM) method as the decision-making mechanism for each operation mode (line follower, obstacle avoidance, and smartphone control) so that the robot's behavior can be defined in a structured and documented manner?
2. How is the performance and success rate of the educational mobile robot in each operation mode, encompassing sensor accuracy, conformity of robot behavior with the FSM model, Bluetooth communication stability, and control system responsiveness?
3. How to implement Scratch/PictoBlox-based visual programming on the educational mobile robot so that students can comprehend programming logic without having to master text-based programming languages?

1.3 Research Objectives

Based on the problem formulation above, the objectives of this research are as follows:

1. To design and construct a multifunctional educational mobile robot based on ESP32 with the implementation of FSM as the decision-making mechanism for each operation mode.
2. To test and evaluate the performance and success rate of the educational mobile robot in each operation mode, encompassing sensor accuracy, conformity of robot behavior with the FSM model, Bluetooth communication stability, and control system responsiveness.
3. To implement Scratch/PictoBlox-based visual programming on the educational mobile robot to facilitate students in comprehending programming logic without requiring mastery of text-based programming languages.

1.4 Research Benefits

Based on the research objectives stated above, the results of this research are expected to provide the following benefits:

1. Theoretical Benefits

   Theoretically, this research provides a scientific contribution to the development of the application of the Finite State Machine (FSM) method in a multifunctional educational robot system based on the ESP32 microcontroller as a reference for subsequent research in the fields of robotics and informatics. Furthermore, this research enriches the scientific body of knowledge on the integration of Scratch/PictoBlox-based visual programming with structured decision-making methods (FSM) as an effective STEM learning approach across various educational levels. This research can also serve as an academic reference in the development of robotics-based STEM learning media that combines R&D methodology, the Prototyping Model, and the Finite State Machine (FSM) method as a structured informatics approach.
2. Practical Benefits

Practically, this research provides an interactive, engaging, and easy-to-use STEM learning medium for students without requiring a programming background, thereby enhancing their interest, motivation, and computational thinking skills. For teachers, this robot can function as a flexible teaching tool to integrate the concepts of science, technology, engineering, and mathematics within a single project-based learning platform in both classrooms and laboratories. For schools, the educational robot developed in this research provides an alternative robotics platform that is more economical compared to commercial platforms such as LEGO Mindstorm, making it accessible to schools across various regions in Indonesia. For future researchers and developers, this research provides a multifunctional educational robot prototype that can be further developed with the addition of IoT features, artificial intelligence, as well as the expansion of the FSM model into a Hierarchical State Machine (HSM).

1.5 Scope and Limitations

The scope and limitations of this research are established to clarify the extent of the discussion and to avoid the expansion of issues that are irrelevant to the research objectives. The limitations of this research are as follows:

1. The educational robot developed utilizes the ESP32 DevKit microcontroller as the main controller with an L293D motor driver and four DC motors coupled with mecanum wheels.
2. The decision-making method implemented is the Finite State Machine (FSM) of the Moore Machine type, which is applied to three robot operation modes, namely line follower mode, obstacle avoidance mode, and smartphone control mode.
3. The sensors used are limited to the HC-SR04 ultrasonic sensor for obstacle distance detection and three TCRT5000 line sensors for track detection on black and white surfaces.
4. The wireless communication used is the built-in Bluetooth Classic of the ESP32, connected to the Dabble application on an Android smartphone, without utilizing WiFi or internet connectivity.

5. The visual programming platform used is PictoBlox based on Scratch, without employing text-based programming languages such as the Arduino IDE during the learning implementation stage.
6. Robot testing is conducted in an indoor environment (classroom or laboratory) with flat floor surface conditions and normal lighting, excluding testing in outdoor environments.
7. This research does not encompass testing the effectiveness of the robot as a learning medium directly on students (user trials), but rather focuses solely on the technical performance testing of the robot system.