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The Development of Embedded Robotic Training Kit Using Raspberry Pi for Beginners in STEM Education within TVET Framework

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ABSTRACT – In the era of the Fourth Industrial Revolution (IR 4.0), the demand for practical and industry-relevant STEM education has grown significantly. This project addressed this need by developing an embedded robotic training kit using Raspberry Pi, which offers an accessible and practical tool for beginners in STEM education and is designed within the framework of technical and vocational education and training (TVET). This kit integrates essential components such as LEDs, buzzers, ultrasonic sensors, and Pi cameras, offering hands-on learning experiences in robotics and embedded systems. Powered by the versatile Raspberry Pi, the kit utilizes Python programming and the Thonny IDE to simplify coding for beginners while encouraging project-based learning to foster creativity and innovation. The project integrates theoretical knowledge with practical application, fostering critical problem-solving skills and preparing students for modern technological demands. By aligning with TVET objectives, the training kit enhances employability by developing essential, industry-relevant competencies.

KEYWORDS : Embedded systems, Raspberry Pi, STEM, TVET, Python programming

1.0 Introduction

Nowadays, technology has become an integral part of our lives and rapidly shapes our future. In the era of the Fourth Industrial Revolution (IR 4.0), the necessity of mastering knowledge and education in science, technology, engineering, and mathematics (STEM) has become more crucial. Technical and vocational education and training (TVET) has played a significant role in preparing skilled workforce for technological challenges in future and enhancing their employability especially in STEM related career. One of the key aspects in STEM is the understanding of embedded system technology and it serves as fundamental in developing robotics and others such as the Internet of thing (IoT).

The integration of Raspberry Pi into STEM education, particularly within the framework of TVET, offers a significant opportunity for enhancing learning experiences in robotics. The TVET framework focus on practical skills and industry relevance, making it suitable for implementing Raspberry Pi-based robotics training kits. This is in line with the TVET framework's focus on employability and industrial relevance, which ensures that students are equipped to meet the demands of the modern workforce [1].

The Raspberry Pi is a small, like the size of a credit card, versatile and cost-effective computing platform, has been widely used in educational settings to facilitate hands-on learning and practical applications in robotics. The Raspberry Pi has been introduced in 2012 and it become a game changer at all levels of education around the world by offering students a chance to build everything from simple circuits to fully functional robots [2]. By pairing with Python, a programming language known for its simplicity and Thonny as Python IDE, the Raspberry Pi becomes even more powerful. Python's clear syntax makes it an ideal first language for beginners, allowing them to focus on creativity rather than getting burdened by complicated code [3] while Thonny offers built-in debugging tools that allow students to step through their code line by line, helping them understand the flow of execution and identify errors.

The combination of Raspberry Pi and Python provides a gateway into the world of robotics, where students can see their code come to life, whether it's lighting up an LED or servo motor move with angular precision. In addition, a variety of simple and interactive components such as push button, buzzers, ultrasonic and pi camera can be used with Raspberry Pi and indirectly offers an entry point into the world of robotics. Studies show that this kind of hands-on learning is incredibly effective. Additionally, students learn best when they are actively involved in making something, whether it is a model, a computer program or a robot [4]. Moreover, the educational value of this approach is supported by previous work regarding the importance of beginner-friendly programming environments in reducing the cognitive load on students [5].

In the nutshells, this training kit is more than just a bunch of components; it is a stepping stone for student to dive into the exciting world of embedded systems especially robotics. It’s designed to make STEM education not only accessible but fun and inspiring, especially within the TVET framework. With this kit, students will see that robotics is not something to be feared but interesting and it’s a field full of possibilities that is waiting to be explored with enthusiasm and creativity.

2.0 Literature Review

The Raspberry Pi, a robust and adaptable single-board computer (SBC), has gained popularity in educational particularly in computer science and engineering. This is due to its extensive capabilities in programming and data processing. One of the primary advantages of using Raspberry Pi in robotics is its capability to interface with wide ranges sensors and modules. For example, present a system that enables indoor location detection and environmental mapping using LiDA and ultrasonic sensors under Raspberry Pi control [6]. The adaptability of Raspberry Pi into a surveillance robot, highlighting its function as a configurable brain that links different peripherals like WiFi modules and cameras for efficient monitoring [7].

The Raspberry Pi provides a more flexible alternative, as it can run a complete operating system and performing complex computations. It allows students to do quite a bit more than just basic input-output, from basic projects like LED blinking to more complex tasks such as robotic control and sensor integration. The PiBot, for example, is a cheap robotic platform that combines a Raspberry Pi 3 and a PiCamera to allow students to experiment with robotics with vision capabilities [8]. Principles of project-based learning (PBL) has been acknowledged as a successful educational strategy in the field of STEM education [9]. By implementing Raspberry Pi as instructional tool in PBL method, it guides students through complex robotics and programming principles by engaging real-world problem-solving while they construct and apply Raspberry Pi. Furthermore, learning of Internet of Things (IoT) concepts, which are increasingly become important in today's technological environment, can be made easier with the use of Raspberry Pi as an instructional tool in educational robotics [10].

The integration of robotic kits based on Raspberry Pi into the TVET framework offers many benefits as well as challenges. Study on how pre-service teachers can employ Raspberry Pi activities to boost their STEM skills indicated significant improvements in problem-solving, creativity, and technological skills, suggesting that Raspberry Pi can effectively address the educational needs of TVET students by providing practical, real-world applications [11]. By giving students, the tools to create and manipulate, educators not just teach them concepts but also empower them to explore and be innovate. Students can use Raspberry Pi and Python to work on projects that interest them, whether it's automating a task, creating a game, or building a robot. The Thonny IDE further enhance the experience by allowing them to see how their code works in real time, which reinforces their understanding and allows them to iterate quickly. This approach known as constructionism and was developed by Seymour Papert, where he believes that children construct their new knowledge by constructing physical and manipulative materials, like blocks, beads, and robotics kits [12]. This is the answer to why the Raspberry Pi, Python and Thonny work so well together in educational environment.

The educational value of Raspberry Pi with Python and Thonny is highlighted in gamified learning approaches, where students perform practical tasks that apply theoretical knowledge to real-world circumstances. This approach not only promotes interest but also develops collaboration among students as they share ideas and code [13]. Such collaborative spaces are critical for improving problem-solving skills and promoting innovation in technological fields. For instance, the development of an autonomous robotic vehicle based on computer vision using Raspberry Pi illustrates how such projects assist learners develop critical thinking and problem-solving skills [14]. Other than that, this combination offers an environment that is simple to use and promotes learning and experimentation for users, particularly beginners, to interact with robotics and programming. The Raspberry Pi was designed to encourage pre-university learners to engage with programming concepts, and Thonny plays a vital part in this educational initiative by allowing students to write and run Python code easily [15].

3.0 Methodology

For this project, the training kit was developed to fill the gap between theory and practice especially for beginners in python programming using Raspberry Pi. In general, this project used Raspberry Pi 3 as the main platform and was powered by 5VDC with 2.1A. In this section, several components and devices in designing and development of the training kit are discussed.

3.1 Hardware Requirements

For this embedded robotic training kit, Raspberry Pi 3 Model B used as the core platform due to its capability to act as a computer for moderate task. The Raspberry Pi operates on Debian based GNU/Linux operating systems (OS) and can connect to the monitor for displaying its Raspberry Pi OS. The 4.3 inch with 800 x 400 resolution Display Serial Interface (DSI) used intended basically for video data. Figure 1 show the Raspberry Pi 3 Model B architecture.

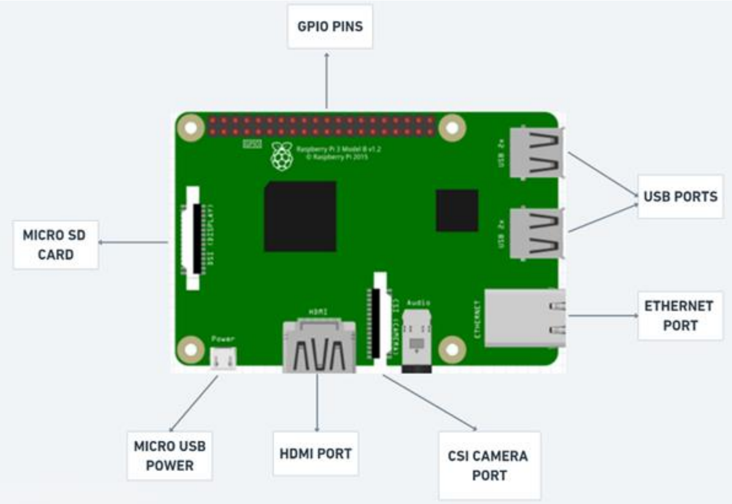


Figure 1: The Raspberry Pi 3 Model B architecture

Model B is the earliest model of the third-generation Raspberry Pi [16]. Table 1 shows its specification.

Table 1: Specifications of Raspberry Pi 3 Model B

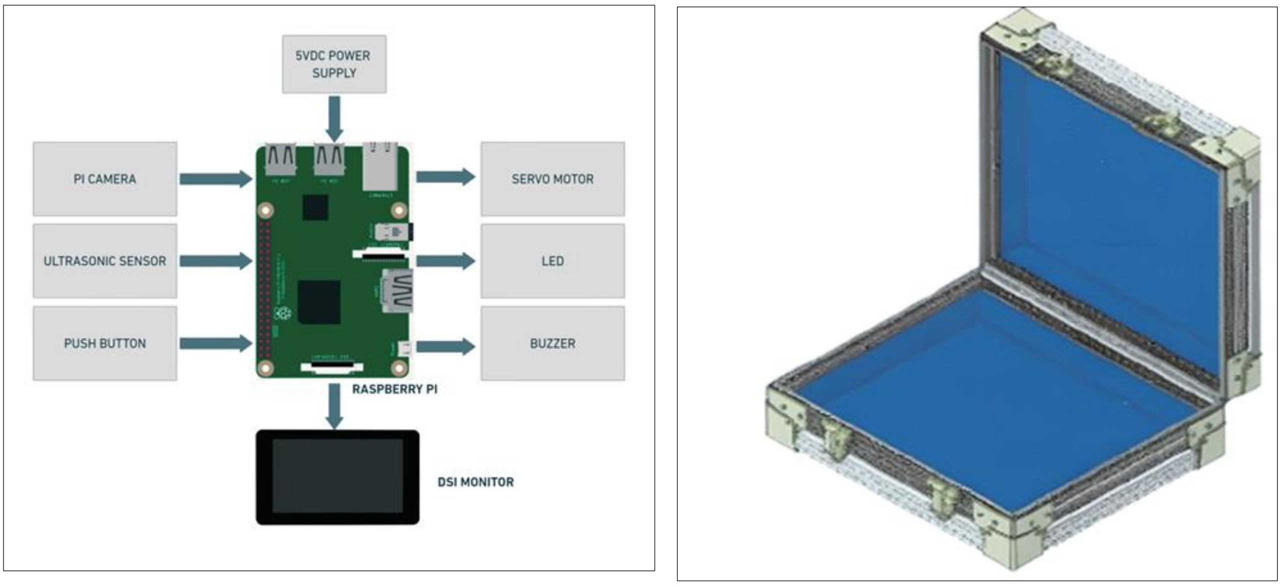
SPECIFICATION
Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
1GB RAM
BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
40-pin extended GPIO
CSI camera port for connecting a Raspberry Pi camera
DSI display port for connecting a Raspberry Pi touchscreen display
Micro SD port for loading operating system and storing data
Micro USB power source up to 2.5A with 5VDC

The kit was designed to include essential components such as LEDs, a buzzer, a servo motor, a push button, a Pi camera, and an ultrasonic sensor. These components as shown in Figure 2 were chosen to cover various aspects of electronics and robotics, offering a well-rounded introduction to practical applications. For this project, Raspberry Pi 8MP camera module V2 is used. It provides high-resolution still images at 3280 x 2464 pixels, measured 25mm x 23mm x 9mm and connects via a 150mm CSI ribbon cable. The SR04P ultrasonic sensor is used as sensor input. It can cover distances ranging from 20mm to 4000mm with dimensions of 45.3mm x 20.4mm x 15.4 mm. SG90 Micro Servo used as actuator output for this project. It has a rotation angle of 180° and measures 23.0mm x 12.2mm x 29.0mm and weighted at 9.0 grams.

a) b) c)

Figure 2: a) Camera module, b) Sensor, c) Actuator

Figure 3 shows block diagram and casing design for this project. The casing is in rectangular design measuring approximately 335mm x 275mm x 118mm and featured with two symmetrical halves that open at a 90°.



a) b)

Figure 3: a) Block diagram, b) Casing design

3.1 Programming Environments

Python was chosen as the programming language due to its simple syntax and versatility. Thonny is a Python IDE that is very suitable for beginners, was selected to facilitate coding, debugging, and testing. Thonny is a new Python IDE for learning and teaching programming that can make program visualization a natural part of the beginners' workflow [17]. It has many userfriendly features such as an easy-to-use interface, syntax checking, and auto-completion. Figure 4 show flowchart of programming process using Python and Thonny for this training kit.

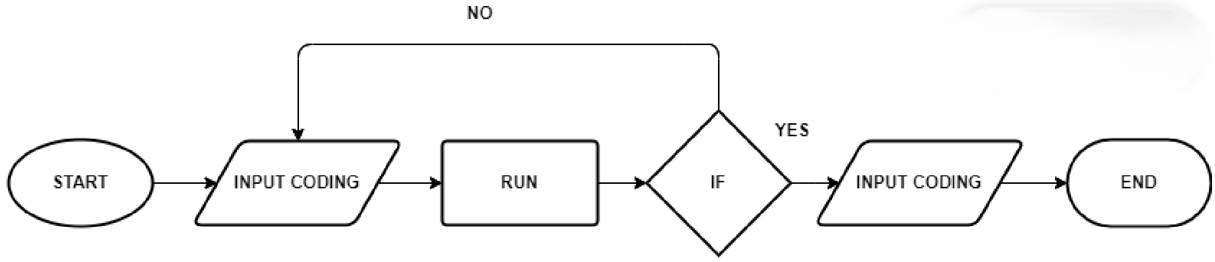
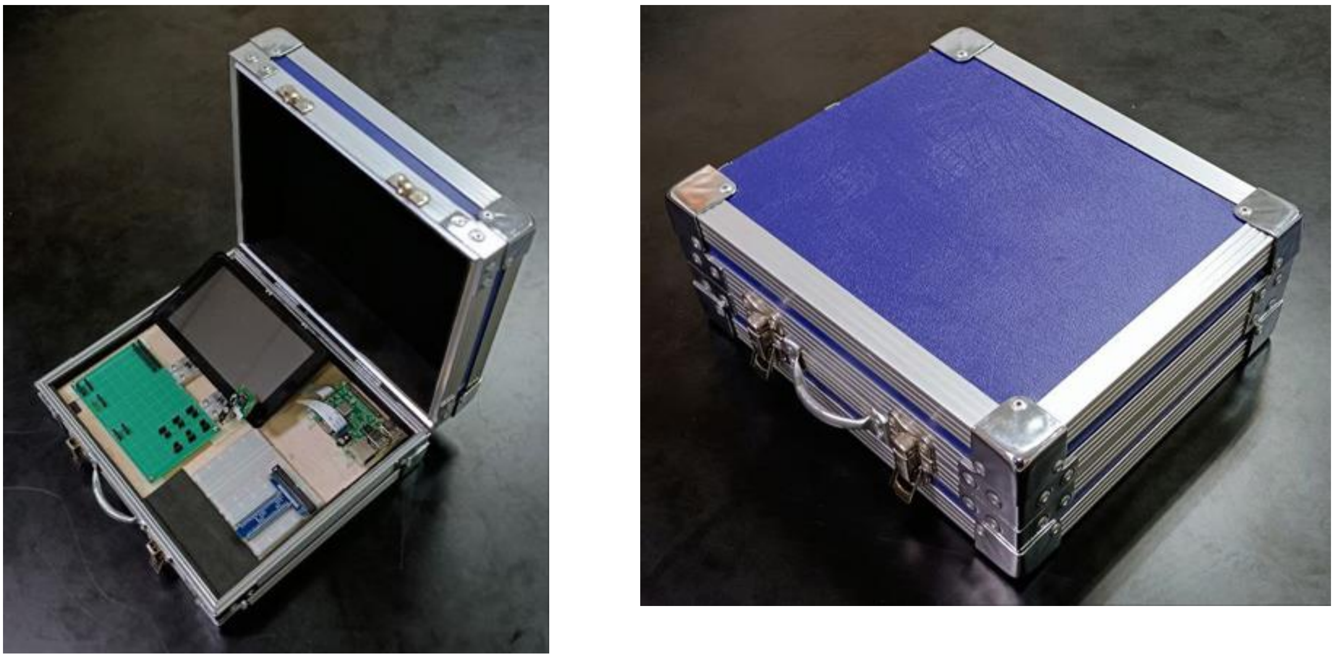


Figure 4: Flowchart of programming process

When using Raspberry Pi GPIO pins to connect external devices, library files need to be imported to program these pins. The library used for this project are gpiozero and RPi GPIO. The gpiozero is a library that not only accesses GPIO pins but also provides direct hardware support for manipulating electronic components and sensors, whereas RPi GPIO is a robust library that supports basic interactions with GPIO pins and allows users to manipulate GPIO pins using code.

4.0 Result

The fully develop embedded robotic training kit using Raspberry Pi 3 Model B shown in Figure 5. To make it easier for students to quickly and efficiently connect to the breadboard, a T-cobbler is used as an extended GPIO. The connections between them use a 2 x 20 connector ribbon cable. The rectangular case design offered enough protection and organisation for the components. Its 335mm x 275mm x 118mm size offered easy access to the hardware for configuration.



a) b)

Figure 5: a) Training kit's arrangement setup, b) Training kit's case

The Raspberry Pi 3 Model B, featuring a 1.2 GHz quad-core Broadcom BCM2837 CPU, performed well when operating under Raspberry Pi OS, as illustrated in Figure 6 with smooth display output with no observable lag on the 4.3-inch Display Serial Interface (DSI). The system maintained a seamless display output, with no observable lag on the 4.3-inch Display Serial Interface (DSI). This display allows students to interact with the Raspberry Pi's graphical user interface, making it easier to visualize and debug their projects. The 1GB of RAM was sufficient for running the Raspberry Pi OS and executing Python programs on Thonny IDE, allowing the system to handle tasks, such as real-time sensor data processing and camera feed without significant lag. This indicates that the chosen hardware platform works well for beginner robotics projects, particularly in educational settings.

Figure 6: The Raspberry Pi OS

The selection of Python as the main programming language as shown in Figure 7, together with the Thonny IDE, significantly improved development, debugging, and execution performance. By combining the gpiozero and RPi.GPIO libraries, students can leverage the capabilities of both high-level and low-level control. For instance, gpiozero can be used for quick prototyping and simple projects, while RPi.GPIO can be employed for more complex tasks that require precise control over the GPIO pins. Python's simple syntax, together with the gpiozero and RPi.GPIO libraries, enabled effective interaction with hardware components, making the programming process more intuitive for beginners.

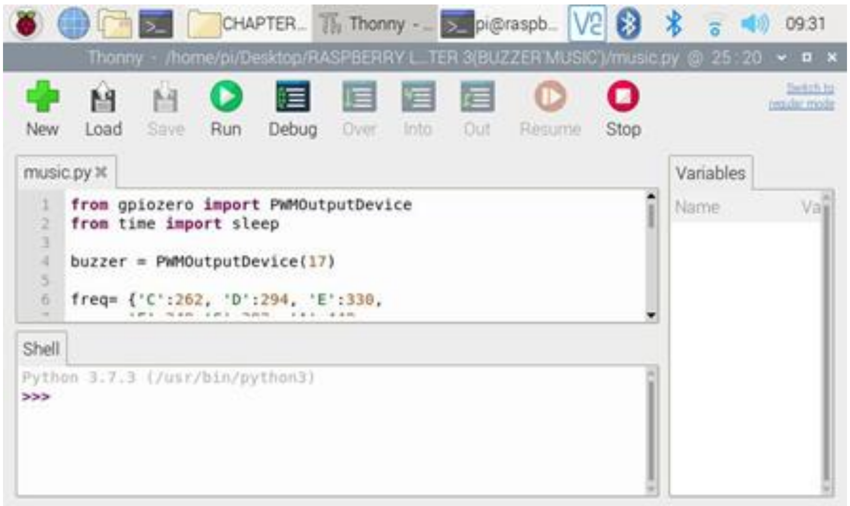
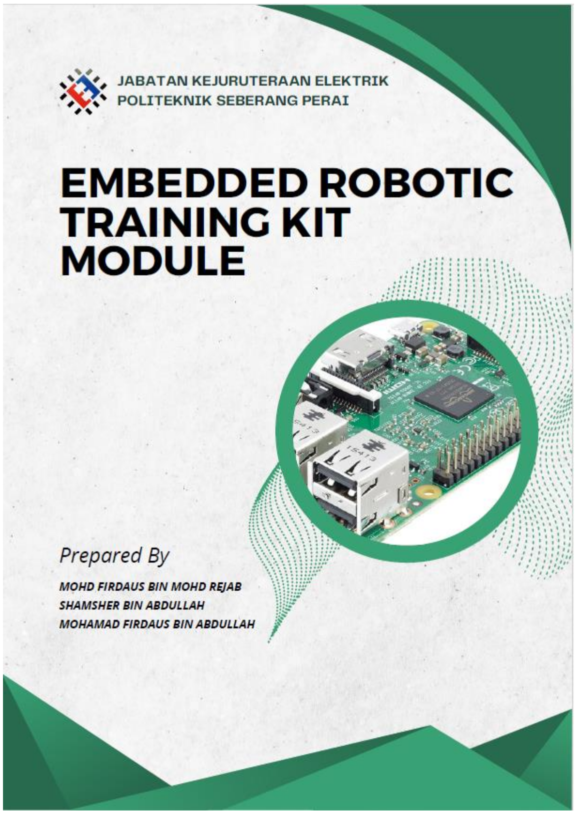


Figure 7: Thonny IDE with Raspberry Pi script

The kit also includes LEDs, a buzzer, and a push button, which are fundamental for teaching basic electronics and programming concepts. The ultrasonic sensor provided accurate distance measurement between 20mm and 4000mm with minimal latency, while the Raspberry Pi 8MP camera module delivered high-quality images and stable real-time feedback which is ideal for object detection. The SG90 micro servo motor responded smoothly by making precise movement with maximum angle of 180° which effective for robotic tasks.

To enhance students' experience and kit's effectiveness, the embedded training kit module has been developed as shown in Figure 8. Through this module, students can undertake projects such as designing a distance measurement system using ultrasonic sensors and controlling servo motor movement. Each project is structured to guide students through planning, programming, and problem-solving processes. This approach has proven effective in strengthening students' understanding of fundamental STEM concepts and building their confidence in overcoming technical challenges.



CONTENTS

a) b)

Figure 8: a) Module's front page, b) Module's contents

The findings obtained from the six educators through the observation form indicate that this training kit met seven key criteria related to its effectiveness. The criteria assessed include the kit's suitability for teaching and learning, the relevance of its components to STEM and TVET objectives, student engagement in practical activities, clarity of instructions, contribution to skill development, enhancement of STEM subject understanding, and alignment with the syllabus. Most of the educators agreed on the effectiveness of the kit in supporting the teaching and learning process, actively engaging students, and aligning with educational goals. The overall mean score for these criteria is 4.88, reflecting a high level of satisfaction. Table 2 summarizes the educators' reviews for the Embedded Robotic Training Kit, highlighting its strong overall performance in terms of design, functionality, and suitability as a teaching aid.

Table 2: Summary of educator review

Item	N	Min	Max	Mean
The kit suitable for use in the teaching and learning process	6	5	5	5.00
Components and tasks included in the kit relevant to the learning objectives of STEM education within the TVET framework	6	4	5	4.67
The kit actively involves students in hands-on learning and practical applications	6	4	5	4.83
The instructions and guidance provided in the kit were sufficiently clear	6	5	5	5.00
The kit contributed to the development of new skills, such as programming and problem-solving.	6	4	5	4.83
The use of the training kit significantly enhanced the understanding of STEM subjects, such as programming and robotics.	6	5	5	5.00
The training kit align with the STEM and TVET syllabus	6	4	5	4.83
OVERALL MEAN				4.88

5.0 Conclusion

The development of an embedded robotic training kit using Raspberry Pi indicates a significant improvement in STEM teaching within the TVET framework. The Raspberry Pi's cost and adaptability, together with the simplicity of Python programming and the Thonny IDE, provide a solid platform for hands-on learning, promoting a deeper knowledge of fundamental concepts and developing essential skills such as problem-solving and creativity. It is in line with TVET's goals of increasing employability through practical, industry-relevant skills, connecting theoretical knowledge to real-world application, and driving additional innovation in STEM disciplines.

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