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Development of esp32-Based Automatic Plant-Watering Control as Vocational Learning Media

Muhammad Nasirudin
SMK Negeri 11 Pandeglang, Indonesia

Email: muhamadnasirudin40@guru.smk.belajar.id

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ABSTRACT

This study developed an ESP32-based automatic plant-watering control system as learning media for vocational microprocessor and microcontroller instruction. The study used a research-and-development design comprising potential-and-problem analysis, data collection, product design, design validation, iterative revision, product trial, usage trial, and production. Data were collected using five-point Likert questionnaires and analyzed descriptively. The prototype integrates an ESP32 controller, soil-moisture sensor, relay, and water pump and was tested across soil-water conditions from the initial state to 200 mL. Feasibility scores were 4.27 from the material expert, 4.16 from the media expert, 4.17 in the product trial, and 4.18 in the usage trial, indicating that the media was feasible to very feasible for instructional use. The study demonstrates the practical value of an authentic embedded-system artifact for linking programming, electronics, sensing, and control in vocational learning. Because the evaluation focused on feasibility rather than comparative learning gains, further research should test effectiveness, reliability, and longer-term classroom outcomes.

Keywords: ESP32; automatic irrigation; learning media; microcontroller; vocational education

INTRODUCTION

Vocational education increasingly requires learning environments in which students can connect abstract programming concepts with observable physical processes. Hands-on engineering tasks, authentic problem contexts, and project-oriented activities can strengthen engagement and disciplinary understanding when learners design, test, and refine functional artifacts (Prince, 2004; Mills & Treagust, 2003; Hmelo-Silver, 2004; Kolodner et al., 2003; Blumenfeld et al., 1991; Bell, 2010; Kokotsaki et al., 2016; Guo et al., 2020). In electronics education, this need is particularly salient because students must coordinate hardware knowledge, algorithmic thinking, debugging, measurement, and system integration rather than memorize isolated component functions (Guzdial, 2015; Grover & Pea, 2013; Wing, 2006; Shute et al., 2017).

At SMK Negeri 11 Pandeglang, the source manuscript identifies limited infrastructure, restricted learning resources, low student attention in industrial-electronics subjects, and difficulties understanding ESP32 software and hardware as practical instructional problems. An instructional prototype that makes sensor input, controller processing, and actuator output visible can therefore function as both a teaching aid

and an authentic engineering system. Physical computing and maker-oriented learning have been associated with productive opportunities for experimentation, iterative design, and computational thinking (Martin, 2015; Papavlasopoulou et al., 2017; Vossoughi & Bevan, 2014; Blikstein, 2013; Halverson & Sheridan, 2014).

The ESP32 is well suited to such activities because a compact board can integrate digital and analog input/output, wireless connectivity, and embedded control. More broadly, Internet-of-Things and sensor-based systems have become important contexts for engineering and STEM education, allowing students to work with real-time data and cyber-physical interactions (Atzori et al., 2010; Gubbi et al., 2013; Al-Fuqaha et al., 2015; Wortmann & Flüchter, 2015; Ray, 2018; Qureshi et al., 2022). Automatic irrigation is an especially accessible application because soil moisture provides a measurable input and pump activation provides an immediately observable output, while smart-irrigation research illustrates the wider relevance of sensing and control to water efficiency (Kim et al., 2008; Gutierrez et al., 2014; Navarro-Hellín et al., 2016; Kamienski et al., 2019; García et al., 2020).

Accordingly, this study aimed to develop an ESP32-based automatic plant-watering control device as vocational learning media and to evaluate its feasibility through expert validation, product trials, and usage trials. The contribution is pedagogical rather than agronomic: the prototype is positioned as a tangible learning medium for microcontroller programming, electronic interfacing, sensing, and automated control.

LITERATURE REVIEW

Microcontroller and IoT Learning Media

Educational media can reduce the distance between symbolic explanation and observable phenomena when representations are aligned with instructional goals. Multimedia and interactive representations are most effective when they manage cognitive load, direct attention to relevant information, and support active processing rather than adding decorative complexity (Mayer, 2009; Mayer & Moreno, 2003; Sweller et al., 2011; de Jong, 2010; Fiorella & Mayer, 2016). For vocational electronics, a functioning microcontroller system can externalize otherwise invisible relationships among source code, sensor readings, logic thresholds, and actuator behavior. Simulation, laboratory experimentation, and physical prototyping are complementary approaches when each is used for a clear pedagogical purpose (de Jong et al., 2013; Brinson, 2015; Potkonjak et al., 2016; Ma & Nickerson, 2006).

Authentic Design, Making, and Vocational Competence

Constructionist and maker-oriented perspectives emphasize learning through the creation of personally and socially meaningful artifacts (Kafai & Resnick, 1996; Martin, 2015; Blikstein, 2013). In engineering education, design projects can promote integration of conceptual knowledge, procedural skill,

collaboration, and iterative problem solving, although benefits depend on scaffolding, assessment, and the quality of task design (Dym et al., 2005; Litzinger et al., 2011; Freeman et al., 2014; Theobald et al., 2020). These principles support the use of an automatic irrigation controller as a learning artifact: students can inspect circuitry, modify code, interpret sensor values, diagnose faults, and relate technical decisions to a real-world application.

The broader technology-enhanced STEM literature further emphasizes alignment among pedagogy, disciplinary content, and technology (Mishra & Koehler, 2006; Chai et al., 2013; Kelley & Knowles, 2016). Studies of virtual, augmented, and physical representations suggest that technology is most valuable when it supports purposeful interaction and inquiry rather than novelty alone (Zacharia & Olympiou, 2011; Bacca et al., 2014; Ibáñez & Delgado-Kloos, 2018; Radianti et al., 2020). Engineering-education scholarship similarly stresses situated learning, explicit design criteria, and coherent project structures (Felder & Brent, 2003; Johri & Olds, 2011; Krajcik & Blumenfeld, 2006; Thomas, 2000).

METHODS

Design and Development Procedure

The study used a research-and-development approach based on ten stages reported in the source manuscript: (1) potential and problem analysis, (2) data collection, (3) product design, (4) design validation, (5) design revision I, (6) product trial, (7) product revision II, (8) usage trial, (9) product revision III, and (10) production. The study was conducted in the Industrial Electronics Engineering Laboratory of SMK Negeri 11 Pandeglang. The source contains a date inconsistency: the abstract reports 1 November–17 December 2021, whereas the Methods section reports 1 November–17 December 2022. This discrepancy is retained as a reporting limitation rather than silently resolved.

Prototype and Instrumentation

The prototype used an ESP32 microcontroller, soil-moisture sensor, relay, water pump, and supporting electronic components. The circuit was designed and fabricated on a PCB, programmed through the Arduino IDE, and tested by varying water volume in the soil medium. Feasibility data were collected from material and media experts and from student product and usage trials using five-point Likert questionnaires. The original study converted qualitative judgments into quantitative scores and summarized them using mean values.

Score	Interpretation
5	Very good
4	Good
3	Fair
2	Poor
1	Very poor

RESULTS AND DISCUSSION

Prototype Function and Sensor Response

The completed device operationalized a simple input–process–output architecture: the soil-moisture sensor supplied input data, the ESP32 processed the reading according to programmed logic, and the relay controlled the water pump. In the source test, the sensor value decreased as water was added, from 50 in the initial condition to 35 at 200 mL. This pattern demonstrates that the prototype generated an observable sensor response suitable for classroom discussion of calibration, threshold logic, analog sensing, and automated actuation.

Soil-water condition	Sensor value
Initial condition	50
20 mL	39
40 mL	39
60 mL	38
80 mL	38
100 mL	38
120 mL	38
140 mL	38
160 mL	37
180 mL	36
200 mL	35



Figure 1. ESP32-based automatic plant-watering learning-media prototype (source manuscript).

Feasibility Evaluation

Expert and user evaluations were consistently positive. The material expert produced an overall mean of 4.27, categorized as very feasible. The media expert mean was 4.16, the product-trial mean was 4.17, and the usage-trial mean was 4.18, each categorized as feasible in the source. The four reported means average approximately 4.20, supporting the conclusion that the prototype was considered suitable for instructional use. The source later reports the material-expert score once as 4.28 and an overall mean of 4.195; because the detailed table and abstract report 4.27, this article preserves 4.27 as the primary table value and flags the discrepancy.

Evaluation stage	Mean score	Reported category
Material expert validation	4.27	Very feasible
Media expert validation	4.16	Feasible
Product trial	4.17	Feasible
Usage trial	4.18	Feasible

The strongest material-expert dimension was usefulness (4.50), while the media evaluation highlighted operation (4.25). During the product trial, the learning dimension reached 4.29, and during the usage trial the operation dimension reached 4.22. These patterns are pedagogically plausible: tangible systems can support experiential learning by making abstract relationships inspectable and manipulable, while iterative product feedback can improve usability (Kolodner et al., 2003; Dym et al., 2005; Litzinger et al., 2011; Martin, 2015). The findings are also consistent with evidence that active, project-oriented STEM environments can improve participation and learning when appropriately structured (Freeman et al., 2014; Kokotsaki et al., 2016; Guo et al., 2020; Theobald et al., 2020).

From an instructional-design perspective, the prototype creates a compact context for integrating electronics, programming, sensing, data interpretation, and control. Rather than treating IoT as an abstract network concept, students can observe how sensor data are acquired and translated into an action. This alignment with authentic engineering practice is important in vocational education, where competence requires coordinated conceptual and procedural knowledge. Nevertheless, feasibility ratings should not be interpreted as evidence of improved learning outcomes; a controlled effectiveness study would be required for that claim.

LIMITATIONS

The study has four principal limitations. First, the source manuscript does not report the number or demographic profile of student respondents or the number of expert validators. Second, questionnaire reliability and validity coefficients are not reported. Third, the evaluation is descriptive and focuses on perceived feasibility rather than learning gains, transfer, retention, or comparative effectiveness. Fourth, the source contains internal inconsistencies in the research year (2021 versus 2022), the material-expert score (4.27 versus 4.28), and the described pump-control threshold; these should be checked against original field records before journal publication. Future work should report sample sizes, instrument psychometrics, sensor calibration, control logic, and experimental or quasi-experimental learning outcomes.

CONCLUSION AND RECOMMENDATIONS

The study successfully developed an ESP32-based automatic plant-watering control system as learning media for vocational microprocessor and microcontroller instruction. The prototype combined a soil-moisture sensor, ESP32 controller, relay, and pump in a functional input–process–output system.

Feasibility judgments were favorable across material-expert validation (4.27), media-expert validation (4.16), product trial (4.17), and usage trial (4.18). The device therefore shows promise as a tangible medium for connecting programming and electronics with an authentic automation task. Future research should move beyond feasibility by evaluating student learning, debugging competence, computational thinking, and transfer; documenting instrument reliability; calibrating sensor thresholds; and testing the system across larger and more diverse vocational-school samples.

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