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Development of an STM32 Microcontroller Training Kit for Microcontroller Programming Based on Project-Based Learning to Enhance Understanding of Microcontroller Programming

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Abstract

This research addresses the competency gap between the graduation outcomes of Electronic Engineering Vocational High School (SMK) students and industry requirements. The theoretical nature of the existing curriculum has resulted in a lack of practical skills among students. The objective of this study was to develop an STM32 Microcontroller Training Kit integrated with Project-Based Learning (PjBL) and assess its feasibility, practicality, and effectiveness in improving learning outcomes in Electronic Engineering competencies. The study used a Research and Development approach with the ADDIE model. The research subjects were 11th-grade students of the Industrial Electronic Engineering program at SMK Negeri 1 Kalinyamatan, divided into an experimental group and a control group. Data were collected through observations, interviews, expert validation, user response questionnaires, and pre-test and post-test assessments. The validation results indicated that the product was highly feasible, with a Content Validity Index (CVI) of 0.97 from media experts and 0.92 from subject matter experts. Practicality testing yielded a CVI score of 0.95, classified as very practical. The effectiveness test using an Independent Sample T-Test revealed a significance value of 0.00<0.05; the post-test mean score for the experimental group was 85.00, significantly higher than the control group's 68.33. The N-Gain analysis showed a 69.89% improvement in the experimental group, indicating that the intervention was moderately effective. In conclusion, the STM32-based PjBL Training Kit is valid, practical, and effective for improving the competencies of SMK students in alignment with industry standards within vocational electronic education.

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INTRODUCTION

The Fourth Industrial Revolution demands that Vocational High Schools (SMKs) dynamically align their curriculum and learning media with the latest technological standards, particularly in competencies related to ARM Cortex-M based microcontrollers such as the STM32, which currently dominate modern industrial applications (President of the Republic of Indonesia, 2022; STMicroelectronics, 2023). However, field observations reveal a significant competency gap among graduates due to the use of outdated learning media that no longer meet the current needs of the manufacturing sector. This issue is further exacerbated by limited access to industry-standard practical tools and the scarcity of innovative teaching models that can enhance both technical skills and critical thinking in students, particularly in the complex field of embedded systems technology.

To address this gap, integrating STM32 microcontroller technology with the Project-Based Learning (PjBL) model presents a strategic solution. STM32 offers advantages such as high performance and energy efficiency for automation applications and the Internet of Things (IoT) (Yiu, 2020), while PjBL has been proven effective in increasing student engagement and practical competencies through the completion of real-world projects (Krajcik & Shin, 2014). Despite the substantial potential of both, research specifically focused on developing STM32-based learning media integrated with PjBL at the SMK level is still very limited. Therefore, this study aims to develop an STM32-based PjBL training kit, assess its validity and reliability, and analyze its effectiveness in improving the microcontroller programming competencies of SMK students.

METHODOLOGY

This study adopts a Research and Development (R&D) approach, implementing the ADDIE (Analysis, Design, Development, Implementation, Evaluation) development model as proposed by Branch (2009). The selection of the ADDIE model is based on its systematic and structured nature, making it highly suitable for ensuring the quality of the educational media development process.

The procedure begins with the Analysis phase, which includes a needs assessment, curriculum review, analysis of student characteristics, and the current learning environment. This phase involves observation, in-depth interviews with subject teachers, and the study of existing learning materials (learning outcomes, learning objectives, and teaching modules). The findings from this phase serve as the foundation for the Design phase, where the researcher develops the conceptual framework, including the design of the STM32 training kit hardware, supporting learning modules, Project-Based Learning (PjBL) scenarios, and evaluation instruments. The Development phase follows, wherein the design is realized into a physical product, which is then validated by experts before being tested.

In the Implementation phase, field trials are conducted using a quasi-experimental design with a pretest-posttest control group. The quasi-experimental design is chosen because random assignment of subjects is not feasible, as the classes are already formed naturally, and thus, interventions are carried out in intact groups. The final phase, Evaluation, is conducted both formatively during the development process and summatively after the implementation to assess the final effectiveness of the product.

The participants and subjects in this study involve two main groups. First, a group of expert validators, consisting of three media experts and three subject matter experts, who assess the product's technical and pedagogical feasibility. These validators were selected based on their academic qualifications and professional competence, including university lecturers and education practitioners (teachers/instructors) with at least a master's degree or relevant certifications, and significant experience in electronics and embedded systems. Second, the field trial subjects are 11th-grade students specializing in Electronics Engineering. These students are divided into an experimental group, which uses the STM32-based PjBL training kit, and a control group, which follows conventional learning methods.

Table 1. Pretest-Posttest Design with Control Group

Group	Pre test	Treatment	Post test
Experimental	O1	X	O2
Control	O3		O4

Explanation:
X : Treatment using the STM32 microcontroller training kit
O1 : Pretest group of the experimental class
O2 : Posttest group of the experimental class
O3 : Pretest group of the control class
O4 : Posttest group of the control class

Data collection was carried out using both non-test and test instruments. The non-test instruments include validation sheets for the media and subject experts and student response questionnaires to measure practicality. The content validity of the instruments was analyzed using the Content Validity Ratio (CVR) and Content Validity Index (CVI), while the reliability was tested using the Intraclass Correlation Coefficient (ICC) with a two-way mixed model for inter-rater agreement and Cronbach's Alpha for the internal consistency of the questionnaires. The test instruments included multiple-choice questions (pretest and posttest) used to measure students' cognitive learning outcomes.

Data analysis was conducted quantitatively to test the effectiveness of the developed media. Prior to hypothesis testing, the pretest and posttest data were subjected to prerequisite tests, including normality testing using the Shapiro-Wilk method and homogeneity testing using Levene's Test. Hypothesis testing was performed using the Independent Sample T-Test to determine the significance of learning outcome differences between the experimental and control groups. Additionally, the improvement in the competencies of students was analyzed using Normalized Gain (N-Gain) based on Hake's (1998) formula, with the following interpretation criteria: high ($g > 0.7$), moderate ($0.3 \leq g \leq 0.7$), and low ($g < 0.3$). To facilitate understanding of the complex research process, the research procedure is visualized in a flowchart that outlines the steps from analysis to evaluation.

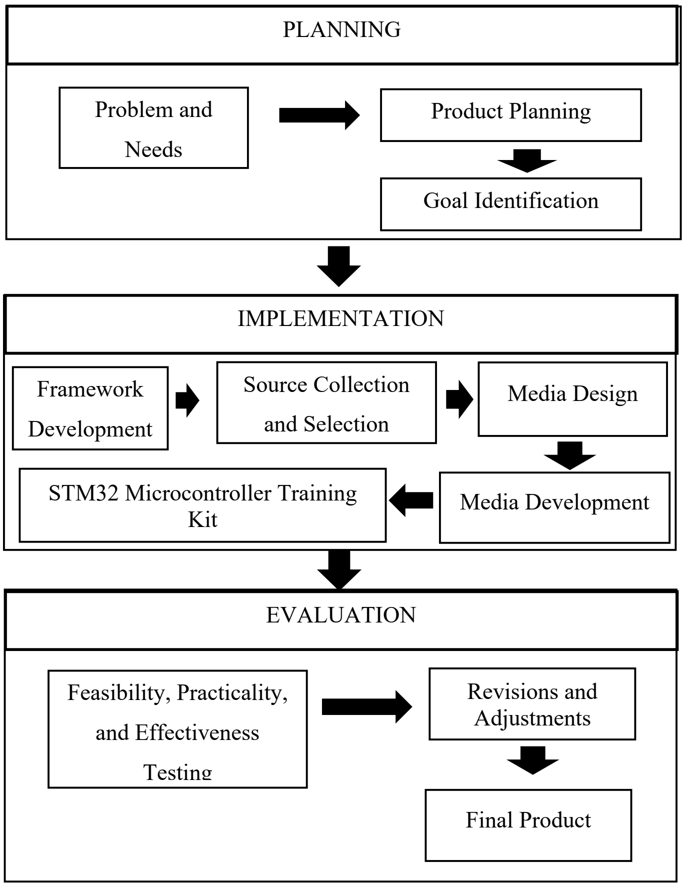

Figure 1. Product Development Flowchart

The research was conducted from November 10, 2025, to December 5, 2025, at SMK Negeri 1 Kalinyamatan, Jepara. Data for media feasibility testing were collected from three media experts and three subject matter experts, while practicality testing data were obtained from 10 Industrial Electronics teachers. Effectiveness data were gathered from 34 students in the experimental group and 34 students in the control group. Data were collected through expert validation sheets (for media feasibility), user response questionnaires (for media practicality), and multiple-choice tests (for media effectiveness). Specifically, the method applied was a quasi-experimental design with a pretest-posttest control group design. The study involved two groups: one experimental group that used the STM32 microcontroller training kit and one control group that received conventional learning. Both groups were given pretests and posttests to measure the effectiveness of the STM32 training kit on student learning outcomes. Data analysis techniques included validity, practicality, and effectiveness analysis using both descriptive and inferential statistics, such as normality and homogeneity tests, and paired sample t-tests to determine significant differences in programming knowledge and microcontroller application outcomes between the groups.

The validity of the STM32 training kit media feasibility instrument was assessed using the Content Validity Ratio (CVR) from Lawshe, and its reliability was tested using the Intraclass Correlation Coefficient. The practicality of the STM32 training kit media was validated using point-biserial correlation and tested for reliability using KR20. The effectiveness test instrument, in the form of a multiple-choice test, was analyzed using item analysis, including validity (point-biserial correlation), reliability (KR20), difficulty index, and discriminative power.

The media feasibility of the STM32 training kit was analyzed descriptively using a five-point scale conversion. The practicality of the media was analyzed quantitatively by calculating the average percentage of practicality, while the effectiveness of the STM32 training kit was analyzed using N-Gain calculations with improvement categories: low ($g < 0.3$), moderate ($0.3 \leq g < 0.7$), and high ($g \geq 0.7$). Significance testing of learning outcome differences between the experimental and control groups was conducted using a t-test with a significance level of 5%.

RESULTS AND DISCUSSION

Research and Development Results Using the ADDIE Model

a) In the Analysis phase, the identification of learning material development needs was conducted, which included analyzing the needs of students, industrial electronics competencies, learning outcomes, and the learning environment. This phase aimed to identify issues with the existing learning materials and assess the relevance of these materials to current industry demands and student characteristics.
b) The Design phase involved the formulation of learning objectives, development of learning scenarios, preparation of materials, and evaluation tools. This conceptual design served as the foundation for product development.
c) In the Development phase, the conceptual design was realized into usable learning tools. Validation was carried out by media and subject matter experts, all with expertise and experience in electronics and microcontroller technology.
d) The Implementation phase aimed to test the practicality and effectiveness of the product, based on validation results and its classroom application. The product was tested with students to assess its impact on their learning outcomes. Teachers, as users, also provided feedback on its practicality through prepared questionnaires.
e) The Evaluation phase was carried out to determine the extent to which the development goals were achieved, through revisions based on user feedback and validation results. This comprehensive evaluation included an assessment of the feasibility, practicality, and effectiveness of the product in improving student knowledge outcomes.

Feasibility of the STM32 Microcontroller Training Kit

Based on data analysis, the overall average score was 0.97, indicating that the product is highly feasible. Therefore, based on the testing results, it can be concluded that the STM32 microcontroller training kit for industrial electronics is valid with minor revisions and does not require significant overhauls, making it suitable for use as a training tool to enhance student knowledge outcomes.

Practicality Test of the STM32 Microcontroller Training Kit

Based on data analysis, with an average response rate of 95%, the user feedback (from teachers) ranged from 75% to 100%, indicating that the STM32 training kit is considered "very practical." It can thus be stated that the STM32 microcontroller training kit is a highly practical learning tool for use in the industrial electronics subject within the Electronics Engineering program.

Effectiveness Test of the STM32 Microcontroller Training Kit

Based on effectiveness analysis and the N-Gain score, the experimental group's gain score was 70%, suggesting that the implementation of the STM32 microcontroller training kit in the industrial electronics subject is quite effective in improving the knowledge outcomes of 11th-grade Electronics Engineering students at SMK Negeri 1 Kalinyamatan, Jepara, for the 2025/2026 academic year. In contrast, the control group using conventional methods had a gain score of 36%, which suggests that the conventional method is ineffective in improving the knowledge outcomes of students in the same class.

In terms of statistical significance, the results of the Independent Sample T-test with the N-Gain percentage data showed a significance value of 0.000 (less than the 0.05 significance level), indicating that the N-Gain data is both effectively distributed and statistically significant. In other words, the STM32 microcontroller training kit significantly improved the knowledge outcomes of students in the experimental group, while the conventional method did not.

The research findings indicate that the STM32 microcontroller training kit significantly improved the knowledge of students in microcontroller programming and application elements (e.g., understanding microcontroller components), conceptual knowledge (e.g., understanding programming flow), and procedural knowledge (e.g., explaining programming steps and algorithms). The strength of the STM32 training kit lies in its ability to present content in a real (non-simulated) and interactive format, bridging the understanding gap that often arises with conventional media. These findings align with previous studies by Putri and Ekohariadi (2024) and Suyadnya et al. (2024), which concluded that such training kits effectively enhance the cognitive skills and learning engagement of students.

The use of the STM32 microcontroller training kit significantly impacted cognitive learning outcomes. A comparative data analysis revealed a substantial difference in post-test scores between students using the training kit and those using conventional methods, with the experimental group averaging a post-test score of 85.00, compared to the control group's 68.33. This improvement was confirmed through the N-Gain test, showing a 69.89% increase in the experimental group, which falls under the "moderately effective" category. In contrast, the control group only showed a low increase of 35.74%. This data indicates that the training kit is an effective cognitive tool that helps students internalize complex programming concepts more easily.

A further positive impact was observed in the psychomotor domain through hands-on learning experiences. The training kit allowed students to interact directly with hardware components, including circuit assembly, microcontroller programming, and system testing. This hands-on approach bridges the gap between theory and practice, which has traditionally been a challenge in simulation-based learning. By providing direct access to I/O pins and peripheral modules, the training kit enabled students to develop real technical skills, which are vital in vocational education for mastering embedded systems competencies.

In addition to technical aspects, the integration of the training kit with the Project-Based Learning (PjBL) model actively developed the problem-solving abilities of students. During project work, students encountered technical challenges, such as sensor reading errors or programming logic issues, which required troubleshooting using the training kit. This debugging experience provided authentic challenges not found in software simulations, thus honing the analytical skills of students when resolving system issues.

From an affective standpoint, the integration of this learning media successfully increased the motivation and engagement of students in the learning process. The presence of an interactive physical media reduced the verbatim delivery and monotony often associated with lecture-based or purely theoretical learning methods. This finding is consistent with the work of Eliza et al. (2025), which showed that the innovative use of the STM32 training kit significantly improved the motivation of students by increasing active participation, perseverance, and self-confidence in practical sessions. This increased motivation positively correlated with better material absorption, as emphasized by Saifullah et al. (2024), who noted that interactive practice media facilitate independent exploration and a more concrete understanding of complex microcontroller concepts.

Lastly, the use of the STM32-based training kit has strategic implications, particularly in enhancing the relevance of the competencies of students to modern industry needs. Given that STM32 microcontrollers (32-bit) have become the mainstream standard in embedded systems and IoT, mastering this technology provides a much higher value than 8-bit microcontroller learning, which is becoming outdated. Gaining hands-on experience with industry-standard hardware not only boosts the confidence of students but also prepares them with the job readiness necessary for the demands of the Fourth Industrial Revolution.

CONCLUSION

This research successfully developed a Project-Based Learning (PjBL)-based STM32 Microcontroller Training Kit using the ADDIE model, which has been proven to be valid, practical, and effective for implementation in Vocational High Schools (SMK). Based on the feasibility test, this product is categorized as "Highly Feasible," with a Content Validity Index (CVI) of 0.97 from media experts and 0.92 from subject matter experts. From the practicality aspect, user feedback (from teachers) indicated that this media is in the "Very Practical" category, with a CVI value of 0.95, signifying the ease of use of the media in facilitating the learning process.

In terms of effectiveness, the implementation of the STM32 Training Kit significantly impacted the cognitive competencies of students. The results of the Independent Sample T-Test showed a significance value of 0.000 (< 0.05), confirming a significant difference in learning outcomes between the class using this media (experimental group) and the control class. This was further supported by the average post-test score of the experimental group, which was 85.00, higher than the control group's 68.33, and an N-Gain improvement of 69.89%, categorized as moderately effective. Therefore, this learning media is recommended as a strategic solution to bridge the competency gap between students and the current industry needs in embedded systems.

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