JPPIPA 11(12) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Development of Interactive Media to Improve CNC Machine Malfunction Handling Skills of TU 3A Based on Immersive Gamification

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Received: October 10 2025
Revised: November 14, 2025
Accepted: December 25, 2025
Published: December 31, 2025

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DOI: 10.29303/jppipa.v11i12.13088

Abstract: This research was conducted to design and produce an electronic module (e-module) for CNC Programming that integrates a project-based learning (PjBL) approach with an immersive gamification strategy, optimized for use on Android-based devices. The study employed a Research and Development (R&D) methodology, adopting the 4D framework consisting of the stages of define, design, develop, and disseminate. Data were obtained from expert validators, lecturers, and students to evaluate the e-module in terms of its validity, practicality, and effectiveness. The validation results indicated that the e-module achieved excellent validity, with average scores of 0.917 for media quality and 0.950 for material quality. The practicality evaluation yielded ratings of 96.94% from lecturers and 91.90% from students, both categorized as very practical. The effectiveness test produced an N-Gain value of 0.69, which reflects a moderate improvement in students' learning performance. Furthermore, the t-test analysis (Sig. 0.001 < 0.05; t-count 3.806 > t-table value) demonstrated a statistically significant difference between the experimental and control groups. Overall, the developed PjBL-based e-module with immersive gamification features was found to be valid, practical, and effective, serving as an interactive learning medium that fosters student engagement and aligns with 21st-century educational demands.

Keywords: Android; CNC programming; E-module; Immersive gamification; Project-based learning

Introduction

Technological progress has fundamentally transformed the landscape of teaching and learning (Almufarreh et al., 2023). The integration of digital technology in education is no longer optional but essential, as it allows for more flexible, interactive, and personalized learning and assessment experiences (Nurbayanni et al., 2023). Information and communication technology (ICT) has been widely implemented to enhance the quality of education in Indonesia (Nurbayanni et al., 2023). To optimize its impact, both government and private institutions continue to provide infrastructure and policy support for technology integration in education (Mali et al., 2023). Consequently, technological utilization has become a central pillar in modernizing Indonesia's educational practices.

Vocational education, which emphasizes mastery of technical and practical competencies, plays a crucial role in preparing graduates who are skilled, adaptive, and ready to enter the workforce (Eliza et al., 2024; Omar et al., 2024). It functions as a bridge between the competencies developed in educational settings and the dynamic needs of the labor market, thereby contributing significantly to the development of a qualified and competitive workforce (Widodo et al., 2025).

How to Cite:
Ramadhan, R., Wulansari, R. E., Indrawan, E., Novaliendry, D., & Saputra, D. A. (2025). Development of Interactive Media to Improve CNC Machine Malfunction Handling Skills of TU 3A Based on Immersive Gamification. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 1163-1171. https://doi.org/10.29303/jppipa.v11i12.13088

In the era of Industry 4.0, the rapid integration of advanced technologies—such as automation, artificial intelligence, and gamification—has transformed both industrial operations and educational approaches. One essential technology in modern manufacturing is the Computer Numerical Control (CNC) machine, known for its precision, efficiency, and role in digital production systems (Supriagi et al., 2021; Yao et al., 2024). The global CNC market, valued at USD 67.5 billion in 2023, is projected to reach USD 80.4 billion by 2028 (Fortune Business Insights, 2021), highlighting the increasing need for competent CNC operators. Therefore, equipping vocational students with advanced troubleshooting and programming skills through innovative training methods has become imperative. Integrating immersive gamification-based augmented reality (AR) into CNC learning provides new opportunities to enhance engagement, simulate authentic problem-solving, and support the transition toward Industry 5.0 learning environments.

Previous research demonstrates that repetitive and hands-on practice substantially improves students' operational performance in machine-based learning (Nuraini et al., 2023). Similarly, incorporating gamification into immersive environments has been shown to enhance motivation, interactivity, and retention by allowing learners to experiment safely without the risk of damaging real equipment (Kedah, 2023; Muliyadi et al., 2023). However, despite the growing use of simulation-based training in vocational education, few studies have successfully integrated gamification mechanisms that merge cognitive engagement, interactive learning, and adaptive feedback systems (Eka et al., 2025; Munandar et al., 2024).

Field observations conducted during the January–June 2025 semester of the CNC Programming course in the Mechanical Engineering Education Study Program at the Faculty of Engineering, Universitas Negeri Padang, revealed that practical instruction is still largely conventional. Lecturers primarily rely on direct demonstrations and visual explanations through static media such as pictures and videos. The absence of Augmented Reality (AR) learning tools in both guided and independent learning contexts limits students' ability to visualize machine troubleshooting procedures. Moreover, restricted access to CNC machines, limited lab hours, and students' anxiety about causing mechanical errors hinder effective practice. These challenges underscore the urgency of developing an interactive digital learning medium that allows safe, autonomous, and repeated practice outside the workshop setting.

Given that 92.06% of Indonesian smartphone users between 2024 and 2025 use Android-based devices, the potential of mobile learning in vocational contexts is substantial. Nevertheless, empirical data reveal that only 3% of students currently utilize smartphones for educational purposes, while 95% express interest in adopting mobile learning applications. This trend highlights an untapped opportunity to transform smartphone use from primarily entertainment-based activities into meaningful learning engagement.

Based on these findings, this research is conducted to develop and evaluate an Android-based electronic module (e-module) integrating project-based learning (PjBL) and immersive gamification strategies for the CNC Programming course. The novelty of this study lies in combining the PjBL approach—which emphasizes contextual, real-world projects—with immersive gamification, which enhances engagement through interactive digital experiences. This integration has not been extensively explored in vocational education, particularly in CNC learning. The research is significant as it aims to produce a valid, practical, and effective learning medium that not only supports conceptual understanding but also enhances students' independence, motivation, and readiness to meet the demands of digital manufacturing in the era of Industry 4.0 and beyond.

Method

This study employed a research and development (R&D) approach using the Thiagarajan 4-D development model, which includes the stages of Define, Design, Develop, and Disseminate (Sugiyono, 2020). This method was chosen to produce an Android-based e-module integrated with immersive gamification features for the CNC Programming course, as well as to test its validity, practicality, and effectiveness as a learning medium.

The participants in this study were 30 students enrolled in the D3 Mechanical Engineering program at Universitas Negeri Padang (UNP). They were divided into two groups: the experimental class (Class 0024), consisting of 15 students who used the developed Android-based e-module, and the control class (Class 0029), also consisting of 15 students who continued learning with conventional materials.

The research began with the Define stage, which aimed to identify fundamental learning problems and instructional needs related to CNC Programming. This stage involved conducting a needs analysis through interviews, curriculum review, and observation of learning activities to determine the appropriate content structure, learning objectives, and features to be embedded in the Android-based interactive e-module.

The next stage was Design, which focused on creating the initial prototype of the Android-based e-module. During this process, the researcher designed the user interface, prepared learning content, created the storyboard for gamified interaction, and developed evaluation instruments, including expert validation sheets, lecturer and student response questionnaires, and pre-test and post-test instruments to measure learning outcomes.

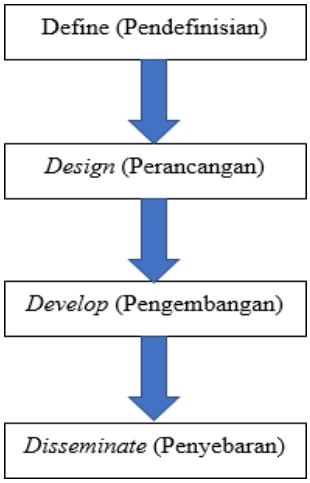

Figure 1. Model 4D

Following the design stage, the Develop stage was carried out to produce and refine the prototype into a valid, practical, and effective product. Validation was conducted by five experts consisting of two material experts who taught the CNC Programming course and three media experts from the field of educational technology. The validation process assessed the accuracy of the content, the suitability of the interface design, the functionality of the application, and its pedagogical appropriateness. After revisions based on expert feedback, practicality testing was carried out by distributing questionnaires to lecturers and students to evaluate usability and feasibility. The effectiveness of the developed e-module was tested using a quasi-experimental design involving both experimental and control groups, with data obtained through pre-tests and post-tests to measure improvements in learning outcomes and student engagement.

The final stage, Disseminate, involved implementing the validated and tested Android-based e-module in other classes within the Mechanical Engineering Department at UNP and promoting its use in partner vocational schools that offer CNC Programming courses. This stage aimed to ensure that the product could be widely adopted and contribute to enhancing learning experiences in technical and vocational education.

To obtain comprehensive results, three types of data were collected, namely validity data, practicality data, and effectiveness data. Validity data were obtained from expert validation sheets, practicality data were collected through lecturer and student response questionnaires, and effectiveness data were derived from students' pre-test and post-test scores. The questionnaires used a five-point Likert scale to assess respondents' attitudes, perceptions, and responses toward the developed media (Sugiyono, 2020). Data analysis for validity and practicality employed Aiken's V formula to determine the level of agreement among experts and respondents. Meanwhile, the effectiveness of the e-module was analyzed through normality and homogeneity tests, independent sample t-tests, and the normalized gain (N-Gain) formula to evaluate learning improvement between the experimental and control groups.

In general, the research process followed a sequential flow consisting of defining the problem, designing the prototype, developing and validating the product, testing its practicality and effectiveness, and finally disseminating the final version of the Android-based e-module for broader educational use.

Result and Discussion

Based on observations in the Department of Mechanical Engineering at FT UNP, it was found that lecturers only used PowerPoint presentations or printed materials as teaching aids. The material was delivered in a one-way manner, with lecturers presenting the material and students passively listening and taking notes. This made the learning process less effective and monotonous. Given these issues, there is a need for learning media that can meet students' needs both inside and outside the classroom. Field observations revealed that D3 Mechanical Engineering students at FT UNP have Android smartphones but do not use them for learning.

Therefore, as an alternative solution to the identified problems, it is proposed that students use their Android smartphones as learning media in the form of e-modules. The learning objectives of the Project-Based CNC Programming e-module, which uses an immersive gamification learning strategy, aim to develop the necessary material for students. Studying CNC programming greatly depends on understanding basic concepts, programming logic, and practical skills. Students with a strong foundation in technology and programming knowledge tend to grasp the material more quickly and can develop CNC programming projects independently.

However, many students struggle due to limited theoretical content or a lack of practical experience in

worksheets. Therefore, interactive, contextual teaching materials are needed to comprehensively improve students' cognitive abilities. These materials should include Project-Based Learning e-modules with immersive, gamified learning strategies. The ultimate goal is for students to meet the desired learning objectives and achieve success.

This initial design is a prototype of an interactive, immersive gamification-based e-learning module that needs to be developed before it can be validated and tested. Currently, the focus is on developing the design framework for displaying learning media. Several menus have been designed, including the "Main Menu," "Module Menu" (containing materials and lessons), "Scan Menu" (with a feature for scanning markers and an alarm button that displays the UI for turning off the alarm), "Case Menu" (containing several cases related to learning materials), and "About Menu" (containing the media developer's profile).

The main menu page is the first point of interaction between users and the application. It offers a user-friendly and informative interface. It prominently displays the application's name along with the specific topics being developed. The introductory page welcomes users and immediately clarifies the application's purpose, scope, and focus. It sets the tone for the learning journey ahead, giving users an idea of what to expect from the platform.

The main menu is designed to be intuitive and user-friendly, allowing users of all levels, especially students, to easily understand and navigate the features. Key visual elements, such as icons, illustrations, and titles, attract attention and provide clear structure. The color scheme, typography, and button placement are optimized to improve usability and reduce cognitive load, creating a smooth, engaging experience from the start.

Figure 2. Main menu

Additionally, this page is the opening screen. It contains the menus found in this interactive learning media. The Main Menu page has several button options: the "Module" button, which presents CNC Programming learning materials; and the "Scan" button, which contains a feature for scanning markers. The Main Menu display also shows the "Case" menu button, which contains cases related to the learning material. This menu includes the "About" button, which displays the profile of the developer of the immersive gamification-based interactive learning media.

The module menu page contains learning materials for TU 3A CNC Programming. Users can select various learning topics that are systematically arranged according to basic competency sequences. Each module contains material explanations and illustrations, as well as access to interactive simulations designed to reinforce conceptual understanding. With this menu, students can learn gradually and independently at their own pace. Figure 3 shows the module menu page display.

Figure 3. Indicator module

On the Scan page, users can scan markers to access troubleshooting steps for any issues that arise. Pointing the camera at a prepared error code marker will display the visual error code on the mobile phone screen. Figure 4 shows the Scan menu page.

Figure 4. Indicator scan

Figure 5 shows the visual display that appears when a marker scan is successful and error code A05 is present. The display appears on the right side of the TU 3A CNC machine screen. The troubleshooting steps that can be taken by the user appear on the left side.

Figure 5. Error code A05

Figure 6 shows the visual display that appears when a marker scan is successful and error code A00 is generated. The display appears on the right side of the TU 3A CNC machine screen. Troubleshooting steps that can be taken by the user appear on the left side.

Figure 6. Error code A00

Figure 7. Button alarm

Figure 7 shows the steps that should be taken when an alarm appears. Users can follow these steps in sequence to resolve the problem and turn the alarm status to "OFF." This interface is designed to enable users to troubleshoot independently and efficiently without referring to the machine manual. The UI appears automatically when the user presses the Alarm button, which is located at the top left of the screen in the Scan menu. This interactive feature helps students understand the causes and solutions for each alarm that may occur during the CNC TU 3A programming process.

The Case menu is used to evaluate student learning. Several objective, multiple-choice evaluation questions are presented at the beginning of the Case menu display. These questions are designed to measure students' understanding of the CNC TU 3A programming and troubleshooting material, as shown in Figure 8. The questions cover conceptual knowledge, procedural understanding, and application in real-life situations that often occur on CNC machines. Students are expected to identify problems, select the most appropriate answers, and apply concepts learned in previous stages. This feature also provides students with direct feedback on the extent to which they have mastered the delivered material.

Figure 8. Button case

Figure 9 shows the final score obtained by users after completing the evaluation case. In this example, the user received a perfect score of 100 points, meaning all answers were correct according to the predetermined answer key. This score serves as direct feedback on the user's understanding of t he material and ability to troubleshoot the TU 3A CNC machine. Additionally, this scoring feature can motivate students to take the learning process more seriously because the evaluation results are measurable and can be viewed in real time. These scores can also indicate the success of the immersive, gamification-based learning process and serve as a source of reflection for users to identify their strengths and weaknesses.

Figure 9. Score

The "About" page contains information about the developers of this immersive, gamification-based, interactive learning application. It also includes the developers' identities and brief profiles, including their names, programs of study, and institutions of origin. Additionally, it displays information about the supervising lecturers who provided guidance and supervision during the development and research process of the application. The purpose of the "About" page is to make the product more transparent and credible, so users know where the learning media came from. The page also recognizes the academic contributions of those involved in the research and application development process.

Figure 10. About

Table 1. Media Expert Validation Result

Assessment Aspects	Average Validator Value	Categories
Presentation Display	0.908	Valid
Usage	0.900	Valid
Function	0.867	Valid
Language	0.892	Valid

Table 2. Material Expert Validation Result

Assessment Aspects	Average Validator Value	Categories
Independent Learning	0.911	Valid
Learn thoroughly	0.975	Valid
Adaptif	0.975	Valid
UserFriendly	0.892	Valid
Stand alone	0.990	Valid
E-module components	0.992	Valid
Aspects of the PjBL approach	0.990	Valid

Table 3. Validity Level Categories (Irsyadunas et al., 2021)

Achievement Level	Categories
0-0.666	Invalid
≥ 0.666	Valid

The assessment of each aspect of material validation falls within the valid category. The average validity score in the material validation reached 0.926, which also falls under the valid category. Considering the assessment of media and material experts acting as validators, this Android application-based Project-Based Learning e-module with immersive gamification is deemed suitable and appropriate for use in the learning process, both in the classroom and independently.

The practicality test of learning media aims to measure the practicality level of the developed learning media (Susilawati et al., 2022). Based on the practicality test, this media obtained an average practicality score of 96.94% in the very practical category on the lecturer response questionnaire. In the student response questionnaire, an average practicality score of 91.90% was obtained, which also falls under the "very practical" category. Therefore, based on the responses from lecturers and students regarding the use of interactive learning media based on the Android application, it can be concluded that this learning media is very practical to use.

Table 4. Practical Data Results from Teacher and Student Response Questionnaires

Indicator	Percentage %lecturers Assessment	Percentage % Student Assessment	Practicality Criteria
Technical	98.33	91.58	Very Practical
Effective	97.50	91.84	Very Practical
Design	95.00	92.28	Very Practical
Equivalence	90.00	90.00	Very Practical
Use of Media	95.00	92.28	Very Practical
Average Percentage (%)	96.94	91.90	Very Practical

Effectiveness of e-learning modules

The e-learning modules that have been developed have undergone a process of validation and practical testing. Furthermore, the effectiveness of this media was tested using gain score tests and independent sample t-tests to measure its success.

Gain Score

When pretest and posttest results are compared using the N-Gain or gain score, the effectiveness of the learning media can be observed through improvements in student learning outcomes, as these scores indicate the extent to which students have progressed after using

the media. If the gain score achieved by students reaches a minimum threshold of ≥ 0.3, which falls into the moderate category, the learning media is then considered effective in enhancing student understanding and performance.

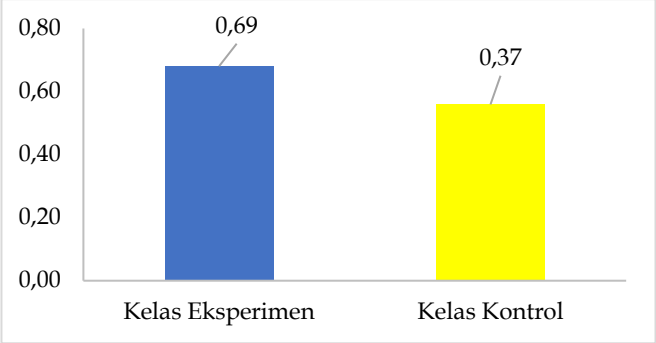

Figure 11. Effectiveness test analysis of gain score value

Based on the results of the analysis, it can be shown that the gain score in the experimental group was higher than that of the control group, with a value of 0.69 in the moderate category. Meanwhile, the control group's gain score was 0.37 in this category as well. It may be inferred from the data on the gain score in the graph above that Android application-based interactive learning media can be considered effective.

Table 5. Normality Test of Pre-test and Post-test Data of Experimental and Control Classes

Class	Data	Shapiro-Wilk		
		Statistic	df	Sig
Experiment	PreTest	.933	15	.231
	PostTest	.856	15	.304
Control	PreTest	.925	15	.219
	PostTest	.972	15	.078

Based on the variance normality test using the Shapiro–Wilk test, which was used to analyze the pretest–posttest results in the experimental and control classes, the results showed that the experimental class pretest data had a Sig. value of 0.231, while the experimental class posttest data had a Sig. value of 0.304. Meanwhile, for the control class pretest data, the Sig. value was 0.219, and for the control class posttest data, the Sig. value was 0.078. Because the significance value of both classes is greater than 0.05, it can be concluded that the experimental and control classes are normally distributed and can proceed to the next analysis.

Table 6. Homogeneity Test of Experimental Class and Control Class Pre-test and Post- test

Velue	Levene Statistic	df1	df2	Sig.
Pre-test	2.227	3	56	.95
Post-tes	1.305	3	49.305	.283

Based on data analysis, the Sig. (Based on Mean) value of the pretest results is 0.95 and the posttest value is 0.283, both of which are greater than 0.05. This indicates that the research data are homogeneously distributed, thus fulfilling the necessary requirements to conduct an independent sample t-test.

Based on Table 7, the analysis results show that the gain score in the experimental group is higher compared to the control group, with a value of 0.68 in the moderate category. Meanwhile, the control group's gain score was 0.52 in this category. From the gain score data shown in the graph above, it can be concluded that the Android application-based Project-Based Learning e-module can be considered effective.

Table 7. Homogeneity Test of Experimental Class and Control Class Pre-test and Post- test

Independent Samples Test				
Levene's Test for Equality of Variances			T-Test for Equality of Means	
	F	Sig.(2-tailed)	T	Df
Equal Variances Assumed	2.902	0.00	3.806	28
Equal Variances Assumed		0.00	3.806	24.458

Discussion

The development of project-based e-learning modules with immersive gamification for CNC programming involves a series of activities and processes aimed at creating modules based on development principles. These modules are designed to be valid, practical, and effective in the field of Mechanical Engineering. The modules were developed using the 4D methodology consisting of four stages: definition, design, development, and implementation (Xue et al., 2023).

In the first stage, the definition stage, a situation analysis, learner analysis, concept analysis, and learning objective formulation were carried out (Kartini et al., 2019). The situation analysis identifies obstacles and problems that may arise during the learning process. The goal is to create appropriate solutions for the specific classroom situation and conditions (Meepung et al., 2022). The main focus is on the D3 Mechanical Engineering FT UNP CNC Machine Programming course. The learner analysis evaluates students' abilities, knowledge, and thinking skills. The concept analysis reviews the basic competency concepts used in

developing project-based e-learning modules for the CNC machine programming course. The concept analysis provides indicators that will be used to design project-based e-learning modules with immersive gamification for the CNC programming course in mechanical engineering at FT UNP, specifically for the CNC TU 3A machine (Siew et al., 2024).

In the design stage, the e-module is designed by considering the material in accordance with the learning outcomes and objectives of the CNC programming course, particularly those related to handling disturbances. The main actions at this stage include writing, evaluating, and editing the proposed e-module while considering language, word structure, the format of objectives and evaluations, project assignments, and video material. The e-module design is based on the results of situation, learner, idea, and learning objective analyses. Therefore, students can access the e-module built using Android Studio on their mobile phones anytime, anywhere. This e-module serves as an m-learning aid. When learning only uses presentation media, such as PowerPoint, this e-module provides students with additional material for personal learning. Additionally, the e-module can be used as an independent learning resource inside and outside the classroom.

Conclusion

This study successfully developed an Android-based e-module for the CNC Programming course integrated with immersive gamification and project-based learning strategies. The resulting product was validated by material and media experts, showing a high level of validity in terms of content accuracy, interface design, and functionality. Practicality testing through lecturer and student responses also indicated that the e-module is easy to use, attractive, and suitable for independent learning. Furthermore, the effectiveness test demonstrated significant improvements in students' learning outcomes and engagement compared to conventional learning methods. Overall, the developed e-module has proven valid, practical, and effective in supporting CNC Programming learning in vocational education. It encourages active, interactive, and flexible learning aligned with the principles of Industry 4.0-based education. The findings confirm that integrating immersive gamification within Android-based learning media can enhance students' motivation and understanding in technical subjects.

Acknowledgments
The authors would like to express their sincere gratitude to the Dean of the Faculty of Engineering, Universitas Negeri Padang (FT UNP); the Head of the master's Program in Technical and Vocational Education and Training; and the lecturers and students of Mechanical Engineering Education at Universitas Negeri Padang for their invaluable support and participation throughout this research project. Special thanks are also extended to Dr. Rizky Ema Wulansari, S.Pd., M.Pd.T as the main supervisor, and Dr. Eko Indrawan, S.T., M.Pd. and Dr. Phil. Dony Novaliendry, M.Kom. as research examiners for their constructive feedback, insightful guidance, and valuable suggestions that greatly contributed to the completion of this study.

Author Contributions
All authors contributed to writing this article.

Funding
No external funding.

Conflicts of Interest
No conflict interest.

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