Jurnal Pendidikan Teknik Mesin Vol. 25, No. 1, June 2025 (55-63)

JPTM
http://journal.unnes.ac.id

DEVELOPMENT AND VALIDATION OF AN E-MODULE TO IMPROVE STUDENTS' UNDERSTANDING OF SMAW WELDING DEFECTS IN VOCATIONAL EDUCATION

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Abstract

Understanding welding defect analysis is a crucial competency in vocational welding education, especially in ensuring the quality and safety of welding outcomes. However, many students struggle to master this material due to the lack of interactive and adaptive learning media. This study aims to develop and implement an electronic module (e-module) to enhance student learning outcomes in Shielded Metal Arc Welding (SMAW) defect analysis at SMK N 5 Semarang. The research uses a Research and Development (R&D) approach based on the 4D model: Define, Design, Develop, and Disseminate. A one-group pre-test post-test design was used, involving 33 Grade XI Mechanical Engineering 2 students. The e-module was validated by experts and classified as "Valid" in terms of content, media, and assessments. Students' average scores increased from 40.61 in the pre-test to 78.64 in the post-test. Statistical analysis using the Wilcoxon Signed-Rank Test and paired t-test showed a significant difference ($p < 0.001$). The average N-Gain score was 0.63, indicating a moderate improvement. The results confirm that the e-module is both feasible and effective. It enhances students' conceptual understanding and supports independent, technology-based learning aligned with the characteristics of digital-native learners.

Key words: E-Module, Independent Learning, Learning Achievement, SMAW Welding Defects

INTRODUCTION

Vocational education is an integral part of the national education system, aiming to equip students with job competencies aligned with industry demands. In this context, Vocational High Schools (SMK) are expected to produce graduates who not only master theoretical concepts but also possess practical skills, particularly in the field of welding technology. One of the core competencies in the mechanical engineering curriculum is understanding the Shielded Metal Arc Welding (SMAW) process and the ability to analyze welding defects as indicators of weld quality.

With the advancement of technology and the demands of Industry 4.0, innovation in the learning process has become essential. From an industry perspective, understanding the types, causes, and detection methods of welding defects is critical for ensuring product quality and safety. Studies on welding defect analysis highlight the direct relationship between welding parameters and the occurrence of defects such as porosity, undercut, slag inclusion, and incomplete penetration (Miño, 2017). Furthermore, research utilizing X-ray and non-destructive testing (NDT) techniques underscores the need for students to develop both visual inspection and NDT skills for effective weld quality evaluation (Alnaily & Aboalhol, 2024).

Despite the importance of these competencies, many vocational schools still face challenges, including limited access to adaptive digital learning resources, insufficient practical facilities, and constrained instructional time. These limitations hinder the delivery of effective, practice-oriented learning experiences. These conditions have raised concerns about students' ability to effectively grasp complex concepts, such as the identification and analysis of welding defects, which require not only theoretical understanding but also critical observation skills (Dwi Cahyono & Ainur, 2018). One promising solution to address these challenges is the use of e-modules as digital learning media. E-modules offer structured, interactive content that supports flexible and self-directed learning (Putra et al., 2023). Compared to other forms of media, e-modules provide a balance between content depth, accessibility, and learner autonomy. Recent studies have demonstrated that e-modules can significantly enhance student learning outcomes in welding subjects at vocational schools (Agustian et al., 2024).

In the specific context of SMAW welding, both mastering welding techniques and analyzing welding defects are considered essential skills. The implementation of e-module strategies has proven effective in enhancing students' cognitive and practical competencies. Research by Yunus et al. (2024) reported a high gain score of 0.72 following the use of a problem-based learning (PBL) based SMAW welding e-module, demonstrating its significant impact on learning outcomes. Furthermore, e-modules designed with self-directed learning principles have been shown to improve students' independent learning capacity and theoretical understanding of SMAW materials (Ramadhan & Jalinus, 2021). Beyond cognitive improvements, the integration of service-learning components within e-modules has also been found to foster students' academic achievement and social empathy as part of character development (Firdaus et al., 2019). Supporting these findings, Safriwardy et al. (2022) demonstrated that systematically developed and expert-validated SMAW welding learning modules can be effectively implemented in vocational education settings, enhancing both instructional quality and learning effectiveness.

Considering the importance of effective and relevant learning media in supporting student competency achievement, this study aims to develop a valid and effective e-module to improve students' understanding of SMAW welding defect analysis at SMK N 5 Semarang. This e-module development is expected to provide a meaningful contribution to strengthening contextual, technology-based vocational education aligned with industrial needs.

METHODS

Research Design

This study employed a Research and Development (R&D) methodology, a research process oriented toward the development and validation of educational products. In the context of education, the R&D approach is particularly relevant because it directly addresses specific classroom issues, such as students' learning difficulties or the lack of adaptive instructional media (Okpatrioka, 2023). Through this approach, researchers identify problems and systematically design, develop, and test innovative solutions, resulting in functional and tested educational products.

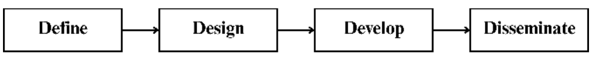

Figure 1. The 4D Development Model

To guide the product development process in a structured manner, this research adopted the 4D model proposed by Thiagarajan et al., (1974). As shown in Figure 1, the model consists of four main stages: Define, Design, Develop, and Disseminate. Through these four stages, this study systematically develops an electronic learning module (e-module) specifically designed to enhance students' understanding of Shielded Metal Arc Welding (SMAW) defect analysis at SMK N 5 Semarang.

Research Procedures

The following is a breakdown of the research procedures based on the 4D model:

1. Define Stage

The Define stage is the initial step of the research that focuses on needs analysis. Through preliminary analysis, the main problem identified is the low understanding of SMAW weld defect analysis among Grade XI Mechanical Engineering (TP) 2 students at SMK N 5 Semarang. This analysis is followed by a study of student characteristics to ensure the solution developed aligns with their needs. Based on this research, a concept analysis was conducted to systematically map and organize essential content, which then serves as the basis for formulating specific and measurable learning objectives as the foundation for e-module and instrument development.

2. Design Stage

In this stage, the initial product draft is designed based on the results of the Define stage. Activities include designing the learning outcome test instrument in the form of objective questions to be used as pre-test and post-test items, with each question aligned with the predetermined learning objectives. An interactive e-module format is selected to present content using a combination of text and images to increase student engagement, with user interface (UI) and user experience (UX) design tailored to be intuitive and easy to use. Finally, a prototype of the e-module is created, containing all content, practice questions, and visual elements according to the chosen format.

3. Develop Stage

The Develop stage is the core of the research, aiming to realize the design into a final product that is valid and tested for effectiveness. Key activities in this stage begin with expert validation of the e-module draft and its test instruments. This validation process involves two experts, including one expert teacher from the Mechanical Engineering Department at SMK N 5 Semarang. The experts assess and provide feedback covering content validity, media feasibility, and the validity of each test item. All quantitative scores and qualitative suggestions obtained are used as a basis for revising and refining the product. After revision, a field trial is conducted involving 33 students of Grade XI Mechanical Engineering (TP) 2 to measure the e-module's effectiveness in real learning situations using a One-Group Pre-test Post-test design.

This design aims to measure the effect of treatment by comparing conditions before and after it is given. The research design pattern is as follows:

$$O_1 \rightarrow X \rightarrow O_2$$

Explanation:

O_1: Pre-test – measurement of initial learning outcomes before treatment.

X: Treatment – learning using the SMAW defect analysis e-module.

O_2: Post-test – measurement of final learning outcomes after treatment.

This study employed a one-group pre-test post-test design without a control group, which is commonly used in classroom-based educational research focused on product development and effectiveness testing (Okpatrioka, 2023). This approach allows researchers to evaluate learning gains attributable to the intervention within a real teaching context.

4. Disseminate Stage

In the Disseminate phase, the finalized e-module was prepared for broader classroom implementation. The module was packaged in an interactive digital format and made accessible through an online platform to facilitate ease of use by students and teachers.

Research Subjects and Location

This study was conducted at SMK N 5 Semarang. The research subjects were 33 students of Grade XI Mechanical Engineering (TP) 2 selected using purposive sampling, based on the consideration that the class is relevant to the research topic.

Research Instruments

The main instrument used for data collection is a learning outcome test. This test consists of multiple-choice questions covering SMAW defect analysis material. The same instrument was used as both the pre-test to measure students' initial abilities and the post-test to measure improvement after using the e-module. The instrument was constructed based on a blueprint and validated by subject matter experts to ensure feasibility and appropriateness.

The learning outcome test used in both pre-test and post-test consisted of 20 multiple-choice questions, each with four answer options and one correct answer. The blueprint for item construction was based on three cognitive indicators: (1) Identification of welding defect types, (2) Understanding of causes of defects, and (3) Determination of corrective actions. Each correct answer was awarded 5 points, with the total possible score being 100. The instrument was validated by expert reviewers to ensure alignment with the instructional objectives.

Data Analysis Techniques

Data analysis in this research is divided into two main parts: analysis of product validation data from experts and analysis of students' learning outcomes.

1. E-Module Validation Data Analysis

Validation data analysis aims to determine the content validity of the e-module product, including material and media aspects, and test instruments. The validation process is carried out quantitatively based on expert assessments to ensure that the product and instruments developed are appropriate for subsequent research stages. A total of 8 experts were involved in this process, with each component being validated by 6 individuals divided into two groups:

1. Five productive teachers from the Mechanical Engineering Department at SMK N 5 Semarang who assessed the three validation components: material, media, and test items.
2. Three expert lecturers from the Department of Mechanical Engineering, Universitas Negeri Semarang (UNNES), each specifically validating one component: one for content, one for media, and one for test items.

The Aiken's V method was used to analyze this validation data, as it is a widely recognized procedure for converting qualitative expert judgments into objective quantitative coefficients (An Nabil et al., 2022). The advantage of this method lies in its ability to provide statistical evidence of content validity, making acceptance, revision, or rejection of items based on measurable data rather than mere opinion.

Aiken's V coefficient is calculated using the original formula proposed by Aiken (1985):

$$V = \frac{\sum s}{[\mathrm{n(c-1)}]}$$

Where:
V: Aiken's content validity coefficient
s: r – lo (the score given minus the lowest score)
n: number of raters
c: number of score categories
r: score given by the rater
lo: lowest score in the scale

In this study, the assessment instrument used a dichotomous scale ("Yes" = 1 and "No" = 0). On this scale, the lowest score (lo) is 0 and the number of categories (c) is 2. Substituting into the formula, the denominator becomes [n(2−1)] = n. Thus, the formula simplifies to:

$$V = \frac{\text{Number of 'Yes'}}{\text{Number Validator (n)}}$$

The resulting V value is then interpreted by comparing it against Aiken's critical value table to determine the validity of each item. An item is considered "Valid" if the calculated V reaches or exceeds the critical value at a given significance level.

Table 1. Aiken's V Criteria

Significance	Critical V Value	Interpretation
p < .05	**1.00**	Item is considered Valid

	< 1.00	Item is considered Not Valid

Based on the table above, with six raters (n = 6), an item is significantly "Valid" if the V coefficient is 1.00. Items not meeting this threshold are considered "Not Valid" and are subject to revision.

2. E-Module Effectiveness Data Analysis

This analysis was conducted on the pre-test and post-test scores of 33 students to assess the effectiveness of the validated e-module. The analysis includes the following stages:

Descriptive Statistics

This analysis provides a basic overview of the pre-test and post-test score data, including the number of data points (N), mean, median, standard deviation, and minimum and maximum values.

Normality Test

To test the research hypothesis, which compares learning outcomes before and after using the e-module, the Wilcoxon Signed-Rank Test was used. This non-parametric test was selected because it does not require the assumption of normal distribution, making it a robust and appropriate choice for learning outcome data, which often does not follow a perfect normal distribution (Zulkipli et al., 2024). A p-value < 0.05 indicates a statistically significant difference.

Paired Samples t-test

This test examines whether there is a significant mean difference between pre-test and post-test scores. If the p-value < 0.05, it can be concluded that the use of the e-module has a significant impact on learning outcomes.

N-Gain Test

N-Gain analysis determines the extent of learning improvement after the intervention. The N-Gain score is calculated for each student and then categorized to assess overall learning effectiveness. The formula is:

$$g = \frac{Posttest\ Score\ -\ Pretest\ Score}{Maximum\ Score\ -\ Pretest\ Score}$$

The interpretation of the N-Gain scores in Table 2 is as follows:

Table 2. N-Gain Score Interpretation

Score (g)	Category
g≥0.70	High
0.30≤g<0.70	Moderate
g<0.30	Low

RESULTS AND DISCUSSION

This section presents the results achieved at each stage of the research and development process, from the define phase to dissemination, followed by an in-depth discussion of each research finding.

Define Stage

The result of the Define stage was the identification of fundamental problems and an in-depth needs analysis. A significant gap was found between the competencies expected in the curriculum and the actual understanding of Grade XI Mechanical Engineering (TP) 2 students at SMK N 5 Semarang, particularly in the subject of SMAW weld defect analysis. The low learning outcomes served as a key indicator of this issue. The analysis of students' characteristics as digital natives also concluded that they have a strong preference for learning media that are visual, interactive, and accessible flexibly. Previous studies have highlighted that digital media tailored to students' contexts and learning needs can significantly improve engagement and comprehension in vocational education settings (Holisoh et al., 2023).

This stage of research became the primary justification for the urgency of developing an innovative learning medium. The decision to develop a product in the form of an e-module was based on its potential to directly address the problem by presenting complex material visually while also meeting the learning style needs of modern students. Thus, this stage produced a strong conceptual blueprint for product development.

Design Stage

At the Design stage, all results from the needs analysis were translated into a concrete product design. The visual design and layout process of the e-module was carried out using the Canva Pro graphic design platform to produce a product with professional and appealing visual quality. The initial product draft was then exported in an interactive PDF format, enabling embedded links and navigation. This approach aligns with recent research emphasizing that the integration of visual and textual elements can significantly enhance student understanding, especially for technical and abstract topics (Manggala et al., 2024). Concurrently, research instruments were also designed, including validation questionnaires, pre-test, and post-test questions, all created and distributed using the Google Forms platform to facilitate data collection and recap.

The final result of this stage was an e-module ready for validation and trial. This design phase emphasized the importance of choosing the right tools to achieve objectives. Canva Pro provided high design flexibility, while Google Forms simplified research data administration. The combination of these platforms created an efficient development workflow from design to data collection. The e-module design is presented in Figure 2.

Figure 2. E-Module Design

Develop Stage

The development stage is the core of this research cycle, where the product is realized, validated, and its effectiveness tested.

Validation Results of E-Module Feasibility

The validation process is a crucial phase in R&D research to ensure the quality and feasibility of the product before implementation. Similar development studies have emphasized the importance of expert validation to ensure that digital learning materials meet educational standards and effectively support learning goals (Hadiyanti et al., 2021). Validation was carried out by 6 experts, consisting of 5 vocational school teachers and 1 university lecturer from UNNES, evaluating three main components: e-module content, e-module media, and test instruments. Data analysis used Aiken's V coefficient with the criterion that an item is declared "Valid" if it reaches a value of V = 1.00.

The validation results of the e-module content were analyzed based on 7 items covering aspects of content feasibility, presentation, and practicality.

Table 3. Content Validation Results

No	Indicator	Total	Value	Category
A. Content				
1	The material presents lathe machine parts	6	1.00	Valid
2	The content is delivered clearly	6	1.00	Valid
B. Presentation				
3	The presentation encourages student activity	5	0.83	Not Valid
4	The presentation is engaging	6	1.00	Valid
5	The presentation is attractive	6	1.00	Valid
C. Practicality				
6	Can be used (played) anytime	6	1.00	Valid
7	Easily accessible online/offline	6	1.00	Valid

The results in Table 3 show that 6 out of 7 items, or 85.7%, were declared "Valid." The core aspects of content and practicality were rated perfectly. There was one note under the presentation regarding "enhancing student activity," which did not reach significant validity. This becomes valuable input for improving the e-module to better promote student interaction.

The validation of the e-module media was analyzed based on 8 items covering aspects of appearance, supporting materials, and media practicality.

Table 4. Media Validation Results

No	Indicator	Total	Value	Category
A. Tampilan				
1	Media includes images	6	1.00	Valid
2	Media includes text	6	1.00	Valid
3	Media includes navigation	6	1.00	Valid
4	Media is interesting and not boring	6	1.00	Valid
B. Materi				
5	Media presents welding defect material	6	1.00	Valid
6	Media includes practice questions	6	1.00	Valid
C. Kepraktisan				
7	Media is easy to use independently	6	1.00	Valid
8	Media can be saved and read again	6	1.00	Valid

Table 4 shows that all items (100%) in the media validation were declared "Valid." This indicates that from technical, visual, and functional perspectives, the developed e-module is highly feasible for use.

The validation of the test instruments was conducted on 6 items covering the aspects of appearance, construction, and language.

Table 5. Test Instrument Validation Results

No	Indicator	Total	Value	Category
A. Appearance				
1	Each question has one correct answer	6	1.00	Valid
2	The question matches the indicator	6	1.00	Valid
B. Construction				
3	The stem is clearly and firmly formulated	6	1.00	Valid
4	The stem does not give clues to the correct answer	6	1.00	Valid
C. Language				
5	The language follows proper Indonesian grammar	6	1.00	Valid
6	The language is communicative	5	0.83	Not Valid

The results in Table 5 show that the test items generally have high content validity, with 5 out of 6 items (83.3%) declared "Valid." However, as with the content validation, item 6 did not reach significant validity, and thus some questions were revised to ensure all sentences are easily understood before being used for the pre-test and post-test instruments.

E-Module Effectiveness Test Results

After being declared feasible, the e-module was implemented in classroom learning. The researcher used SPSS to analyze the e-module's effectiveness. Its effectiveness was measured by comparing the pre-test and post-test results shown in Table 6 below.

Table 6. Descriptive Statistics Analysis Results

Statistik	Pre-test	Post-test
Number of Students (N)	33	33
Mean	40.61	78.64
Standard Deviation	9.98	4.55
Minimum Score	25	70
Maksimum Score	60	85

Based on Table 6, there is a sharp increase in students' learning outcomes. The average score nearly doubled, from 40.61 to 78.64. The results of this study indicate a significant improvement in students' understanding of SMAW welding defect analysis after the implementation of the e-module, as reflected in both the pre-test and post-test scores.

To strengthen the analysis and ensure result validity, both the Wilcoxon Signed-Rank Test and the paired samples t-test were applied. The Wilcoxon test was chosen as a non-parametric approach suitable for small sample sizes and data that do not meet normality assumptions (Zulkipli et al., 2024). The paired samples t-test was also conducted to provide a parametric comparison and cross-validate the findings from different statistical perspectives. This dual testing strategy helps confirm the robustness of the observed learning gains.

A normality test was conducted using the Wilcoxon Signed-Rank method to determine whether the data came from a normally distributed population. The results are shown in Table 7.

Table 7. Wilcoxon Signed-Rank Normality Test Results

Data Group	Statistic	Significance Value (p-value)	Result
Pre-test & Post-test	0.0	0.001	Normal

The hypothesis test results in Table 7 show a test statistic of 0.0 with a p-value of < 0.001. Since this value is far below the 0.05 significance threshold, the null hypothesis, which states no difference, is rejected. The test statistics of 0.0 reflect that all post-test scores were higher than pre-test scores, indicating a consistent positive improvement among all students. Therefore, it can be concluded that there is a statistically significant difference in student learning outcomes before and after using the e-module. This provides strong evidence that the developed e-module is effective in improving students' understanding of SMAW welding defect analysis.

Next, a hypothesis test was conducted to determine whether there was a significant difference between pre-test and post-test results. The paired sample t-test results are presented in Table 8.

Table 8. Paired Samples t-Test Results

Data Group	Statistic-t	Significance Value (p-value)
Pre-test & Post-test	-21.36	< 0.001

The t-test results in Table 8 show a t-statistic of -21.36 with a significance value of $p < 0.001$. Since this p-value is much lower than the 0.05 threshold, it can be concluded that there is a highly significant difference between learning outcomes before and after using the e-module. The large negative t-value reflects the substantial increase in post-test scores compared to pre-test results. This improvement is attributed directly to the learning intervention.

Based on the pre-test and post-test results, the gain scores ranged from 0.44 to 0.80, falling into the moderate to high categories. The average N-Gain score was 0.63, categorized as moderate. The gain score percentages are presented in Table 9.

Table 9. N-Gain Test Results

Category	Number of Students	Percentage (%)
High	8	24.2%
Moderate	25	75.8%
Low	0	0%
Total	33	100%

The N-Gain analysis in Table 9 further reinforces the effectiveness of the e-module. The results, showing 24.2% of students in the "High" category, 75.8% in the "Moderate" category, and the absence of students in the "Low" category, reflect the effectiveness of the e-module in facilitating learning across varying levels of student ability. The structured content, combined with the interactive features and visual elements of the e-module, appears to have supported students in achieving a "Moderate" category of understanding. Additionally, the alignment of the test items with the instructional objectives, ensured through expert validation, contributed to the consistency of student performance across the group.

This study proves that the developed e-module is not only valid but also effectively improves students' understanding in a measurable way. These results reinforce findings from recent studies indicating that interactive e-modules can effectively enhance students' cognitive achievements in vocational education contexts (Anita Winandari et al., 2022). Documentation of the trial activity is shown in Figure 3.

Figure 3. E-Module Trial Activity Documentation

The effectiveness of this e-module, as demonstrated by the data, can be attributed to several key features, most notably its capacity to facilitate self-paced learning and deliver instructional content through engaging visual formats. By allowing students to access the material anytime and revisit difficult concepts at their own pace, the e-module supports deeper understanding and retention of complex topics such as SMAW welding defect analysis. The flexibility to access the module anytime and anywhere was cited as a major factor contributing to this increased motivation (Fitriana et al., 2024). Moreover, the integration of images and interactive elements caters to the learning preferences of digital-native students, who tend to respond more positively to visually-rich content than traditional text-based instruction.

This finding highlights the broader significance of incorporating relevant and contextually appropriate digital media into vocational education. Not only does it align with current technological trends and student behavior, but it also addresses the need for more adaptive, student-centered learning tools in skill-based subjects. As vocational schools strive to prepare students for real-world industrial demands, learning media like this e-module serve as a bridge between theoretical knowledge and practical application, ultimately contributing to improved learning outcomes and workforce readiness.

Disseminate Stage

At the final stage, the validated and effective e-module product was finalized for dissemination. The e-module, originally in PDF format, was converted into a more interactive and engaging digital flipbook using the FlipHTML5 platform. To maximize accessibility and distribution, a unique QR Code was created using bit.ly, linking directly to the e-module flipbook.

The use of FlipHTML5 and a QR Code is a highly effective modern dissemination strategy. The QR Code can easily be printed, posted on classroom bulletin boards, shared in teacher communication groups, or included in MGMP presentation materials. This strategy ensures that the product reaches a wider audience with minimal technical barriers, allowing this learning innovation to be sustainably adopted. Such strategies align with current trends in vocational education that emphasize technology integration to improve accessibility and user adoption of digital learning tools (Fadhilah & Thahir, 2023). Here is the QR Code and link to the SMAW weld defect analysis e-module in Figure 4.

https://bit.ly/E-ModulAnalisisCacatLasSMAW

Figure 4. E-Module QR Code

CONCLUSIONS

Based on the findings from the implementation of e-module-based learning for SMAW welding defect analysis, the following conclusions can be drawn:

1. This study aimed to develop a valid and effective e-module to improve students' understanding of SMAW welding defect analysis at SMK N 5 Semarang. The objective has been achieved, as

evidenced by the significant increase in students' learning outcomes, with the average score rising from 40.61 in the pre-test to 78.64 in the post-test.

2. The e-module demonstrated effectiveness in enhancing student motivation and engagement. Both the Wilcoxon and paired t-test results showed a significant difference ($p < 0.001$) between pre-test and post-test scores. The N-Gain analysis further confirmed this improvement, with 75.8% of students categorized as moderate and 24.2% as high in learning gains, and no students falling into the low category.
3. The e-module product was validated by experts and declared feasible for classroom use, with validation scores of 85.7% for content, 100% for media, and 83.3% for test instruments, placing it within the "Valid" category.
4. The e-module supports self-directed and visual learning, aligning with the learning characteristics of digital-native students. The combination of interactive content, visual aids, and accessible digital formats contributed to improved conceptual understanding of welding defects.
5. The dissemination process through digital platforms and QR code integration has facilitated easy access and encourages broader adoption of the e-module across other schools and learning contexts, and is aligned with industry needs.

For future research, the development and testing of similar e-modules could be extended to other welding techniques such as Gas Metal Arc Welding (GMAW) or Tungsten Inert Gas (TIG) welding. Additionally, conducting comparative studies involving different digital learning models or control groups is recommended to further explore the effectiveness of various instructional approaches in vocational education.

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