



Development of a Problem-Based Learning Interactive E-Module to Improve Learning Outcomes in Lathe Machining Techniques at Vocational High School

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ABSTRACT

This study aims to develop and evaluate the effectiveness of an interactive e-module based on Problem-Based Learning (PBL) to improve students' cognitive learning outcomes in lathe machining techniques. The research was conducted using the Research and Development (R&D) method with the Alessi and Trollip development model, involving stages of planning, design, and development. The resulting e-module was created using Flip PDF Professional and enriched with multimedia elements such as animated explanations, instructional videos, and quizzes. The media was validated by experts and tested on 64 students from a vocational school in Magetan, Indonesia. Statistical tests including the Kolmogorov-Smirnov test, Levene's test, paired sample t-test, and N-Gain analysis were applied to evaluate the normality, homogeneity, significance, and effectiveness of the learning outcomes. The results showed that the PBL-based e-module significantly improved students' learning performance, with an average N-Gain score of 0.71 (high category). Furthermore, student response was overwhelmingly positive, with a satisfaction rate of 93.13%. The integration of PBL within an interactive digital platform successfully increased student engagement, supported higher-order thinking, and fostered deeper conceptual understanding. These findings confirm that interactive e-modules designed with PBL can serve as effective instructional tools in vocational education settings.

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1. INTRODUCTION

Vocational education plays a pivotal role in preparing young people to thrive in the labour market, yet persistent gaps remain in aligning the competencies cultivated in vocational high schools with the dynamic needs of industry. Indonesia's policy architecture signals commitment to relevance and quality, but outcomes for vocational high school graduates continue to lag, with unemployment cited as a marker of misalignment between schooling and work (Werdiningsih et al., 2021). Employability depends not only on occupation specific skills but also on transferable capabilities that enable transitions into work and entrepreneurship, alongside personal development that supports adaptability (Morselli & Ajello, 2016; Rahayu et al., 2024). Building integrated pathways that connect vocational programs with general education is essential for holistic competency development and for meeting evolving job requirements (Hamdani et al., 2021; Subiyantoro et al., 2023). These strategies foster lifelong learning and agility, both central to productivity in a rapidly changing economy (Ding et al., 2023). This background indicates the need for responsive pedagogies and assessments that more faithfully map to contemporary workplace demands.

Within this backdrop, the teaching of lathe machining techniques reveals a stubborn learning bottleneck. Students struggle with the mathematics that underpin cutting parameters, including cutting speed, spindle speed, feed rate, and machining time, and these difficulties yield fragile conceptual models and frequent errors (Mutohhari et al., 2021; Sudira et al., 2022). Teacher centred exposition and static print materials emphasise procedures rather than conceptual integration, limiting transfer to authentic machining scenarios and hindering informed trade offs under production constraints (Mutohhari et al., 2021). Feedback that arrives late or in aggregate form rarely corrects process level misconceptions that arise during calculation steps. As a result, students find it difficult to anticipate effects on surface finish, tool life, and cycle time or to diagnose poor results. These issues invite designs that couple conceptual scaffolding with practice in realistic contexts and that make parameter relationships visible in the moment of calculation. Addressing this bottleneck is important for educational quality and for workplace readiness in machining.

Technology enhanced learning offers practical pathways to close these gaps. Mobile learning has matured into an accessible medium for interactive and self paced study that can deliver multimodal explanations, immediate feedback, and adaptive practice, and it is increasingly feasible in Indonesian vocational settings where smartphone ownership is high (AlSaied & Akhtar, 2021; Shail, 2019). Delays in adopting effective digital media risk entrenching the mismatch between graduate competencies and industry expectations, while timely conversion of existing content into interactive mobile experiences can improve conceptual depth and readiness for work (AlSaied & Akhtar, 2021; Supriyono, 2019). System initiatives such as the Teaching Factory model and closer school industry partnerships illustrate how curriculum can align with production realities, but they require complementary classroom designs that explicitly build the conceptual foundations students need to succeed during authentic tasks (Suharno et al., 2019). In our context, students already own smartphones, yet purpose built mobile materials for machining calculations remain scarce, which motivates a targeted intervention to leverage this infrastructure.

A robust design rationale follows from two complementary strands. The Cognitive Theory of Multimedia Learning proposes that carefully structured multimedia reduces extraneous cognitive load and supports active selection, organisation, and integration of information, with empirical studies showing that designs using dual channels, segmentation, signalling, and appropriate modality choices improve learning across contexts (Samala & Amanda, 2023; Huda et al., 2020; Theimer, 2019). In parallel, Problem Based Learning organises instruction around meaningful problems that scaffold knowledge construction, collaborative reasoning, and self directed inquiry, with reported gains in engagement, critical thinking, and achievement in STEM and vocational domains (Sakulwichitsintu, 2023). Mobile platforms can amplify these affordances by delivering interactive and context rich content on students own devices, while virtual simulations provide safe and iterative practice with immediate feedback on parameter choices in numerical control environments (Li et al., 2017; Zhao et al., 2023). When these principles are combined in an e module for machining, students can move between explanation, practice, and reflection within a unified sequence that mirrors expert reasoning and that links formulas to performance outcomes. Such a design promises to reduce cognitive friction during formula use and to strengthen understanding of variable interdependencies that drive quality, time, and tool life.

Accordingly, this study aims to develop and validate a Problem Based Learning based interactive e module, grounded in the Cognitive Theory of Multimedia Learning, to improve cognitive learning outcomes in lathe machining techniques for vocational students. The first research question asks how such an e module can be effectively developed for vocational high school learners given competency standards and classroom constraints. The second research question examines the extent to which the module enhances student learning outcomes in machining parameter calculations with attention to effect magnitude and educational significance. To address these questions, we follow a structured development process with expert and practitioner validation, alongside classroom evaluation that compares learning before and after implementation (Richardo et al., 2024; Suwondo et al., 2024). The intended contribution is a replicable and mobile ready solution that addresses a documented bottleneck in machining education and that supports schools and policymakers in scaling digital innovations that measurably improve job relevant competencies (AlSaied & Akhtar, 2021; Rahayu et al., 2024; Subiyantoro et al., 2023).

2. MATERIAL AND METHOD

Study Design and Participants

A one-group pretest–posttest design was employed to evaluate an interactive Problem-Based Learning (PBL) e-module in Grade XI Machining at Yosonegoro Vocational High School, Magetan (Indonesia), during the 2024/2025 academic year. Sixty-four students participated; all owned Android smartphones and had completed introductory lathe coursework. Participation was voluntary and no exclusion criteria were applied (Klaßen et al., 2013). Inferential analyses included only cases with complete pre- and posttest data; counts and reasons for missingness (e.g., absence, technical issues) were recorded a priori.

Instruments

Expert Validation (Alpha Test)

A panel of two media experts, two content experts, and three vocational practitioners assessed content accuracy, instructional design, technical quality, and appearance. They used a 4-point Likert scale (4 = strongly agree to 1 = strongly disagree). Item- and scale-level Content Validity Indexes (I-CVI and S-CVI) were calculated,

and feedback led to refinements such as clearer machining diagrams, added audio explanations, and minor interface color adjustments. The instrument grid used in this research can be seen in the following Table 1 and Table 2.

Table 1. Expert team's validation questionnaire grid

No	Aspect	Indicator
1	Content	Suitability of material to competencies
		Appropriate presentation of material
		Suitability of material to purpose
		Appropriateness of the evaluation questions according to the indicators that must be achieved
		Accuracy in using language and spelling
		Order of material content
2	Learning	Clarity of material presentation
		Interesting presentation of material
		Systematic presentation of material
		Clarity of learning objectives
		Feedback on learning motivation
		Use of easy-to-understand language
		Question formulation according to core competencies

Table 2. Media expert team validation questionnaire grid

No	Aspect	Indicator
1	Content and Objectives	Accuracy of font selection
		Accuracy of color selection
		Completeness of audio use
		Balanced use of images
		Accuracy of communicative media
		Clarity of navigation use
		Sequence of navigation presentation
		Suitability to student situations
2	Instructional	Provide learning opportunities
		Provide learning support
		Motivating qualities
		Instructional flexibility
		Tests and assessments impact students
3	Technic	Readability
		Ease of use
		Program management display/screenshot

Usability and Acceptability (Beta Test)

Sixty-four students completed a 20-item usability questionnaire (domains: appearance, content/objective, benefits, and technical/operational) on the same 4-point scale. Internal consistency was evaluated with Cronbach's α , and both subscale and total mean percentages were reported. The instrument grid used in this research can be seen in the following Table 3 and Table 4.

Table 3. Practitioner assessment questionnaire grid for learning media

No	Aspect	Indicator
1	Appearance	Screen display Proportional layout (text and image layout) Appropriate background selection Legible text size and font type Supporting animations, colors, images, and sound Attractive learning media
2	Content and Purpose	Appropriateness to learning objectives Appropriateness of images to the material Clarity of the structure of the material presented Accuracy of language use Easy to understand and comprehend the material Depth of material presented
3	Benefits	Facilitates student understanding Increases interest in the teaching and learning process Lesson material will be more clearly understood Improved understanding with evaluation questions
4	Technical/Operation	Media usage instructions Ease of operation Buttons/navigation

Table 4. Student assessment questionnaire grid for learning media

No	Aspect	Indicator
1	Appearance	Screen display Proportional layout (text and image layout) Appropriate background selection Legible text size and font type Supporting animations, colors, images, and sound Attractive learning media
2	Content and Purpose	Appropriateness to learning objectives Appropriateness of images to the material Clarity of the structure of the material presented Accuracy of language use The material is easy to understand and comprehend The depth of the material presented
3	Benefits	Facilitates student understanding Increases interest in the teaching and learning process Lesson material will be more clearly understood Improved understanding with evaluation questions
4	Technical/Operation	Media usage instructions Ease of operation Buttons/navigation

Learning-Outcomes Test

A 25-item multiple-choice test (score range 0–100) measured cognitive mastery of lathe-machining parameters. Items were evenly distributed across the four units, validated by two machining instructors, and showed good reliability ($KR-20 = 0.82$). The instrument grid used in this research can be seen in the following Table 5.

Table 5. Pretest and posttest grid

	Learning Objective Flow (ATP)	Question Item Indicators	Question Items
2.1.1	Students are able to understand and analyze cutting speed	Given a statement about lathe operation, students can determine cutting speed.	2
2.1.2	Students are able to understand analyzing the rotational speed of a lathe	Given a statement about lathe operation, students can determine lathe rotational speed.	1
2.1.3	Students are able to understand and analyze feeding speed	Given a statement about lathe operation, students can determine feed rate.	2
2.1.4	Students are able to understand and analyze lathe machining time	Given a statement about lathe operation, students can determine lathe machining time.	5

Intervention

The e-module, authored with Flip PDF Professional (Android/Windows delivery), comprised four units—cutting speed, spindle rotation, feed rate, and machining/turning time—distributed across ~35 interactive pages (text, figures, animations, and embedded quizzes). Design followed the Cognitive Theory of Multimedia Learning: segmentation (learner-paced chunks), signaling (visual cueing of key parameters), and modality (synchronized narration with visuals). Instruction implemented a full PBL cycle (problem presentation → data exploration → solution formulation → reflection). The classroom implementation consisted of two 75-minute sessions, bracketed by a pretest and posttest; learners could review materials asynchronously. Typical time-on-task was 60–75 minutes.

Research Procedure

The research procedure followed Alessi and Trollip's three-stage model. It began with the planning phase, in which the team delineated the scope, articulated learning objectives, and developed a storyboard to structure the sequence of content and activities. In the design phase, screen layouts, narration scripts, and quiz logic were produced to align interaction flow and assessment with the instructional goals. The development phase encompassed the creation and programming of graphical, audio, and video assets to produce a fully functioning e-module ready for testing. Implementation proceeded according to the following timeline: Weeks 1–2 involved an alpha expert review followed by revisions; Week 3 comprised beta usability testing with subsequent final refinements; and Weeks 4–5 involved classroom deployment consisting of a pretest, two instructional sessions using the e-module (each 75 minutes), and a posttest. Throughout implementation, teachers acted as facilitators to ensure that every student completed all activities, and fidelity checks verified full completion of the module as designed.

Data Analysis

Table 6. Validation Achievement Conversion Rate

Score	Interpretation
81% - 100%	Very appropriate
61% - 80%	Appropriate
41% - 60%	Moderate
21% - 40%	Less Appropriate
0% - 20%	Not appropriate

Data were analyzed using SPSS 25. Normality was assessed with the Kolmogorov–Smirnov test, and homogeneity with Levene's test. Paired-sample t-tests compared pre- and posttest scores. Effect sizes were calculated using Cohen's *d* (small = 0.2, medium = 0.5, large = 0.8) with 95 % confidence intervals. Following Hake's categories: low (< 0.3), medium (0.3–0.69), high (≥ 0.7) for *N*-Gains, as the effectiveness was also

evaluated with the normalized gain (N-Gain) formula (Hake, 1998). Besides that, the tested media were considered suitable for use. Then, the media will subsequently be implemented in classroom teaching to enhance the learning outcomes of Machining Techniques students at Vocational School Magetan. The criteria for interpretation of the evaluation scores can be seen in Table 6.

3. RESULTS

Media Development Stages

The initial production phase involved creating a problem-based e-module media product. The researcher first developed the initial product as a document using Microsoft Word, which was then converted into a PDF file. The PDF file was uploaded to the Flip PDF Professional application in HTML5 format. In Flip PDF Professional, the developer edited the e-module to make it interactive by adding animated images, instructional videos, YouTube links, QR codes, audio explanations of the material, and practice exercises. After the editing process was complete, the media could be published either in HTML format or as an app.



Figure 1. E-modul Development

This media offers significant advantages in delivering explanations to students. The e-module includes several interactive features, such as voice notes that provide explanations of the material, background music, animations, instructional videos, as well as tests and evaluations. With these features, it is expected that students will be able to fully grasp the material, thereby improving their learning outcomes. Additionally, the use of the problem-based learning (PBL) syntax in the development of the e-module will aid students in solving problems and gaining a deeper understanding, which can further enhance their learning results. An example of the application's interface can be seen in Figure 2.

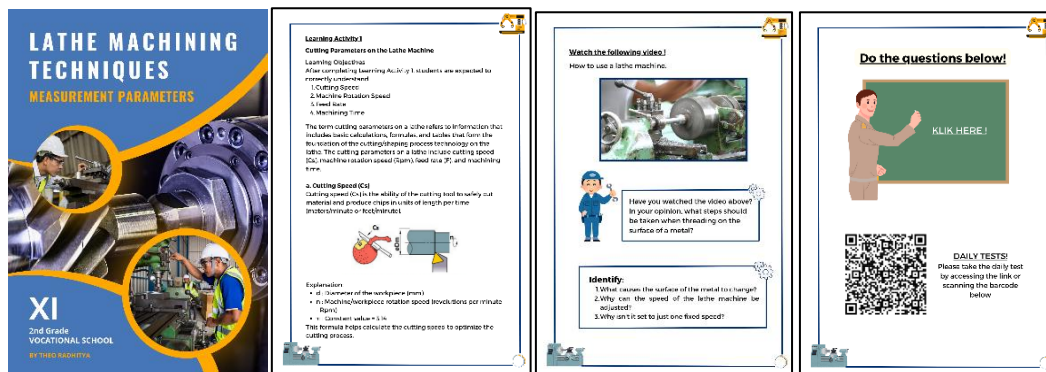


Figure 2. Cover View, Material and Exercises of the E-Module Product

Analysis Result of Alpha Test

The alpha test was conducted to assess the quality of the developed media using expert judgment. Two media experts evaluated the content and objectives, instructional quality, and technical aspects. Two material experts assessed the accuracy of the content and learning aspects, while three practitioner experts assessed the appearance, content, purpose, and usefulness of the media.

The results of the expert validation showed that the developed e-module was considered "Very Appropriate" across all domains assessed. The media experts rated the content & objective at 82.5%, instructional aspects at 78.5%, and technical aspects at 79.5%. The material experts gave a higher rating, with content & objective at 85.5%, instructional quality at 82.5%, and technical quality at 84.5%. Practitioners gave

particularly high ratings, with appearance, content & objective, benefits, and technical/operational aspects all receiving ratings above 90%. The results of the assessment are presented in Table 7.

Table 7. Results of Expert and Practitioners Assessment Recapitulation

Validator Group	Domain / Aspect	Average Score (%)	Category
Media Experts (n=2)	Content & Objective	82.5	Very Appropriate
	Instructional	78.5	Appropriate
	Technical	79.5	Appropriate
Material Experts (n=2)	Content & Objective	85.5	Very Appropriate
	Instructional	82.5	Very Appropriate
	Technical	84.5	Very Appropriate
Practitioners (n=3)	Appearance	93.5	Very Appropriate
	Content & Objective	93.5	Very Appropriate
	Benefits	92.0	Very Appropriate
	Technical / Operational	93.0	Very Appropriate

Analysis Results of Beta Test

The beta test aimed to assess user functionality and the overall user experience of the e-module. A survey was administered to 64 Machining students from Yosonegoro Vocational High School to gather their responses on four key aspects: appearance, content and objectives, benefits, and technical/operational aspects. The results showed that the students rated the module highly, with an overall score of 93.13% in the "Very Appropriate" category. The highest scores were given in appearance and technical/operational aspects, both receiving 24.77% and 23.75% of the total score, respectively. The table below shows the results of the student response survey regarding the media. Table 8 shows students' responses to the developed media with a score of 93.13 % in the "Very Appropriate" criteria. The results of the student's responses to the media are presented in Table 8.

Table 8. Results of Students' Questionnaire

Aspect	Number of Questions	Total	Percentage
Appearance	1,2,3,4,5	1628	24.77%
Content and objective	6,7,8,9,10	1590	22.27%
Benefits	11,12,13,14,15	1478	22.34%
Technical/operational	16,17,18,19,20	1495	23.75%
Total		5960	93.13 %
Maximum	20 Questions	6400	100%

Statistical Analysis of the Influence of Interactive Media Products

Table 9. Results of the Kolmogorov-Smirnov Normality Test

Description		Kolmogorov-Smirnov ^a		
		Statistic	df	Sig.
Learning outcomes	Pre test	0,099	60	.200*
	Post test	0,086	60	.200*

The normality test was conducted using the Kolmogorov-Smirnov test on both pre-test and post-test data. The results indicated that the data for both the pre-test and post-test were normally distributed (Sig. = 0.200 for both). This suggests that the data were appropriate for parametric testing. The results of the normality test are shown in Table 9. Based on Table 9, it can be seen that the significance value (Sig.) from the Kolmogorov-Smirnov test is 0.200, which is greater than 0.05. This indicates that the pre-test and post-test data in the

experimental class are normally distributed. This test was conducted to determine whether the samples used came from a population with homogeneous variance. The results of the homogeneity test are presented in [Table 10](#) below.

Table 10. Results of the Homogeneity Test

	Description	Levene Statistic	df1	df2	Sig.
Learning outcomes	Based on Mean	0,067	1	118	0,796
	Based on Median	0,129	1	118	0,720
	Based on Median and with adjusted df	0,129	1	117,958	0,720
	Based on trimmed mean	0,056	1	118	0,814

Based on the statistical results using SPSS 25, the significance value of the post-test was 0.796, which is greater than 0.05 ($0.796 > 0.05$). It can be concluded that the pre-test and post-test results from both the control and experimental classes originate from populations with equal or homogeneous variances. Hypothesis testing was carried out using the paired sample t-test to analyze the differences between pre-test and post-test results. The data from the paired sample t-test are shown in [Table 11](#).

Table 11. Results of the Paired Sample t-Test

Description	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pre Test - Post Test	-46,950	10,633	1,373	-34,202	59	0,000

Based on the results of the analysis, it can be concluded that the significance value (Sig.) is $0.000 < 0.05$, indicating that there is a statistically significant difference in the average scores between the pre-test and post-test. Therefore, the use of PBL-based interactive e-module media significantly improves student learning outcomes in the lathe machining subject for eleventh-grade students at Yosonegoro Vocational High School. Effectiveness Test using N-Gain Score test was conducted using SPSS, and the results are shown in [Table 12](#).

Table 12. Results of the N-Gain Score Test

Description	N	Minimum	Maximum	Mean	Std. Deviation
N-Gain	60	0,37	0,97	0,71	0,12673
Valid N (listwise)	60				

Based on the N-Gain Score calculation in [Table 12](#), the average N-Gain score was 0.71, which falls into the high category. Thus, it can be concluded that the implementation of the PBL-based interactive e-module is effective in improving students' learning outcomes in the topic of lathe cutting parameters in the lathe machining subject for eleventh-grade students of the Mechanical Engineering program at Yosonegoro Vocational High School.

4. DISCUSSION

The results show large and educationally meaningful improvements in students cognitive outcomes after exposure to the problem based interactive e module for lathe machining. The paired sample comparison indicated a highly significant gain from pre test to post test, and the average normalised gain of 0.71 falls in the high category that signals strong mastery growth rather than a marginal shift. This pattern accords with evidence that interactive resources can lift performance when they make thinking visible and keep learners engaged through multimedia elements ([Ichsan et al., 2020](#)). In our setting, expert panels rated the product very appropriate across content, instructional, and technical dimensions, which aligns with known requirements for usable mobile learning applications in formal education ([Klaßen et al., 2013](#)). Students also reported very high usability, a factor that often mediates the translation of design quality into actual learning time on task in technology supported lessons ([Liu, 2024](#)). Because all learners could access the module on Android or Windows,

the delivery matched the device ecology of the class and reduced barriers to adoption noted in prior implementations of digital learning tools (Klaßen et al., 2013). Together, these acceptability and feasibility indicators provide a credible basis for routine classroom use alongside traditional workshop activities (Zhang et al., 2024).

Several design mechanisms likely contributed to the gains observed. The module deliberately applied segmentation, signalling, and modality to reduce extraneous cognitive load while directing attention to high value relations among cutting speed, spindle speed, feed rate, and machining time, a strategy consistent with contemporary multimedia learning accounts (Mayer, 2024). The learning path followed a complete problem based cycle that required students to interpret data, formulate solutions, and reflect on outcomes, which mirrors project and problem structures that have improved higher order thinking and transfer in engineering education (Gomez del Rio & Rodriguez, 2022). Immediate feedback at the point of calculation helped students diagnose and correct misconceptions during practice, rather than after the fact, an approach that strengthens conceptual integration. Animated demonstrations and narrated worked examples likely supported dual channel processing and reduced cognitive friction during formula use, as seen in other interactive learning environments (Liu, 2024). The embedded quizzes provided short loops of explanation, practice, and verification, a structure associated with gains in critical thinking and achievement in school settings that use problem based strategies (Setiawan et al., 2023). In combination, these elements made variable interdependencies more transparent and connected formulas to performance outcomes that matter in machining (Zhang et al., 2024). Such coherence between pedagogy and media is central to turning procedural rehearsal into conceptually grounded competence (Mayer, 2024).

The findings also highlight practicality and potential for scale within vocational schools. Multiplatform access and clear navigation map onto established design requirements for mobile learning, which reduces cognitive overhead unrelated to the target content and encourages sustained engagement during demanding topics (Klaßen et al., 2013). The very appropriate ratings from media experts, content experts, and practitioners indicate that objectives, interface, and assessments were coherently aligned, a validation pattern echoed in module development efforts beyond engineering such as health and interprofessional education (Goni et al., 2023; Nagelli et al., 2023). In day to day teaching, instructors can repurpose the embedded quizzes as formative checks that flag misconceptions early without slowing the class, which mirrors effective practices in other applied and computational domains (Xi et al., 2023). Worked examples within the module also support novices as they transition from explanation to independent problem solving, a scaffold that has shown value in complex technical learning (Zhang et al., 2015). Because students reported high motivation and positive experiences, the resource is positioned to complement workshop practice by front loading conceptual preparation and enabling on demand rehearsal outside class (Ichsan et al., 2020). This practical fit strengthens the case for adoption in settings where smartphone ownership is already universal and where mobile ready materials remain scarce (Klaßen et al., 2013).

Important limitations qualify these conclusions and guide future work. The one group pre test to post test design cannot fully rule out maturation or test familiarity effects, and a single school context limits generalisability to other programmes and regions. Although measurement showed strong internal consistency and distributional assumptions were satisfied, stronger causal inference will require randomised or multi site designs that compare the module with well specified alternatives. Future studies should include delayed post tests to examine retention and transfer from calculation routines to real machine setup choices that matter for productivity and quality. It will also be useful to isolate which multimedia principles contribute most in combination with the problem based cycle, for example the effects of coherence or redundancy and the timing of narration relative to animation in machining contexts (Mayer, 2024). Comparative designs could test whether adding reflective video journaling or structured peer discussion further strengthens conceptual integration and decision making during authentic tasks (Gomez del Rio & Rodriguez, 2022). Finally, iterative design based research can support continuous improvement and localisation while building communities of practice that connect classroom learning with workplace demands, extending the promising outcomes reported here into sustained institutional change (Zhang et al., 2015).

5. CONCLUSION

The development and implementation of the PBL-based interactive e-module have proven to be effective in enhancing students' cognitive learning outcomes in lathe machining techniques. Statistical analysis indicated a significant improvement in post-test results and a high N-Gain score, reflecting the success of the

module in supporting student comprehension. The multimedia-rich features, such as instructional videos and animations, made the learning process more engaging and accessible. In addition, the integration of PBL facilitated problem-solving and critical thinking, contributing to meaningful learning experiences. Students responded positively to the media, showing high levels of satisfaction. These findings suggest that PBL-integrated interactive e-modules are a powerful educational innovation and can be recommended for broader application in vocational education to meet the demands of 21st-century learning.

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