JIPS 7 (1) (2026)
Jurnal Inovasi Pendidikan dan Sains
E-ISSN 2721-9119
https://ejournal.unwmataram.id/JIPS

Feasibility Evaluation of CAM Milling Learning Materials Based on Project-Based Learning Assisted by Inventor CAM Ultimate: A Study of Validity and Practicality

Elfahmi Dwi Kurniawn[1*], Nopriyanti[2], Rudi Hermawan[3], Ari Saputra[4], Prandika Dafatriz Arta[5], Rangga Satria Suprayogo[6], Putri Indah Yanti[7]

[1,2,3,4,5,6,7]Program Study Mechanical engineering Education, Faculty Teacher Training and Eduction, Universitas Sriwijaya, Indonesia

----
Corresponding Author:
Author Name*: Elfahmi Dwi Kurniawan
Email*: elfahmi_dwi_kurniawan@unsri.ac.id

Accepted: January 10th 2026. Approved: April 19th 2026. Published: April 27th 2026

ABSTRACT

This study aims to develop valid and practical CAM Milling instructional materials based on Project-Based Learning (PjBL) and assisted by Inventor CAM Ultimate for the Advanced CAM course. Using the 4D development model—Define, Design, Develop, and Disseminate—the materials were designed to address the lack of CAM-focused resources and provide project-oriented learning experiences. Validation by material and media experts resulted in average scores of 4.29 and 4.56, categorized as *very valid*. Field trials involving 20 students produced a practicality score of 4.33, indicating *very practical* use. These results confirm that the developed instructional materials meet the criteria of validity and practicality, making them suitable for mechanical engineering education.

Keywords: CAM milling, inventor CAM ultimate, validity and practicality

INTRODUCTION

Computer-Aided Manufacturing (CAM) has emerged as a key technology in the 21st century [1], [2] and is the foundation of modern manufacturing [3]. CAM is a technology that utilizes software and computer systems [4] [5] to automate and simplify complex manufacturing processes [6] and utilizes innovative approaches for efficient product design and processing [7]. CAM allows machine control through programs to drive CNC (Computer Numerical Control) machines using 3D/2D models of the product to be manufactured. The designed product is then optimized by CAM to be used as a numerical code that controls the CNC center [8]to simulate tool movements, time estimation, and predict product shape deviations [9] as well as maximize efficiency and minimize errors [10] and is able to convert engineering designs to final products [11].

Amidst these dynamics, vocational higher education, particularly the Mechanical Engineering Education Study Program, plays a strategic role in preparing human resources (HR) who are not only technically skilled but also able to adapt to technological developments. Mechanical engineering students are not only required to master scientific knowledge and engineering skills, but also must be able to transfer that knowledge in the context of education in vocational schools in the future. In this regard, CAM Milling learning is an important material that must be taught contextually, applicatively, and in accordance with industry needs. However, based on observations of learning practices, it was found that CAM Milling learning still tends to be theoretical, lacks project exploration, and does not utilize innovative learning approaches. CAM learning strategies should be student-centered because the learning consists of product design, which is then optimized by the CAM system to become a numeric code that controls the CNC center [8] to simulate tool movements, estimate time, and predict product shape deviations [9] as well as maximize efficiency and minimize errors [10].

As the 21st-century educational paradigm evolves, the Project-Based Learning (PJBL) approach has become a relevant learning model for application in engineering education [12]. PJBL emphasizes a student-centered learning process [13] through the completion of real-world projects, which are more collaborative, active, [13], critical thinking [12], [14], [15], and creative [16], [17]. In CAM Milling learning, the PJBL approach provides space for students to experience the process of design planning, programming, simulation, and structured project-based evaluation. This certainly brings students' learning experience closer to the real industrial world. Through PJBL, students will also develop soft skills [18] [19] such as communication skills [20], teamwork [21], problem solving [22], and time management [23], which are important competencies in the modern work environment.

Unfortunately, the integration of PJBL into CAM Milling teaching materials has not been widely adopted. Most teaching materials do not address CAM Milling, and those currently available are textual, procedurally oriented, and not designed around a project context. This makes learning less engaging and less challenging for students to explore ideas and skills independently. Previous research has developed CNC/CAM learning videos [24], [25], teaching materials [26], [27], [28], [29], jobsheets [30], [31], [32], modules [33], interactive media prototypes [34]. Based on the results of previous research, it has not specifically touched on the CAM Milling aspect assisted by the Inventor CAM Ultimate application and the development of PJBL-based teaching materials mostly focuses on other fields such as automotive, control systems, or CNC/CAM turning and other learning approaches not PJBL.

This situation indicates a gap between the needs of the workforce and learning readiness [35] in vocational education environments. Students who will become prospective engineering teachers need to be facilitated with teaching materials [36] that not only provide basic knowledge and skills but also foster critical and productive thinking. CAM Milling teaching materials based on PJBL can be an alternative answer to bridge this gap. Using projects as the core of learning, students will be responsible for their own work processes and results [37]. This aligns with the principles of vocational education that emphasize learning through direct experience and real-world practice [38], are more active [39], and can improve students' cognitive, affective, and psychomotor abilities [40].

Through the development of PJBL-based CAM Milling teaching materials, it is hoped that the quality of learning will improve. These teaching materials not only serve as a means of conveying information but also serve as a tool for developing the holistic competencies of engineering education students. Furthermore, the developed teaching materials are expected to be used flexibly by lecturers and students. The teaching materials in this study are a collaboration of modules and job sheets. The collaboration of these three types of materials is expected to achieve learning objectives and improve student learning experiences and outcomes [41], [42], [43].

This research is crucial for designing, developing, and testing valid and practical PJBL-based CAM Milling teaching materials for vocational learning. The research focuses on needs analysis, project-based teaching material design, and validation by experts and users. The results are expected to contribute significantly to the development of technology-based and pedagogical engineering teaching materials in education.

RESEARCH METHODS

The development procedure refers to the 4D instructional design model introduced by [44] The 4D model combines the steps in development [45]. There are four stages in the development of the 4D model: define, design, develop, and disseminate. The development procedure can be described in the figure below:

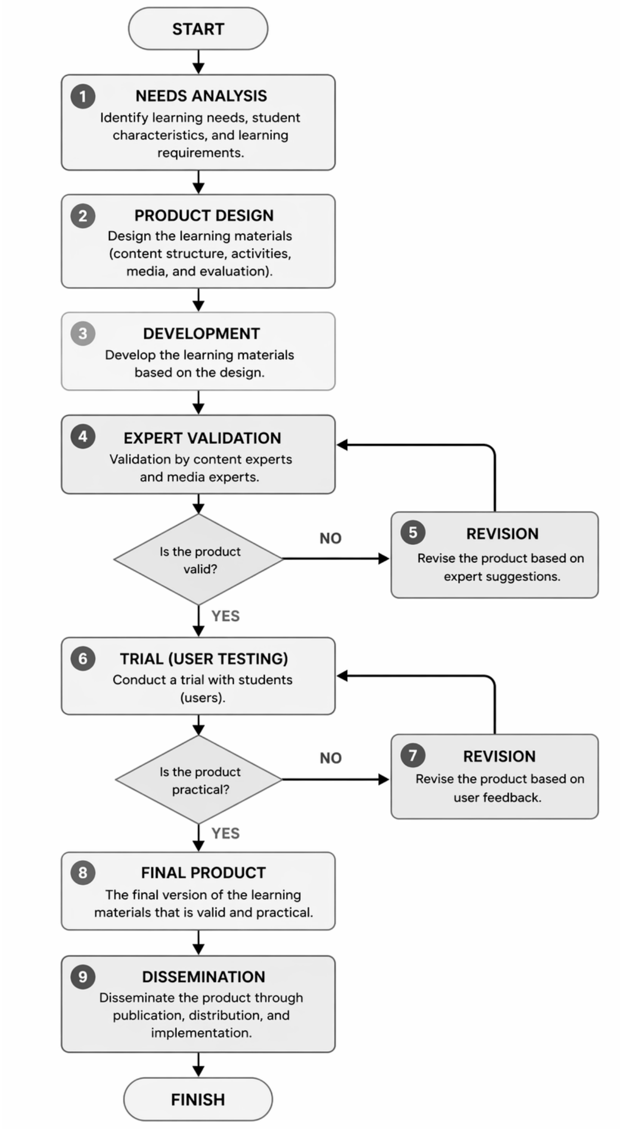


Figure 1. Research Design

1. Product Trial Design

Trials are conducted by asking others to evaluate the product being developed. Trial respondents are usually selected to represent the target group. The product validation subjects are two experts: a material expert and a media expert. The trial subjects for the CAM Milling Teaching Material Assisted by the CAM Ultimate Inventor Based on PJBL (Problem-Based Learning Materials) in this development research are 20 students. The questionnaire instrument is a validation sheet containing assessment items for each aspect.

2. Data Analysis Techniques

Data collection techniques using questionnaires. The instrument sheet was analyzed using data tendency categories. The resulting assessment scores were then converted into values by using a tendency category table.

Table 1. Data Tendency Categories[46]

Score Interval	Category
4,21 – 5,00	Very Valid/Practical
3,41 – 4.20	Valid/ Practical
2,61 – 3,40	Adequately Valid/ Practical
1,81 – 2,60	Less Valid/ Practical
1,00 – 1,80	Not Valid/ Practical

RESULT AND DISCUSSION

1. Stage Define

The researcher conducted the procedures in the Define stage by analyzing the difficulties, problems, and needs of students in learning Advanced CAD/CAM. The competencies that students are expected to achieve according to the curriculum were also analyzed. Based on the results of this needs analysis, the researcher selected appropriate learning media and began designing the initial format, concept, and content of the instructional material. From this process, an initial prototype of the instructional material was developed as a foundation for further development.

Needs analysis is a crucial initial step in the development of instructional materials or learning media. The students' needs and characteristics significantly influence the design and effectiveness of instructional materials [47]. The needs, characteristics of students, and learning objectives must be analyzed first to ensure that the developed learning media are relevant and effective [48].

Based on this foundation, the researcher designed the instructional material by taking into account the students' needs and learning objectives. This process includes structuring the content, selecting appropriate media, and designing the prototype—steps that are consistent with best practices in needs-based instructional design.

The stages in the define phase were aligned with the needs of the research and are described as follows:

a. Front-End Analysis

A preliminary investigation conducted through interviews with the course lecturer indicated that although the CAD/CAM course covers both CAD and CAM components, classroom learning remains limited to CAD. This condition occurs because no learning materials are yet available to support the CAM content. To address this need, this study developed CAM Milling learning materials using the Inventor CAM Ultimate application. With this application, students only need to add the CAM add-on without learning a completely new software, allowing them to adapt more quickly to an interface that is already familiar to them.

b. Learner Analysis (Enhanced Academic Version)

An interview was conducted with four students who had previously completed the Advanced CAD/CAM course. The findings indicate that the students come from diverse educational backgrounds, including general senior high schools (SMA), Islamic senior high schools (MA), and vocational schools (SMK). Students from SMA and MA typically have no prior experience with design software, whereas those from SMK generally possess only manual technical drawing skills and have not been exposed to computer-based design applications.

The interviews further revealed that CAM-related content, particularly CAM Milling, has not been delivered effectively due to the absence of dedicated instructional media supporting the topic. In contrast, CAD topics have been supplemented with instructional materials provided by the lecturer. This discrepancy contributes to students' passive learning behavior, as they tend to rely on direct instructions rather than engaging actively in the learning process. Consequently, their critical and analytical thinking skills are not optimally developed. To enhance the quality of instruction, the development of learning media based on the Project-Based Learning (PjBL) approach is deemed essential. The PjBL approach is recognized for its potential to promote students' critical thinking, analytical skills, and problem-solving capabilities.

c. Task Analysis

In this stage, the process of identifying and organizing the material to be included in the learning product was carried out. The material was aligned with the needs of the Advanced CAD/CAM course in the Mechanical Engineering Education Study Program at FKIP Unsri and compiled from various reference sources, then matched with the course syllabus (RPS). The content includes 3D model design, basic concepts of CAM milling, machine setup, creating workpieces in CAM milling, 3-Axis CAM Milling Setup, 2D Milling Operations, Simulation, and Post-Processing in CAM Milling.

d. Concept Analysis

This stage was conducted by asking a series of questions to the course lecturer to trace the core concepts taught in the Advanced CAD/CAM course. The researcher also examined the course syllabus (RPS) as a reference in designing the learning product. The analysis revealed that the main material includes 3D model creation and manufacturing process planning. The learning process also emphasizes the use of CAM Milling features in the Inventor CAM Ultimate application, including the initial setup and the available machining features.

Through this material, students are expected to independently design manufacturing processes and generate G-Code from the models they have created.

e. Specifying Instructional Objectives

In this stage, the researcher formulated the instructional objectives for developing the learning materials based on the integration of the task analysis and concept analysis. The product developed serves as a guide for using the Inventor CAM Ultimate application in learning CAM Milling. The development objectives include: producing interactive e-learning materials that facilitate students' understanding of CAM Milling processes; providing digital learning resources that align with the vocational education curriculum in the field of machining technology; and offering flexible, independently accessible learning media to support digital learning.

2. Stage Design

After completing the needs analysis and designing the initial draft of the instructional material, the researcher proceeded to the validation stage conducted by experts, including material and media specialists. The results of this validation served as the basis for the researcher to carry out a series of revisions, ensuring that the developed product increasingly met feasibility standards. The next stage was the field trial. During the trial, the researcher received various feedback from students, prompting further revisions. The development of instructional tools within the 4-D model requires an iterative process of validation, revision, and testing until the product is deemed suitable [44]. The gradual involvement of both experts and users ensures the quality, feasibility, and effectiveness of the developed instructional material [49].

a. Media Selection

At this stage, the researcher determined the type of learning media to be developed. A textbook was selected as the primary medium. This selection is supported by literature indicating that textbooks function as a guide for instructors in determining instructional methods, while also serving as a resource for students to review or study the material independently. Findings from interviews with lecturers and students revealed that no media specifically supports CAM-related content, whereas students require learning materials that can enhance their analytical abilities, critical thinking, and collaboration skills in accordance with the learning outcomes stated in the Advanced CAD/CAM syllabus (RPS). Based on these needs, the researcher decided to develop Project-Based Learning (PjBL)-based instructional materials to ensure accessibility and alignment with the targeted competencies.

b. Format Selection

At this stage, the researcher determined the learning content and designed the structure and layout of the instructional material, including the arrangement of text, illustrations, and visual elements. The developed learning material consists of several main sections. The preliminary section includes the cover, preface, table of contents, list of figures, and list of tables as elements of identification and navigation.

The main content is organized into several chapters. Chapter I introduces the material by presenting an overview, learning outcomes, and user guidelines. Chapter II discusses the fundamental concepts of CAM Milling, including definitions, working principles, and its relationship with CAD and CNC. Chapter III explains the use of Autodesk Inventor, covering its definition, system requirements, installation procedures, and key features. Chapter IV outlines materials related to Autodesk Inventor CAM Ultimate, including installation processes and explanations of features that support CAM Milling.

Furthermore, Chapter V provides an operational guide for Inventor CAM Ultimate Milling, including workpiece creation, setup configuration, 2D milling operations, simulation procedures, and post-processing. Chapter VI elaborates on the application of Project-Based Learning in CAM Milling instruction, including project design, case studies, and its implementation. Chapter VII offers practice activities in the form of jobsheets to reinforce students' understanding.

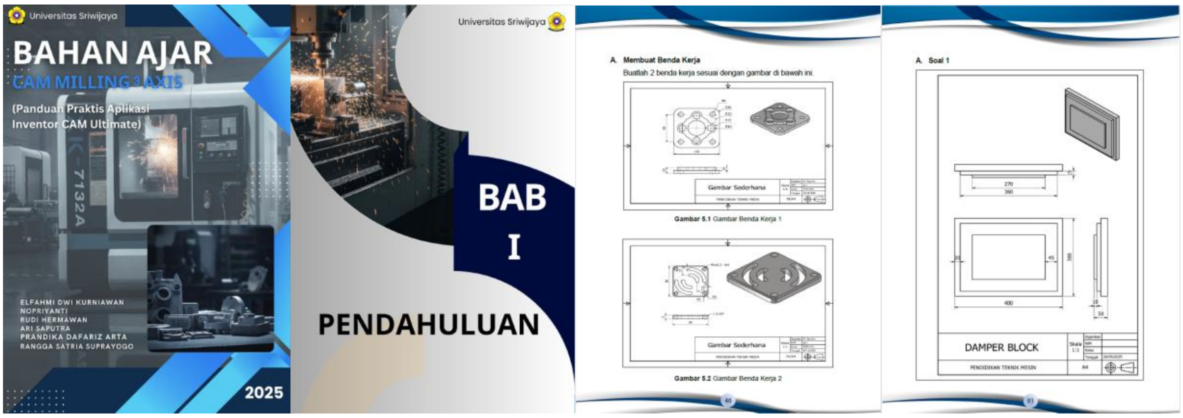
The final section of the material consists of the bibliography, glossary, and index, serving as supporting references and navigation for important terminology.

c. Initial Design

At this stage, the researcher prepared a prototype of the instructional material developed based on the analysis conducted during the Define and Design phases. The prototype represents the initial draft of the learning material, structured according to the identified needs, content organization, and previously formulated instructional design.

In addition to preparing the prototype, the researcher also designed the assessment instruments to be used prior to the trial implementation. These instruments were first validated by instrument experts before being submitted to material and media experts. The assessment tools include evaluation questionnaires for expert validators as well as user evaluation questionnaires.

The following section presents the prototype of the instructional material prepared by the researcher.



Picture 2. Teaching Material Prototype

3. Stage Develop

After completing the analysis and designing the initial draft of the instructional material, the researcher proceeded to the development stage by conducting validity testing with experts, including material and media specialists. The results of this validation served as the basis for improving the initial product. Subsequently, the researcher carried out trials with users. At each stage, various feedback was obtained and used to refine the instructional material, thereby enhancing its quality. The process of revision and testing was conducted iteratively until the instructional material reached a very high level of practicality. The development of products within the 4-D model requires a continuous process of validation, revision, and testing until the product is deemed feasible and effective [44]. The steps in this phase are as follows:

a. Expert Appraisal

At this stage, the researcher submitted the instructional material prototype along with the research instruments to material and media expert validators. The experts assessed the quality of the instructional material and provided the necessary feedback for improving both the content and the visual presentation.

Expert evaluation is crucial because the instructional material must undergo assessment regarding content accuracy, alignment with learning objectives, and design quality. Validation is conducted to ensure that the material meets the required standards; if the criteria are not yet met, the validation process is repeated until the desired level of validity is achieved. In addition, Validated learning media can significantly enhance students' learning outcomes [50].

b. Material Expert Validation

In this development, the material expert validators were Dr. M. Amri Santosa, S.T., M.Pd., and Romy Saputra, S.Pd., M.Pd.T. The instructional components were organized into four indicators, while the content or material components were developed into 44 indicators. Based on the validation process conducted by these two experts, the assessment data were obtained as described below.

Table 5. Table of Material Expert Validation

Name	Average	Category
M. Amri Santosa	4,26	Very Valid
Romy Saputra	4,33	Very Valid
Average	4,29	Very Valid

The results of the material expert evaluation indicated an average score of 4.29, which falls into the *very valid* category. Nevertheless, the material experts provided several suggestions, including the absence of clearly stated learning objectives or outcomes, the need for more detailed explanations regarding Project-Based Learning (PjBL), the addition of annotations on figures, improvements to the jobsheets in the practice exercises, and corrections to writing conventions that were still inaccurate.

Based on these recommendations, the researcher revised the material by correcting writing errors, clarifying spelling and punctuation, adding annotations to figures, and improving the jobsheets in the manufacturing steps and practice exercises. Complete comments along with the follow-up revisions can be found in the appendix.

c. Media Expert Validation

In this development, the media expert validators were Ainun Maulidina, S.Pd., M.Pd., and Efri Meldianto, S.Pd., M.Pd. The display aspect was developed into four indicators, comprising a total of 24 assessment items. The validation results from these two experts are presented as follows:

Tabel 6. Table of Media Expert Validation

Validator Name	Average	Category
Ainun Maulidina	4,43	Very Valid
Efri Meldianto	4,69	Very Valid
Average	4,56	Very Valid

The results of the media expert evaluation indicated an average score of 4.56, which falls into the *very valid* category. Students were considered able to conduct experiments by utilizing the available media. During this evaluation process, the researcher received several suggestions, including the need to enhance the cover design by adding supporting elements, improve the color composition to make it more appealing, and revise the summaries, which were considered too simple. Based on these recommendations, the researcher revised the cover and chapter covers, added more visually engaging elements, and redesigned the summaries to be more complete and informative. After the revisions were completed, the instructional material was then trialed with users, namely students of the Mechanical Engineering Education Study Program.

d. Develomental Testing

This stage involves the process of testing the planned product on actual subjects. Field trials were conducted to obtain direct feedback in the form of responses, reactions, and comments from students as the target users, as well as input from observers regarding the developed instructional material. The results of the trial were used to make product improvements.

The processes of trial, revision, and testing were carried out iteratively until a valid and truly useful instructional material was produced [44]. A total of twenty students participated in the field trial. The trial was conducted with students who had completed the Advanced CAD/CAM course, representing high, medium, and low academic ability levels. The data from the questionnaires they completed were then processed and presented in

Table 7. Respondent Trial Results

Score Interval	Category	Frekuensi	Percentage (%)
4,21–5,00	Very Valid/ Practical	15	67
3,41–4.20	Valid/ Practical	5	33
2,61–3,40	Adequately Valid/ Practical	0	0
1,81–2,60	Less Valid/ Practical	0	0
1,00–1,80	Not Valid/ Practical	0	0

The results of the field test with twenty participants showed that 75% of the students rated the instructional material as *very practical*, while the remaining 25% rated it as *practical*. Students in the *practical* category still provided positive feedback and stated that the instructional material is suitable for use in the learning process.

At this stage, the researcher also received several suggestions, including the need for clearer explanations in tables and the use of terms that may be unfamiliar to general readers. Based on these recommendations, Table 3 was revised by adding more detailed descriptions, resulting in an improved version of the developed instructional material.

A development product is considered practical if it is richer than standard learning materials and easy to use by students or educators. A field test was conducted with 20 students who had similar criteria, namely having completed the Advanced CAD/CAM course. They provided feedback in the form of comments and completed an evaluation questionnaire, resulting in an average score of 4.33, which falls into the *very practical* category. The distribution of responses indicated that 75% of participants rated the material as *very practical*, while 25% rated it as *practical*.

The practicality assessment focuses on data that demonstrate the students' ability to confirm the effectiveness of the product in improving learning outcomes prior to field trials. The practicality of learning media ensures that it is easy to use and apply in the learning process, thereby supporting both teachers and students in delivering and receiving instructional content [51]. Accordingly, the PjBL-based instructional material supported by the Inventor CAM Ultimate application is considered valid and practical to support the learning process in the Advanced CAD/CAM course.

4. Stage Disseminate

The final stage in the development process is Disseminate, which involves distributing the product to users. In this phase, the developed product is to be disseminated once it has been formally validated by the experts [52]. At this stage, the researcher distributed the revised and validated instructional material in PDF format and uploaded it to Google Drive for easy access. The link was then shared with students of the Mechanical Engineering Education Study Program through the lecturer of the Advanced CAD/CAM course, ensuring that the instructional material was used in a directed and organized manner.

According [44], the Disseminate stage is a critical step in the 4-D development model because it ensures that the product reaches the target users and can be applied in real learning contexts. The systematic dissemination of developed products is necessary to optimize the utilization of instructional materials by students [53].

CONCLUSION

The PjBL-based Advanced CAM Miliing material is deemed suitable for use in the Advanced CAD/CAM course as it meets both validity and practicality criteria. Its validity is supported by evaluations from material experts, who provided an average score of 4.29, and media experts, who provided a score of 4.56, both of which fall into the *very valid* category. Furthermore, the results of a field test with 20 students showed an average score of 4.33, categorized as *very practical*. Therefore, this instructional material not only meets quality standards in terms of content and presentation but is also user-friendly and effective in supporting the learning process in the Mechanical Engineering Education Study Program.

ACKNOWLEDGMENTS

"The research/publication of this article was funded Universitas Sriwijaya 2025. In accordance with the Rector's Decree Number: 0027/UN9/LPPM.PT/2025, on September 17, 2025".

REFERENCES

[1] N. Hatem, Y. Yusof, A. Z. A. Kadir, K. Latif, and M. A. Mohammed, "A novel integrating between tool path optimization using an ACO algorithm and interpreter for open architecture CNC system," *Expert Syst. Appl.*, vol. 178, no. May 2020, p. 114988, 2021, doi: 10.1016/j.eswa.2021.114988.

[2] P. Y. Wang, W. A. Yang, and Y. P. You, "A hybrid learning framework for manufacturing feature recognition using graph neural networks," *J. Manuf. Process.*, vol. 85, no. September 2022, pp. 387–404, 2023, doi: 10.1016/j.jmapro.2022.10.075.

[3] F. D. Michelacci, G. Han, and S. Kim, "Autonomous process optimization of a tabletop CNC milling machine using computer vision and deep learning," *CIRP J. Manuf. Sci. Technol.*, vol. 60, no. March, pp. 153–164, 2025, doi: 10.1016/j.cirpj.2025.04.009.

[4] M. R. Pahlevi, Syafri, and A. Susilawati, "Perencanaan Cad Cam Mesin Cnc Milling Router 3 Axis Dengan Perangkat Lunak Mastercam," *J. Tek. Mesin*, vol. 4, no. 2, pp. 1–7, 2017.

[5] H. Wang, W. Qu, T. Wang, X. Wu, and H. Sun, "Accuracy analysis of all-ceramic crowns with different materials in CAD/CAM digital replication mode," *BMC Oral Health*, vol. 25, no. 1, 2025, doi: 10.1186/s12903-025-05892-9.

[6] M. N. M. Kamal, "Comparison between relining of ill-fitted maxillary complete denture versus CAD/CAM milling of new one regarding patient satisfaction, denture retention and adaptation," *BMC Oral Health*, vol. 25, no. 1, 2025, doi: 10.1186/s12903-024-05298-z.

[7] C. Guo, Z. Wang, K. Li, L. Ye, N. Yu, and F. Gong, "Domain knowledge integrated CAM system based on multi-objective path optimal planning and deep convolutional neural network," *Expert Syst. Appl.*, vol. 282, no. April, p. 127788, 2025, doi: 10.1016/j.eswa.2025.127788.

[8] M. Plaza and W. Zebala, "A decision model for investment analysis in CNC centers and CAM technology," *Comput. Ind. Eng.*, vol. 131, no. March, pp. 565–577, 2019, doi: 10.1016/j.cie.2019.03.028.

[9] M. A. Dittrich, F. Uhlich, and B. Denkena, "Self-optimizing tool path generation for 5-axis machining processes," *CIRP J. Manuf. Sci. Technol.*, vol. 24, pp. 49–54, 2019, doi: 10.1016/j.cirpj.2018.11.005.

[10] J. Schmid and R. Pichler, "Seamless data integration in the CAM-NC process chain in a learning factory," *Procedia Manuf.*, vol. 45, pp. 31–36, 2020, doi: 10.1016/j.promfg.2020.04.038.

[11] D. H. U. Ningsih, "Computer Aided Design/Computer Aided Manufacturing (CAD/CAM)," *J. Teknol. Infirm. Din.*, vol. X, no. 3, pp. 143–149, 2005, doi: 10.1007/s12614-015-5448-7.

[12] I. J. Nurhidayah, F. C. Wibowo, and I. M. Astra, "Project Based Learning (PjBL) learning model in science learning: Literature review," *J. Phys. Conf. Ser.*, vol. 2019, no. 1, 2021, doi: 10.1088/1742-6596/2019/1/012043.

[13] D. Nababan, A. K. Marpaung, and A. Koresy, "Strategi Pembelajaran Project Based Learning (Pjbl)," *J. Pendidik. Sos. dan Hum.*, vol. 2, no. 2, pp. 706–719, 2023, [Online]. Available: https://publisherqu.com/index.php/pediaqu

[14] A. Fitriyah and S. D. Ramadani, "Pengaruh Pembelajaran STEAM Berbasis PJBL (Project-Based Learning) Terhadap Keterampilan Berpikir Kreatif dan Berpikir Kritis," *J. Educ.*, vol. 3, no. 1, p. 7, 2021, doi: 10.26737/jpmi.v1i1.76.

[15] M. Aini, D. S. Ridianingsih, and I. Yunitasari, "Efektivitas Model Pembelajaran Project Based Learning (Pjbl) Berbasis Stemterhadap Keterampilan Berpikir Kritis Siswa," *J. Kiprah Pendidik.*, vol. 1, no. 4, pp. 247–253, 2022, doi: 10.33578/kpd.v1i4.118.

[16] F. Al-Kamzari and N. Alias, "A systematic literature review of project-based learning in secondary school physics: theoretical foundations, design principles, and implementation strategies," *Humanit. Soc. Sci. Commun.*, vol. 12, no. 1, pp. 1–18, 2025, doi: 10.1057/s41599-025-04579-4.

[17] M. Muhtar *et al.*, "Implementation of Project-Based Learning Model in Vocational High Schools: A Bibliometric Analysis," *Educ. Process Int. J.*, vol. 15, 2025, doi: 10.22521/edupij.2025.15.169.

[18] F. Musa, N. Mufti, R. A. Latiff, and M. M. Amin, "Project-based Learning (PjBL): Inculcating Soft Skills in 21st Century Workplace," *Procedia - Soc. Behav. Sci.*, vol. 59, no. 2006, pp. 565–573, 2012, doi: 10.1016/j.sbspro.2012.09.315.

[19] L. Andriani, S. Suhirman, M. S. Ihsan, and F. A. Rahman, "Pengaruh Model Pembelajaran Project Based learning (PjNL) Terhadap Kemampuan Komunikasi dan Berpikir Kreatif Peserat Didik," *J. Inov. Pendidik. dan Sains*, vol. 4, no. 2, pp. 102–107, 2023, [Online]. Available: http://publications.lib.chalmers.se/records/fulltext/245180/245180.pdf%0Ahttps://hdl.handle.net/20.500.12380/245180%0Ahttp://dx.doi.org/10.1016/j.jsames.2011.03.003%0Ahttps://doi.org/10.

1016/j.gr.2017.08.001%0Ahttp://dx.doi.org/10.1016/j.precamres.2014.12

[20] F. Firman, D. Desyandri, and M. Ovartadara, “Penerapan Model Project Based Learning dalam Meningkatkan Komunikasi Matematis SiswaSekolah Dasar,” *Didakt. J. Ilm. PGSD FKIP Univ. Mandiri*, vol. 22, no. 2, pp. 322–338, 2022.

[21] R. N. Sari and A. Atiningsih, “Implementasi Project Based Learning Untuk Meningkatkan Keterampilan Kolaborasi Siswa Pada Materi Tata Surya,” *LAMBDA J. Ilm. Pendidik. MIPA dan Apl.*, vol. 3, no. 1, pp. 22–28, 2023, doi: 10.58218/lambda.v3i1.550.

[22] D. Oktaviana and R. Haryadi, “Pengaruh Model Pembelajaran Problem Based Learning (Pbl) Terhadap Kemampuan Pemecahan Masalah Mahasiswa,” *AKSIOMA J. Progr. Stud. Pendidik. Mat.*, vol. 9, no. 4, p. 1076, 2020, doi: 10.24127/ajpm.v9i4.3069.

[23] B. Prasetya and H. Prasetiawan, “Upaya Meningkatkan Manajemen Waktu Melalui Bimbingan Klasikal Model Project Based Learning (PjBL) pada Siswa Sekolah Menengah Atas,” *Bull. Couns. Psychother.*, vol. 4, no. 2, pp. 250–257, 2022, doi: 10.51214/bocp.v4i2.286.

[24] F. Febriansyah and E. D. Kurniawan, “Pengembangan Video Tutorial Cam Berbasis Case Method Di Program Studi Pendidikan Teknik Mesin FKIP UNSRI,” *EDUTECH J. Teknol. Pendidik.*, vol. 24, no. 2, pp. 1009–1017, 2025, doi: https://doi.org/10.17509/e.v24i2.83112.

[25] A. R. R. S. Putri and W. D. Kurniawan, “Pengembangan Video pembelajaran youtube untuk Mata Pelajaran CNC Lathe Cam Kelas XI Jurusan Teknik Pemesinan di SMK Negeri 1 Sidoarjo,” *JPTM*, vol. 12, no. 2, pp. 236–240, 2023.

[26] A. Pratama and E. D. Kurniawan, “Pengembangan Buku Ajar Berbasis Metode Kasus Materi Cam Dengan Bantuan Aplikasi Inventor Cam Ultimate,” *EDUTECH J. Teknol. Pendidik.*, vol. 24, no. 2, pp. 876–888, 2025, doi: https://doi.org/10.17509/e.v24i2.83075.

[27] E. D. Kurniawan, Nopriyanti, R. Hermawan, P. Mahendra, and M. Milky, “Validity Test of CNC Simulator Application Guidebook for Android,” *AIP Conf. Proc.*, vol. 3052, no. 1, 2024, doi: 10.1063/5.0201171.

[28] B. Burhanudin, E. Suryono, A. Prasetyo, B. Margono, Z. Zainuddin, and A. Rahmatulloh, “Pengembangan Pola Pembelajaran Pemograman Cnc Melalui Integrasi G Code, Simulator Cnc Dan Cam,” *Abdi Masya*, vol. 4, no. 2, pp. 219–224, 2023, doi: 10.52561/abma.v4i2.310.

[29] E. D. Kurniawan, Nopriyanti, and S. D. Sucipto, “Pengembangan Modul Elektronik Berbasis Video Tutorial Pada Matakuliah CAD/Cam Materi Gambar 3D,” *Maj. Ilm. Sriwij.*, vol. XXX, no. 17, 2018.

[30] R. Rianto and E. D. Kurniawan, “Pengembangan Jobsheet Berbasis Case Method CNC Lathe 2A di Program Studi Pendidikan Teknik Mesin FKIP UNSRI,” *EDUTECH J. Teknol. Pendidik.*, vol. 24, no. 2, pp. 951–957, 2025, doi: https://doi.org/10.17509/e.v24i2.83108.

[31] W. A. Putra, “Pengembangan Jobsheet Mata Pelajaran NC/CNC dan CAM berbasis Produk,” Universitas Negeri Padang, 2021. [Online]. Available: http://repository.unp.ac.id/38555/

[32] F. Prasetya, B. R. Fajri, and F. Ranuharja, “Development design augmented reality-based jobsheet in CNC programming subjects,” *Int. J. Innov. Creat. Chang.*, vol. 10, no. 11, pp. 50–67, 2020.

[33] E. D. Kurniawan, N. Nopriyanti, R. Hermawan, and P. I. Yanti, “Pengembangan Modul Pembeljaran Berbasis STEM pada Materi CNC Milling Simulator,” *J. Pendidik. Tek. Mesin*, vol. 10, no. November, 2023.

[34] B. S. H. Purwoko, “Pengembangan Mesin CNC Virtual sebagai Media Interaktif dalam Pembelajaran Pemrograman CNC,” *J. Penelit. Dan Eval. Pendidik.*, vol. 13, no. 2, 2009.

[35] K. D. Pramesti, N. I. Meisya, and R. Amrillah, “Relevansi Lulusan Perguruan Tinggi dengan Dunia Kerja,” *J. Pendidik. Islam dan Sos. Agama*, vol. 03, no. 04, pp. 236234–243, 2024.

[36] D. Darmansyah, R. Pratiwi, and R. E. Sari, “Bahan Ajar Digital dan Evaluasi Model Extenics bagi Guru di SMA Rambatan,” *J. Educ. Res.*, vol. 4, no. 4, pp. 1824–1832, 2023, [Online]. Available: https://www.jer.or.id/index.php/jer/article/view/568%0Ahttps://www.jer.or.id/index.php/jer/article/download/568/329

[37] M. Shafiul A., D. Agus S., and D. Nurhadi, “Mengkombinasikan Project-Based Learning dengan STEM untuk Meningkatkan Hasil Belajar Teknikal dan Karakter Kerja Siswa SMK,” *Februari*, vol. 43, no. 1, pp. 41–50, 2020.

[38] E. S. Siregar, “Studi Kualitaitf Internalisasi Nilai Kewiraushaan dalam Pembelajaran Sekolah Vokasi di SMKN PP (Pertanian Pembangunan) Batang Hari,” *Inspirasi Edukatif J. Pembelajaran Aktif*, vol. 6, no. 2, pp. 492–507, 2025.

[39] A. D. F. Attarix, S. J. Fadilah, A. D. Cahyo, I. M. Arsana, and D. Wulandiyah, “Penerapan Model Pembelajaran Project-Based Learning pada Mata Pelajaran CNC dengan Bantuan Aplikasi CNC Simulator untuk Meningkatkan Hasil Belajar Peserta Didik Kelas XI SMKN 3 Surabaya,” *Pendas J. Ilm. Pendidik. Dasar*, vol. 15, no. 1, pp. 37–48, 2024.

[40] B. Rahim *et al.*, “Effectiveness of Project-Based Learning in Metal Welding Technology Course with STEAM Approach in Vocational Education,” *TEM J.*, vol. 13, no. 2, pp. 1481–1492, 2024, doi: 10.18421/TEM132-62.

[41] B. Jiang *et al.*, “Local corner smoothing based on deep learning for CNC machine tools,” *Sci. Rep.*, vol. 15, no. 1, 2025, doi: 10.1038/s41598-024-84577-9.

[42] M. Milki and N. Nopriyanti, “Pengaruh Penggunaan Buku Panduan Aplikasi Cnc Simulator for Android Terhadp Kemampuan Pembuatan Program Cnc Pada Mahasiswa Pendidikan Teknik Mesin Fkip Unsri,” *Jambura J. Eng. Educ.*, vol. 2, no. 2, pp. 21–29, 2023, doi:

https://doi.org/10.37905/jjee.v2i2.20221.
[43] D. Ardianto, Y. A, N. Helmi, and E. Indrawan, "Efektivitas Penggunaan Cnc Simulator Untuk Meningkatkan Hasil Belajar Pada Pembelajaran Teknik Pemesinan Nc/Cnc Dan Cam Kelas Xii Smk Negeri 1 Bukittinggi," *J. Vokasi Mek.*, vol. 3, no. 4, pp. 62–67, 2021, doi: 10.24036/vomek.v3i4.246.
[44] S. Thiagarajan, "Instructional development for training teachers of exceptional children: A sourcebook.," 1974.
[45] W. R. Borg and M. D. Gall, *Educational Research: An Introduction*, 4th ed. New York: Longman, 1998.
[46] A. B. Benedicto, "Development , Validation , and Acceptability of Instructional Module in Organization and Management," *Int. J. Sci. Manag. Stud.*, vol. 8, no. August, pp. 96–114, 2025, doi: 10.51386/25815946/ijsms-v8i4p107.
[47] A. Gozali, D. Samuel Budiawan, and A. Eno Pratiwi, "Needs Analysis on the Development of Instructional Material for Intensive Listening Course," *Educ. English as a Foreign Lang. J.*, vol. 5, no. 1, pp. 48–56, 2022, doi: 10.21776/ub.educafl.2022.005.01.06.
[48] I. Saputri and A. Asrizal, "Needs Analysis for Development of Digital Teaching Materials With Augmented Reality for Optical Instruments Materials," *Phys. Learn. Educ.*, vol. 1, no. 3, pp. 146–153, 2023, doi: 10.24036/ple.v1i3.65.
[49] Z. Arifin, *Evaluasi Pembelajaran: Prinsip, Teknik, Prosedur.* Bandung: PT. Remaja Rosdakarya, 2009.
[50] I. Amalia and B. Sujatmiko, "Pengembangan E-Modul Berbantuan Flipbook Berbasis PJBL Guna Meningkatkan Hasil Belajar Siswa Pada Mata Pelajaran Teknik Animasi 2D," *J. IT-EDU*, vol. 7, no. 1, pp. 92–99, 2020, [Online]. Available: https://ejournal.unesa.ac.id/index.php/it-edu/article/view/50147%0Ahttps://ejournal.unesa.ac.id/index.php/it-edu/article/download/50147/41298
[51] E. I. Sari, N. Huda, and S. Syamsurizal, "Pengembangan Media Pembelajaran Matematika Berbasis Konstruktivisme pada Materi Segitiga Siswa Kelas VII SMP," *J. Cendekia J. Pendidik. Mat.*, vol. 5, no. 2, pp. 1721–1728, 2021, doi: 10.31004/cendekia.v5i2.601.
[52] A. S. Ajri and R. Perdana, "Pengembangan Perangkat Pembelajaran Fisika Berbasis Problem Based Learning Untuk Meningkatkan Kterampilan Berpikir Kritis," *J. Inov. Pendidik. dan Sains*, vol. 4, no. 1, pp. 53–60, 2023.
[53] W. Fatihah, "Diseminasi Modul Ajar pada Kegiatan Implementasi Kurikulum Merdeka dan Proses Pembelajaran di Kelas," *J. Abdimas Kartika Wijayakusuma*, vol. 4, no. 1, pp. 1–11, 2023, doi: 10.26874/jakw.v4i1.273.