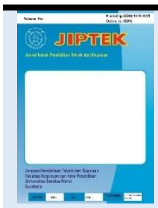

JIPTEK: Jurnal Ilmiah Pendidikan Teknik dan Kejuruan

Jurnal Homepage: https://jurnal.uns.ac.id/jptk

Industry-Oriented Computer-Aided Manufacturing Learning Models in Vocational Higher Education: A Multi-Case Qualitative Study

Tri Adi Prasetya[1*], Chrisna Tri Harjanto[2], Dwi Rahdiyanta[3]

[1*,2,3]Department of Mechanical Engineering Education, Universitas Negeri Yogyakarta, Indonesia

Email: triadiprasetya@uny.ac.id,

ABSTRACT

Vocational higher education is required to produce graduates with Computer-Aided Manufacturing (CAM) competencies that align with rapidly evolving industrial demands. However, variations in learning models across institutions often result in inconsistent competency outcomes. This study aims to explore and analyze CAM learning models implemented in Diploma-level vocational higher education and examine their relevance to workplace requirements. Employing a qualitative multi-case study approach, data were collected from four vocational higher education institutions in Indonesia through observations, document analysis, and semi-structured interviews with lecturers and industry partners. The findings identify three dominant CAM learning models: textbook-based, industry-based, and internet literacy-based learning. The industry-based model demonstrates the most substantial alignment with workplace competencies, particularly in problem-solving and adaptability, while the textbook-based model remains effective for foundational conceptual understanding. Internet literacy-based learning supports independent learning but requires structured guidance to ensure depth of competency. The study highlights the importance of integrating soft skills, including leadership and problem-solving, into CAM learning models to enhance graduates' employability in Industry 4.0. These findings provide practical insights for curriculum designers and vocational institutions in developing more industry-responsive CAM learning strategies.

***Keywords**: CAM Competencies, CAM Learning Models, Vocational Higher Education*

JIPTEK: Jurnal Ilmiah Pendidikan Teknik dan Kejuruan
Vol 19 Issue 1 2026
DOI: https://doi.org/10.20961/jiptek.v19i1.113488

INTRODUCTION

Indonesia is currently in the 21st century, a period marked by increasingly fierce global competition across fields, from goods and commodities to services and labor. This development is inseparable from the arrival of the Industrial Revolution 4.0, which has been developing rapidly since the early 2000s, along with advances in information technology and digital innovation (Ngatiman et al., 2023). This industrial transformation has had a significant impact on the world of work, where the use of robots and machines is increasingly widespread and has the potential to replace various types of jobs, thus giving rise to technological disruption in the industrial sector (Daduna, 2019; Hopster, 2021; Pinto & Reis, 2023).

The presence of the Industrial Revolution poses a threat to humans (Bhalerao et al., 2023). The effect of the Industrial Revolution is the gap between the poor and the rich (Mohajan, 2019). There is cost reduction, but there is an increase in performance, product, and service improvements, taking into account consumer preferences and behavior, and artificial intelligence-based production automation that discriminates against mass labor (Ślusarczyk, 2018). Threats for those who are not ready to face the technological advances of the industrial revolution 4.0 are included in the disrupted generation (Affaki et al., 2024; Kasali, 2017).

Developments in the manufacturing industry are speedy (Kipper et al., 2021). The longer it takes, the more sophisticated the machines and tools used. Many new jobs have appeared, and jobs have disappeared. The future for employment is positive for Indonesia, and more new jobs will be created in 2030 than jobs lost due to automation (McKinsey & Company, 2019). One development in manufacturing automation is the use of CAM.

Computer-Aided Manufacturing (CAM) applications are used to Design a machine part and create a CNC program for the machining process (Li, 2018; Mastercam, 2018). CNC programming simulation has great potential to be developed (Sutopo, Setiadi, Prasetya, et al., 2024). CAM refers to computer systems that convert engineering designs into final products. The production process requires the creation of process planning and production scheduling, which describes how a product is made, what resources are needed, and when and where these resources will be delivered. The production process also requires control and coordination of physical processes, equipment, materials, and labor. With CAM, computers assist managers, engineering/manufacturing engineers, and production workers with the automation of production tasks (Plaza & Zebala, 2019).

The dynamics of education 4.0 have penetrated vocational higher education, which is very closely related to ready-to-use employment providers in the industry (Saari et al., 2021; Thong & Ngoc, 2023). Vocational higher education 4.0 will fuse with technology and information in the integration of machines and production processes, so that it is known as the Computer Integrated Manufacturing (CIM) program, which is communicated by humans, so that they can integrate the two (McGrath et al., 2019). This is different from vocational education 3.0, where the world of work is between computers and manufacturers, with humans as intermediaries or executors.

Indonesia must be able to increase competitiveness in terms of both product and service quality, in line with market demands and developments in automation technology. Increasing competitiveness begins with preparing high-quality Human Resources (HR), a factor in achieving excellence in the face of competition. Technical and Vocational Education and Training (TVET) is concerned with the process of acquiring practical knowledge and skills for the world of work (Francisco John Mark & Neri, 2023). TVET provides theoretical and practical knowledge in schools, training institutions, or companies. TVET is needed to equip students with the skills to secure employment (Tukundane et al., 2015).

In addition, TVET produces human resources who are ready to adapt to the organization and workplace (Hadi et al., 2015).

Improving the quality of education is a process that must be carried out continuously to improve the quality of the teaching and learning process (Garira, 2020; Gomez Zermeño & Blanco Mejía, 2020). Basically, every learning process that is carried out is directed to achieve the goals that have been determined (Adams et al., 2022). Learning is a series of interactive activities between teachers and students that require comprehensive planning, including mastery of basic skills and theories, time allocation, achievement indicators, and structured learning stages. Learning effectiveness is determined not only by the quality of planning but also by the level of student activity during the learning process, which significantly influences learning outcomes in vocational education (Prasetya et al., 2021).

Learning is an activity that proceeds through the stages of design, implementation, and evaluation, interpreted as the interaction of students with educators and learning resources in a learning environment (Nguyen et al., 2022). The activity of the learning process is characterized by the occurrence of educative interactions (Venatius et al., 2023). The educational process is an interaction that is aware of goals, starting methodologically from the educator and pedagogical learning activities for the students. This process systematically goes through the design, implementation, and evaluation stages. Learning in vocational education must be aligned with real workplace conditions, including operational risks and safety requirements in machining environments, which demand not only technical competence but also strong risk awareness and procedural discipline (Billett, 2011; Djatmiko et al., 2020).

Vocational higher education must equip students with the CAM competencies required by the world of work. The learning model applied by each vocational college also varies. The lecture model is not enough to equip students with CAM competencies. Learning must be adapted to actual conditions in the industry (Schmid & Pichler, 2020). There are also various sources of job giving. Therefore, it is necessary to reveal the different CAM learning models applied by vocational higher education.

The Industrial Revolution 4.0 brings significant challenges to vocational education, especially in preparing competent graduates in the field of manufacturing technology (Duplák et al., 2024). Although many studies discuss the need for technical skills in this era, there is still limited research that examines the effectiveness of CAM learning models in the context of vocational higher education. This study aims to address this gap by exploring various CAM learning models and their relevance to industry needs.

Based on the current learning, it still focuses on hard skills. Vocational higher education still provides minimal soft skills for students (Apri Nuryanto et al., 2024; Prasetya et al., 2025b). The lack of prior research continues to show a focus on hard skills only (Boere et al., 2023; Heuser et al., 2024; Teichmann et al., 2019; Volkmann et al., 2020). There is a need for research to identify the learning skills required in the industry. Therefore, it is necessary to reveal various CAM learning models that can equip students to survive in the industry.

RESEARCH METHODS

This study uses a qualitative case-study design. Data were collected through semi-structured interviews, observations, and document analysis. Data validation was carried out through method triangulation, including cross-checking interview results with curriculum documentation. The research products to be produced are findings in the identification of CAM learning models implemented in vocational higher education. This research was carried out at the Diploma 4 (D4) Mechanical Engineering, Universitas Negeri Yogyakarta; D4 Mechanical Engineering Technology, Vocational School, Universitas Gadjah Mada; D4 Mechanical Engineering Production and Maintenance, Politeknik Negeri Semarang; and D4 Engineering Manufacturing Technology, Politeknik ATMI. The subjects of this research are lecturers who are experts in CAM. As a research design, this research is a qualitative field research. Among the several elements to be explained, it is a type of field research. This study chose a case study approach because, with this approach, researchers can more sharply examine the problem of applying the CAM learning model to equip students to face the world of work. Data validation was carried out through methodological triangulation, including cross-checking interview results against curriculum documents and direct observations. Researchers used the Miles and Huberman data analysis model. Data analysis activities for the Miles and Huberman model are carried out interactively with three steps: data reduction, data display, and verification/conclusion drawing.

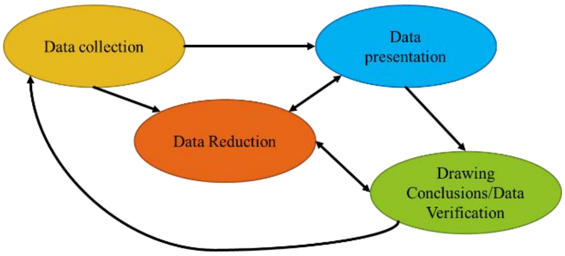

Figure 1. Data analysis technique of the Miles and Huberman model (Miles & Huberman, 1994)

Carrying out interviews with vocational higher education students using interview guidelines. The interview guide instrument is shown in Table 1.

Table 1. Interview guidelines

No	Theme	Question
1	Study program curriculum	What kind of curriculum is used in the Study Program? Does the profile of graduates in the study program support CAM competencies? What courses can support CAM learning in your study program?
2	CAM learning tools	What learning tools must lecturers provide to teach CAM to students? What is the CAM learning model/method like here? What are students given in CAM learning? What does the CAM job sheet look like here? Where do the jobs done in CAM courses come from? Does CAM learning involve collaboration with industry?
3	CAM learning facilities	What software is used in CAM? How many computer devices are provided in CAM learning?

RESULTS

The results of the first interview with the CNC Laboratory Coordinator and a CAM supporting lecturer who was studying in the D4 Mechanical Engineering program at Universitas Negeri Yogyakarta were derived from graduates' profiles and the Program Learning Outcomes (PLO) for the study programs. CAM learning applied to D4 Mechanical Engineering at UNY starts from the CNC course. Students practice manually creating CNC programs and using machine settings first. After becoming proficient in Manual Data Input (MDI), students are trained to design and create CAM programs in CAD/CAM courses.

CAD-CAM learning was initially conducted through lectures, discussions, and demonstrations on CNC machines. After that, step into the material and CAM simulations using Mastercam X7. The G-code generated by the program is then sent to the CNC machine. The CAM competencies taught range from creating 2D/3D images to toolpath movement. CAM teachers use job sheets as a medium for students to practice. This job sheet is sourced from references to training manuals such as Mathematisch Technische Software (MTS) and Daewoo, and the instructor develops jobs. For human resources in learning, 100% of CAM supporting lecturers already have competency certificates, while CAM technicians do not yet have them. Facilities for learning CAM, both software and hardware, have been fulfilled. The software used in CAM learning is Mastercam X7, Autodesk Inventor, and Autodesk HSMWorks. Researchers then analyzed the interview results to identify learning patterns, as shown in Figure 2.

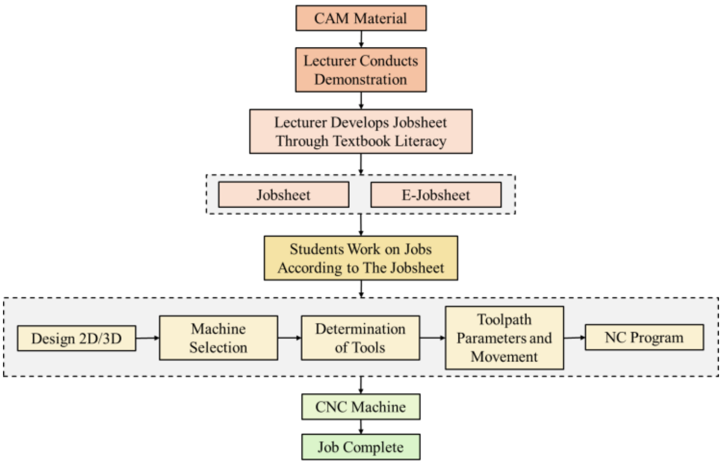

Figure 2. Textbook-Based CAM Learning

The second interview was with the Head of the D4 Engineering Manufacturing Technology Study Program at the ATMI Polytechnic. Based on interviews conducted by researchers, information was obtained that the profiles of study program graduates were directed as Educators in the Field of Engineering and Manufacturing Processes, Research Engineers for Materials and Plastic Manufacture, Planners and Controllers of Manufacture Processes, Planners of Reverse Engineering (Tool Making and Fine Stamping Specialist), Industrial Equipment Design Engineering, Mold Design Engineer, Engineer for Plastic Processing, and Technology Consultant of Manufacture. The Head of the D4 Engineering Manufacturing Technology Study Program explained that the program has a philosophy of not making finished plants but of creating seeds that can become all plants. On that basis, the D4 Manufacturing Technology Engineering study program produces graduates ready to work anywhere in the machinery field. CAM learning uses a 2-week module in the CAD CAM Laboratory for the initial stage. After applying it later in the CNC Milling section, I will work on industrial order jobs. The CAM competencies taught range from creating 2D/3D images to toolpath movement, in learning CAM using the PowerMill Delcam software. This software is used because partner industries widely use it, so learning is directed toward doing jobs in those industries.

The third interview was conducted with the Head of the D4 Mechanical Engineering Technology Study Programme at Gadjah Mada University Vocational School, who also serves as a lecturer in Computer-Aided Manufacturing (CAM). The interview results showed that the study programme's graduate profile is directed towards roles as Mechanical Design Engineers, Engineering Consultants, Project Engineers, and Engineering Supervisors. Graduates are expected to be able to design, implement, and realise design-based products, as well as carry out continuous improvements.

From a human resources perspective, both lecturers and laboratory technicians hold full competency certification. The curriculum of the D4 Mechanical Engineering Technology Study Programme is structured using a priority scale aligned with industry needs. CAM learning is implemented through modules, job sheets, and applied technology projects derived from lecturers' research and industrial orders. The CAM competencies covered include 2D and 3D modelling, tool and tool-path selection, tool-path programming, and mould making. For instance, students are required to develop a machining process plan for shafts using Mastercam software. The interview data were subsequently analysed to identify CAM learning patterns, as illustrated in Figure 3.

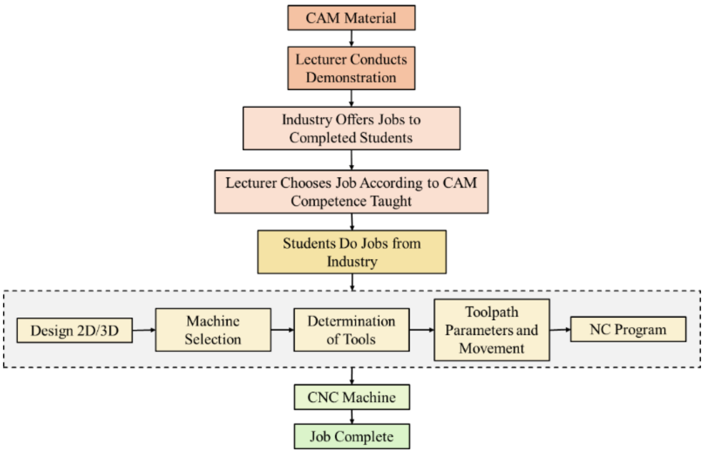

Figure 3. Industry Job-Based CAM Learning

The fourth interview was with lecturers from the D4 Mechanical Engineering Production and Maintenance Study Program at Semarang State Polytechnic. Based on interviews conducted by researchers, the profiles of study program graduates emphasized competence in production machinery and maintenance. The D4 TMPP curriculum does not yet have specific CAM courses. CAM learning itself takes place in CAD courses. Learning to use Autodesk Inventor software. The portion of CAM learning remains relatively small, and students are asked to actively seek information online. The researchers then analyzed the interview results to identify learning patterns, as shown in Figure 4.

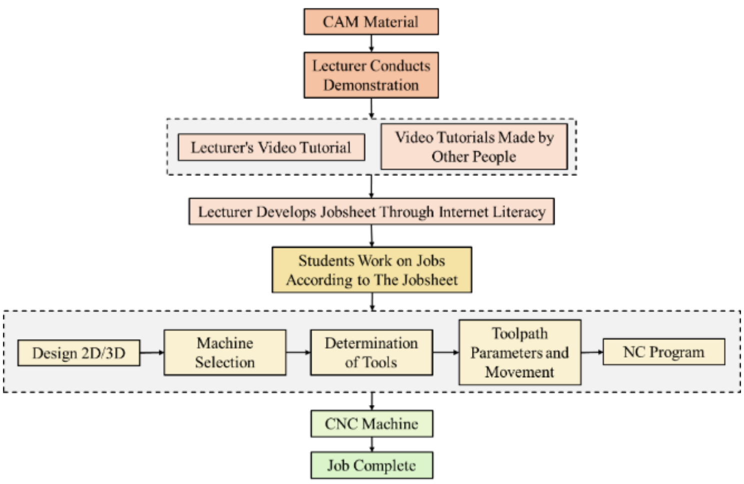

Figure 4. Internet Literacy -Based CAM Learning

DISCUSSION

Based on the interview results, the CAM learning model was found to exist in each institution. CAM learning has developed quite rapidly. CAM learning aims to equip students with the competence to work in the industry. The explanation of the learning model based on the results of the interview development is as follows.

Textbook-based CAM learning is learning refers to the jobs provided in textbooks. Learning with this model relates to reference textbooks on training manuals, such as Mathematisch Technische Software (MTS) and Daewoo. Through the references in these books, the lecturer takes and develops jobs for job sheets. This learning is repeated for students. This learning model uses the drill technique approach presented in the job sheet. Figure 2 shows that lecturers who apply this model tend to dominate the start of lectures. The lecturer explains the CAM material to students. Lecturers perform practical demonstrations of operating CAM software and CNC machines. Lecturers also develop worksheets based on existing reference books. The job sheet includes turning and milling operations. The content and presentation of CAM material gradually start from easy to complex. Students working with CAM software must arrive correctly. To check the truth, you can use a simulation on the CAM software. Once correct, transfer the NC program to the CNC machine to make actual workpieces. The advantage of this model is that it is easier for lecturers to develop job sheets based on existing reference books. In addition, the material's content and presentation are denser.

The job industry-based CAM learning model is expected to work on industrial products. This model is effective in providing concretization of industrial design jobs. This includes experience for students in working on industrial products, as well as lecturers assisting with product design catalogs suitable for industrial work. Figure 3 explains that collaboration between universities and industry is the key to the successful implementation of CAM learning. The CAM learning model is for students to work on industrial products as assigned by the industry. This is, of course, only about industries with strong partnerships that can work together to link and match CAM learning. The lecturer begins the lecture by explaining CAM material to students. Lecturers first conduct demonstrations and practical exercises to operate CAM software and CNC machines. Lecturers choose jobs in industries suitable for students to work in. Students must correctly make the NC program. Once correct, transfer the NC program to the CNC machine to create actual workpieces. If there is a mistake in the student's work, he must pay for it himself. The advantage of this CAM learning model is that students can work on industrial products. This will provide experience for students to be ready to work after graduation (Putra et al., 2023).

Internet literacy-based CAM learning is a learning development that utilizes internet information as a product in CAM courses. This method is quite helpful for lecturers in enriching design teaching materials. Students can view online videos about working with CAM software. Students receive examples of the manufacturing process and the results of workpieces produced using CAM software. This learning model encourages students to explore and work with CAM software independently using online instructions. Figure 4 explains that the CAM learning model enables students to study and work on products online. The lecturer begins the lecture by explaining CAM material to students. Lecturers conduct demonstrations and practical exercises in operating CAM software and CNC machines. Students can also learn CAM online. Lecturers post online jobs suitable for students to work on. Students must correctly make the NC program. Once correct, transfer the NC program to the CNC machine to create actual workpieces. This learning model has advantages in working on student products. This can open up insight into various product variations that students can work on.

Based on interviews, various types of CAM competencies are taught in vocational schools. This learning model equips students with CAM competencies. (Kavade, 2020). Learning content includes 2D & 3D Design topics, as well as 2D & 2½D Toolpath to 3D Toolpath. CAM learning jobs at vocational higher education are adapted to existing software and machines. CAM software affects the effectiveness of CAM learning (Abouelala et al., 2015). Lecturers must choose jobs that students can do. This adjustment is due to the rapid technological development in the industry. So vocational higher education finds it challenging to match industry facilities.

CAM learning in vocational higher education is highly useful to the manufacturing industry because it can reduce training costs for new workers. Using a computer to create technical drawings makes the product design process faster and more accurate. In addition, production machines can be adjusted automatically with the help of computers, so that the production process becomes more efficient (Mourtzis et al., 2022). However, CAM learning also has some drawbacks. For example, CAM learning processes are often expensive because the required licenses and equipment are costly. In addition, there is a gap between the competencies taught and those in the industry. For this reason, a link and match is needed between vocational higher education and industry.

The discussion of these findings shows that the industry-based model has the highest relevance to the needs of the workforce, in line with literature that emphasizes the importance of the link and match between vocational education and industry (McGrath et al., 2019). However, the main challenges are the high cost of procuring CAM software and hardware, as well as the competency gap between students and the industrial workforce. The inadequate technology skills and knowledge negatively impact TVET engineering lecturers, exposing their inability to teach their students to use technology tools in their learning (Chiloane et al., 2022).

Vocational higher education plays a vital role in preparing workers in the manufacturing industry to support the economy (Mohamad et al., 2023). In addition, in order for the quality of the workforce produced by vocational higher education to be appropriate and relevant to the world of work. The implementation of vocational higher education must be in harmony with the world of work (Fjellström, 2014; Renta

Davids et al., 2017). Learning that equips students with competencies aligned with the world of work, including business and industry, supports the success and relevance of diploma four education as a producer of a workforce aligned with the world of work.

Based on an analysis of the limitations of the three existing learning models, it is necessary to develop a CAM learning model that is more relevant to current industrial needs. Computer-Aided Manufacturing (CAM) learning no longer focuses solely on mastering technical skills and the ability to operate software and manufacturing machines, but also needs to systematically develop soft skills that support teamwork and collaboration in a dynamic industrial environment (Prasetya et al., 2025a; Sutopo, Setiadi, Nashir, et al., 2024). Skills such as leadership, critical thinking, and problem-solving competencies are key in cross-functional and multidisciplinary CAM projects (Harjanto, 2026). These findings have direct implications for vocational education policy in Indonesia, particularly the need to adjust the CAM curriculum to integrate the development of hard and soft skills in a balanced manner, strengthen industrial project-based learning, and enhance collaboration between vocational education units and industry partners. This policy is expected to produce graduates who are not only technically competent but also adaptive, collaborative, and ready to face the demands of the modern manufacturing industry.

CONCLUSIONS AND SUGGESTIONS

Conclusion

This study offers novelty by identifying and evaluating three Computer-Aided Manufacturing (CAM) learning models applied in vocational higher education, namely: (1) textbook-based CAM learning, (2) industry-based CAM learning, and (3) internet literacy-based CAM learning. These three models represent different approaches to equipping students with CAM competencies. Among the three, the industry-based learning model shows the highest level of relevance for preparing students to face the challenges of the world of work, as it reflects actual practices and competency requirements in the manufacturing industry. However, the effectiveness of this model will be optimal when it is systematically integrated into the development of soft skills, particularly leadership and collaboration, which are essential for implementing cross-functional and multidisciplinary CAM projects. Therefore, future CAM learning needs to balance mastery of technical skills with the development of soft skills that support critical thinking, problem-solving, and professional adaptability in a dynamic industrial environment.

Suggestion

This study remains limited to the institution's geographical scope and lacks quantitative data. Therefore, further research is recommended to test the effectiveness of the CAM learning model using a quantitative or mixed-methods approach and to develop similar models across different industrial and national contexts. Further research is expected to strengthen the empirical basis for developing industry-oriented, sustainable CAM learning.

REFERENCE

Abouelala, M., Janan, M. T., & Brandt-Pomares, P. (2015). Methodology of selecting CAM software package for education based on a questionnaire. *International Journal of Mechanical Engineering Education*, *43*(2), 77–93. https://doi.org/10.1177/0306419015588397

Adams, T., Koster, B., & Brok, P. den. (2022). Patterns in student teachers' learning processes and outcomes of classroom management during their internship. *Teaching and Teacher Education*, *120*, 103891. https://doi.org/10.1016/j.tate.2022.103891

Affaki, O. El, Benhadou, M., & Haddout, A. (2024). Lean Management, IATF Automotive Standard, Industry 4.0, and Operational Excellence: Correlation Analysis and Synergy Model Development. *TEM Journal*, *13*(4), 2884–2893. https://doi.org/10.18421/TEM134-24

Apri Nuryanto, Tri Adi Prasetya, & Chrisna Tri harjanto. (2024). *Soft skills pada pendidikan vokasional : panduan praktis untuk mengembangkan mahasiswa siap kerja*. UNY Press.

Bhalerao, Y., Davies, D., Karad, S., & Nagarkar, M. (2023). Effects of Globalization and Isomorphism on Higher Education Institutions in India – Pathways of Academic Autonomy. *Journal of Engineering Education Transformations*, *37*(1), 157–170. https://doi.org/10.16920/jeet/2023/v37i1/23141

Billett, S. (2011). *Vocational education: Purposes, traditions and prospects*. New York: Springer.

Boere, N. A., de Jong, B., Jansen in de Wal, J., & Cornelissen, F. (2023). Does training content matter? Differences between soft- and hard-skill trainings in transfer motivation. *Journal of Workplace Learning*, *35*(9), 274–290. https://doi.org/10.1108/JWL-03-2023-0046

Chiloane, G., de Jager, T., & Mokgosi, P. (2022). TVET Engineering Lecturers' Perceptions on the Application of Technology Tools in Teaching and Learning in South Africa. *The International Journal of Technologies in Learning*, *29*(2), 29–44. https://doi.org/10.18848/2327-0144/CGP/v29i02/29-44

Daduna, J. R. (2019). Disruptive effects on logistics processes by additive manufacturing. *IFAC-PapersOnLine*, *52*(13), 2770–2775. https://doi.org/10.1016/j.ifacol.2019.11.627

Djatmiko, R. D., Adhitama, R. K., & Prasetya, T. A. (2020). The analysis of machining job risk in vocational workshop. *Journal of Physics: Conference Series*, *1446*(1), 012026. https://doi.org/10.1088/1742-6596/1446/1/012026

Duplák, J., Dupláková, D., Yeromina, M., & Mikuláško, S. (2024). Analysis of Robotic Joints` Motion for Dental Handling Operations Using RoboDK Simulator. *TEM Journal*, *13*(4), 3009–3014. https://doi.org/10.18421/TEM134-35

Fjellström, M. (2014). Vocational education in practice: A study of work-based learning in a construction programme at a Swedish upper secondary school. *Empirical Research in Vocational Education and Training*, *6*(1), 1–20. https://doi.org/10.1186/1877-6345-6-2

Francisco John Mark, S., & Neri, J. J. (2023). Evaluating The Philippine TVET Competency Assessment and Certification System Using SERVQUAL Model. *Journal of Technical Education and Training*, *15*(3 Special Issue), 46–54. https://doi.org/10.30880/jtet.2023.15.03.005

Garira, E. (2020). Needs assessment for the development of educational interventions to improve quality of education: A case of Zimbabwean primary schools. *Social Sciences & Humanities Open*, *2*(1), 100020. https://doi.org/10.1016/j.ssaho.2020.100020

Gomez Zermeño, M. G., & Blanco Mejía, D. (2020). Development of Significant Learning through Scratch Programming Logic of Secondary School Students. *The International Journal of Technologies in Learning*, *27*(2), 21–36. https://doi.org/10.18848/2327-0144/CGP/v27i02/21-36

Hadi, M. Y. A., Hassan, R., Razzaq, A. R. A., & Mustafa, M. Z. (2015). Application of Thinking Skills in Career: A Survey on Technical and Vocational Education Training (TVET) Qualification Semi-professional Job Duties. *Procedia - Social and Behavioral Sciences*, *211*(September), 1163–1170. https://doi.org/10.1016/j.sbspro.2015.11.155

Harjanto, C. T. (2026). Development of a Team-Based Experimental Learning (TeBEL) Model to Enhance Higher-Order Thinking Skills in Industrial Product Problem-Solving Desarrollo de un modelo de aprendizaje experimental basado en el trabajo en equipo (TeBEL) para mejorar las h. *Salud, Ciencia y Tecnología*, *6*. https://doi.org/10.56294/saludcyt20262534

Heuser, P., Letmathe, P., & Vossen, T. (2024). Skill development in the field of scheduling: A structured literature review. *European Journal of Operational Research*, *April*. https://doi.org/10.1016/j.ejor.2024.04.005

Hopster, J. (2021). What are socially disruptive technologies? *Technology in Society*, *67*(April), 101750. https://doi.org/10.1016/j.techsoc.2021.101750

Kasali, R. (2017). *Millennials dan Disruption*. Rumah Perubahan.

Kavade, M. V. (2020). An effective use of visual aids for teaching computer aided manufacturing (CAM) laboratory – A case study. *Journal of Engineering Education Transformations*, *33*(Special Issue), 558–555. https://doi.org/10.16920/jeet/2020/v33i0/150115

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by industry 4.0. *Technology in Society*, *64*, 101454. https://doi.org/10.1016/j.techsoc.2020.101454

Li, X. (2018). Curriculum reform and practice of mechanical CAD/CAM technologys. *International Journal of Emerging Technologies in Learning*, *13*(8), 78–89. https://doi.org/10.3991/ijet.v13i08.9040

Mastercam. (2018). *Mastercam Basics Tutorial*. CNC Software Inc.

McGrath, S., Mulder, M., Papier, J., & Suart, R. (2019). Handbook of Vocational Education and Training. In S. McGrath, M. Mulder, J. Papier, & R. Suart (Eds.), *Handbook of Vocational Education and Training*. Springer Nature Switzerland. https://doi.org/10.1007/978-3-319-94532-3_72

McKinsey & Company. (2019). Automation and the Future of Work in Indonesia. *McKinsey & Company*, *September*, 21–28. https://www.mckinsey.com/~/media/McKinsey/Featured Insights/Asia Pacific/Automation and the future of work in Indonesia/Automation-and-the-future-of-work-in-Indonesia-vF.ashx

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook* (Second Edi). Sage Publication, Inc.

Mohajan, H. K. (2019). The First Industrial Revolution: Creation of a New Global Human Era. *Journal of Social Sciences and Humanities*, *5*(4), 377–387.

Mohamad, N., Affandi, H. M., Sohimi, N. E., Kamal, M. F. M., Herrera, L. M., Zulkifli, R. M., & Abas, N. H. (2023). Exploring TVET Institution Directors' Barriers in Managing Malaysian TVET Institutions-Industry Partnership. *Journal of Technical Education and Training*, *15*(1), 277–287. https://doi.org/10.30880/jtet.2023.15.01.024

Mourtzis, D., Panopoulos, N., & Angelopoulos, J. (2022). A hybrid teaching factory model towards personalized education 4.0. *International Journal of Computer Integrated Manufacturing*, *00*(00), 1–21. https://doi.org/10.1080/0951192X.2022.2145025

Ngatiman, S., Sulaiman, T., & Wong, K. Y. (2023). The Challenges of Implementing Industrial Revolution 4.0 Elements in TVET. *Journal of Technical Education and Training*, *15*(3 Special Issue), 169–181. https://doi.org/10.30880/jtet.2023.15.03.015

Nguyen, L. T., Kanjug, I., Lowatcharin, G., Manakul, T., Poonpon, K., Sarakorn, W., Somabut, A., Srisawasdi, N., Traiyarach, S., & Tuamsuk, K. (2022). How Teachers Manage Their Classroom in The Digital Learning Environment – Experiences from the University Smart Learning Project. *Heliyon*, *8*(September), e10817. https://doi.org/10.1016/j.heliyon.2022.e10817

Pinto, C. A. S., & Reis, A. da C. (2023). Characteristics of Education 4.0 and its Application in Industry 4.0. *Journal of Engineering Education Transformations*, *37*(1), 51–61. https://doi.org/10.16920/jeet/2023/v37i1/23131

Plaza, M., & Zebala, W. (2019). A decision model for investment analysis in CNC centers and CAM technology. *Computers & Industrial Engineering*, *131*, 565–577. https://doi.org/https://doi.org/10.1016/j.cie.2019.03.028

Prasetya, T. A., Harjanto, C. T., & Frayudha, A. D. (2021). The Effect of Students' Learning Activities and Creativity on The Learning Outcomes in The Aerodynamics. *Jurnal Dinamika Vokasional Teknik Mesin*, *6*(1), 69–76.

Prasetya, T. A., Munadi, S., Sukardi, T., & Setiyawan, A. (2025a). Developing Industry-Relevant Soft Skills Through Peer-Engaged Project Application Model (PEPA): A Vocational Education Perspective. *Journal of Applied Engineering and Technological Science, 7*(1), 296–305. https://doi.org/https://doi.org/10.37385/jaets.v7i1.7146

Prasetya, T. A., Munadi, S., Sukardi, T., & Setiyawan, A. (2025b). Essential Soft Skills for Engineering in Industry 4.0: A Systematic Literature Review. *International Journal of Engineering*

Education, *41*(5), 1376–1385. https://www.scopus.com/inward/record.uri?eid=2-s2.0-105016784210&partnerID=40&md5=9afec6f3e02254b302f68ea519c46604

Putra, A. B. N. R., Sumarli, Suhartadi, S., Kiong, T. T., & Rahmawati, A. D. (2023). Synchronisation Model of Campus-Industry Partnership Through Smart Expert System Hybrid Advisory for Industrial Internship Students and Teaching Assistance in the Era of Independent Learning. *Journal of Technical Education and Training*, *15*(3 Special Issue), 142–153. https://doi.org/10.30880/jtet.2023.15.03.013

Renta Davids, A. I., Van den Bossche, P., Gijbels, D., & Fandos Garrido, M. (2017). The Impact of Individual, Educational, and Workplace Factors on the Transfer of School-Based Learning into the Workplace. In *Vocations and Learning* (Vol. 10, Issue 3). Vocations and Learning. https://doi.org/10.1007/s12186-016-9168-1

Saari, A., Rasul, M. S., Yasin, R. M., Rauf, A. A., Hilmi, Z., Ashari, M., & Pranita, D. (2021). Skills Sets for Workforce in the 4th Industrial Revolution : Expectation from Authorities and Industrial Players. *Journal of Technical Education and Training*, *2*, 1–9.

Schmid, J., & Pichler, R. (2020). Seamless data integration in the CAM-NC process chain in a learning factory. *Procedia Manufacturing*, *45*, 31–36. https://doi.org/10.1016/j.promfg.2020.04.038

Ślusarczyk, B. (2018). Industry 4.0 – Are we ready? *Polish Journal of Management Studies*, *17*(1), 232–248. https://doi.org/10.17512/pjms.2018.17.1.19

Sutopo, S., Setiadi, B. R., Prasetya, T. A., Harjanto, C. T., Sasongko, B. T., & Saputri, V. H. L. (2024). Peer-Project-Based Learning in CNC Simulation Programming Courses. *TEM Journal*, *13*(4), 3079–3085. https://doi.org/10.18421/TEM134-42

Sutopo, Setiadi, B. R., Nashir, I. M., Lutviana, V. H., Saputri, Arifin, A., Prasetya, T. A., Harjanto, C. T., Tri, B., & 1, S. (2024). Enhancing students ' self-efficacy and creativity in computer numerical control machining through peer-assisted project-based learning. *Jurnal Pendidikan Vokasi*, *14*(2), 232–243.

Teichmann, M., Ullrich, A., & Gronau, N. (2019). Subject-oriented learning - A new perspective for vocational training in learning factories. *Procedia Manufacturing*, *31*, 72–78. https://doi.org/10.1016/j.promfg.2019.03.012

Thong, H. Van, & Ngoc, L. T. (2023). Digital Transformation in University Education at Dong Thap University: An Overview. *Journal of Engineering Education Transformations*, *37*(2), 72–81. https://doi.org/10.16920/jeet/2023/v37i2/23151

Tukundane, C., Minnaert, A., Zeelen, J., & Kanyandago, P. (2015). Building vocational skills for marginalised youth in Uganda: A SWOT analysis of four training programmes. *International Journal of Educational Development*, *40*(February), 134–144. https://doi.org/10.1016/j.ijedudev.2014.10.007

Venatius, A. S., Musta'amal, A. H., & Ekwok, O. B. (2023). Developing Framework for Teaching Technical Skills to Metalwork Undergraduates in Vocational-Based Education in Nigeria. *Journal of Technical Education and Training*, *15*(2), 11–20.

https://doi.org/10.30880/jtet.2023.15.02.002

Volkmann, M., Legler, T., Wagner, A., & Ruskowski, M. (2020). A CAD feature-based manufacturing approach with OPC UA skills. *Procedia Manufacturing*, *51*, 416–423. https://doi.org/10.1016/j.promfg.2020.10.059