Proceedings of the 4th International Conference on Innovation in Engineering and Vocational Education (ICIEVE 2021)

Vocational High School Technical Skills Facing the Industrial Era 4.0

Ridwan Yanuardi*, Isma Widiaty, Mumu Komaro
Universitas Pendidikan Indonesia
Bandung, Indonesia
*ridwanyanuardi@upi.edu

***Abstract*—Industry 4.0, marked by *cyber-physical* collaboration and the manufacturing industry. The underlying technological conditions of I4.0 require automation, digitization and interconnection. The use of technology can increase the competitiveness of the industry, application of technology also requires a new set of knowledge and skills. In operating machining engineering technology in the Industry 4.0 era, it's requires a workforce who can combine classic machines and Information Technology (IT). Vocational High Schools whose purpose is to provide manpower, need to pay attention to the technical competencies required for the presence of this technology, so that there is a match between the competencies needed by the industry and the competencies taught in schools. To describe what technical competences students need to have in Mechanical Engineering Vocational High School, a *literature review* was conducted, using the *Pagani*, *Kovaleski*, and *Resende* protocols. 27 articles published in international journals were selected for further study. The results of this study provide insight and input to vocational education managers, regarding various information on technological advances in the Industry 4.0 era and what technical competencies are needed. So that it can be input for curriculum developers in determining what competencies need to be present in the Mechanical Engineering Vocational School curriculum**

Keywords— technical skill, vocational, industry 4.0

I. Introduction

Indonesia's commitment to accelerating the implementation of Industry 4.0 is marked by the launch of a *road map* titled "*Making Indonesia 4.0*" in 2018. Indonesia have 10 national priorities in the "*Making Indonesia 4.0*" initiative. One of them is improving the quality of Human Resources, through aligning the national education curriculum with future industrial needs [1]. In accordance with the context of vocational education whose graduates are prepared for industry [2]. It is necessary to improve the quality of human resources in order to deal with the application of new technologies in the implementation of industry 4.0, network technology for highly automated production systems [3]. The application of new technologies requires the competence of workers who can combine basic interdisciplinary and multidisciplinary knowledge, to be ready to work rationally in complex industrial situations [4-6]. Able to operate smart factories in the Implementation of Industry 4.0 in the mechanical engineering industry sector, a workforce that has professional competence is needed, mastering a combination of classical mechanical engineering and Information Technology (IT) [7]. An identification of the changing competency demands for mid-skill workers in manufacturing is required [3]. The industrial revolution 4.0, with its intrinsic digital and innovative features, demands new technical expertise. Therefore, the following questions arise: What technical skills need to be mastered in the face of technological developments in the industrial era 4.0 in the field of machining engineering?

In order to answer this question, an extensive literature search identified the currently developing machining engineering technologies used in the industry and what technical expertise is required to operate these technologies. The results of the research are expected to be able to provide an overview of the priority competencies needed in the industrial era 4.0, to be used as material for evaluating the relevance of the curriculum in the future.

II. Research Methods

This article aims to obtain information related to the technical competencies that Mechanical Engineering Vocational High School students need to have in dealing with the machining field technology that is developing in the industry 4.0 era. Taking into account the research objectives, six keyword groups were compiled.

1. “Industry 4.0" and "Vocational School"
2. "Industry 4.0" and "Machining"
3. Industry 4.0 and Competence or "Ability" or "Skill"
4. "Machining" and "Competence" or "Ability" or "Skill"
5. "Vocational School" and "Competence" or "Ability" or "Skill"
6. "Vocational School" and "Machining"

The search was carried out on three journal databases, namely *Science Direct*, *Taylor and Francis* and IJRVET, searching for articles published in the period 2011 to 2021. The selected articles were collected using the *Mendeley* reference manager. A total of 2891 articles were collected which were then deleted as many as 5 articles were duplicated, then the rest of the articles were selected based on the title and abstract, leaving 247 articles. The remaining articles were selected based on inclusion and exclusion criteria, leaving 84 articles. After calculating the InOrdinatio value. Articles in accordance with the inclusion criteria and have a positive InOrdinatio value, with a value of α = 8. There are 27 articles left to carry out the data extraction stage (see table 1).

TABLE I. INCLUSION AND EXCLUSION CRITERIA

Inclusion criteria	**Exclusion criteria**
English language	Other than English
Year of publication in the last 10 years (2011 to 2021)	Published before 2011
Empirical research published through international journals and international conferences	*Book chapters*, theses, short reports, non- *peer-reviewed* studies, and non-empirical studies or articles that provide little empirical evidence.
Related to mechanical engineering technology in the context of Industry 4.0	Industrial Technology 4.0 beyond machining engineering

III. RESULTS AND DISCUSSION

The focus of Industry 4.0, lies in digitalization and cyber-physical production systems. Industry 4.0 is more than just technology, human resources are becoming more important in the industrial era 4.0 [8]. The technological conditions underlying I4.0 require automation, digitization and interconnection [9]. Articles discussing industrial machining engineering technology 4.0 are grouped first by publisher, Figure 1. Procedia manufacturing and Procedia CIRP contain more articles discussing the use of technology in industry 4.0, each accounting for 18.52% of the total articles studied.

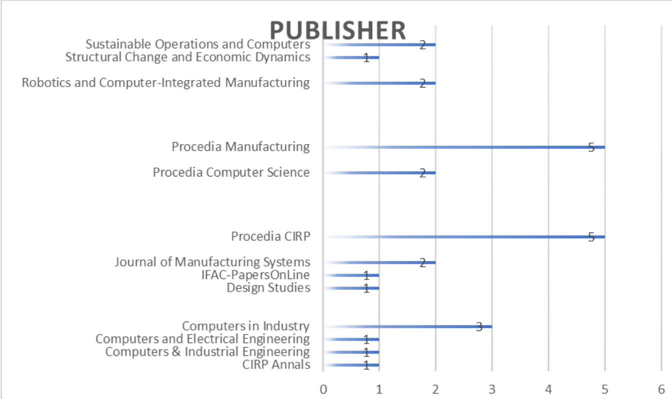

Fig. 1. Article publishers.

TABLE II. TECHNOLOGIES FOUND IN ARTICLES

Technology covered	**Number of Articles**
CAD/CAM	4
Virtual Reality or Augmented Reality	8
Cyber-Physical Machine Tools	8
3D printing or additive manufacturing	4
Maintenance	3
Amount	27

Grouping articles with the classification of technologies discussed is shown in Table 2. In this way researchers can focus more on analyzing the content of each technology discussed in the article. To study the technology that developed in the Industry 4.0 era and the technical competencies required through literature, several cases were identified. Of these, 27 articles present cases of technological developments, then analyze capabilities related to the use of these technologies, as shown in Table 3.

TABLE III. INTERDISCIPLINARY AND MULTI-DISCIPLINE ABILITY

Context	Technology	Interdisciplinary Ability	Multidisciplinary Ability	Reference
Product development	CAD CAM	Technical Drawing Ability Ability to create 3D models with Computer Aided Design Application Simulating manufacturing processes with the CAM app Virtually visualize using VR and AR apps	Save and open data in various formats. Leveraging the Cloud platform to support file exchange and storage	(Cirillo et al. [9]) (Jimeno-Morenilla et al. [10]) (Schallock et al. [8]) (Promyoo et al. [11])
	Virtual Reality (VR), Augmented Reality (AR)			(Nunes et al. [12]) (Shen et al. [13]) (Schumann et al. [14]) (Mourtzis et al. [15]) (Marino et al. [16]) (Mourtzis et al. [17])
Manufacturing Process	Cyber-Physical Machine Tools	Enlarge the operator's scope of work by loading programs, programming CNC, and monitoring multiple machines at the same time Changing programs, encoding and storing in memory	Store and manage data effectively IoT Cloud Computing Digital data transfer Remote access	(Krugh & Mears [18]) (Romero et al. [19]) (Ure & Skauge [20]) (Liu, Vengayil, et al. [21]) (Zhu & Xu [22]) (Liu, Xu, et al. [23]) (Deng et al. [24])

Table 3 cont.

	3D printing or additive manufacturing	Ability to create 3D models with the Computer Aided Design application Using 3D printing tools		(Cirillo et al. [9]) (Jimeno-Morenilla et al. [10]) (Schallock et al. [8]) (Franco et al. [25]) (Jandyal et al. [26]).
Maintenance	Digital Maintenance	Maintain basic condition (cleaning, lubricating, checking bolt tightness) Maintain operating conditions (proper operation and visual inspection) Finding damage, especially through visual inspection and early identification of signs of abnormality during surgery. Improve skills such as equipment operation, setup and adjustment, and visual inspection.	It requires the ability to interact with computers, access digital databases, and analyze Big Data to be able to predict events	(Reis & Campos [27]) (Roy et al. [28]) (Gallo & Santolamazza [29])

A. Product Development in Industry 4.0 Era

Digital product development has been proposed to overcome the challenges faced when developing increasingly complex modern products [11]. Product design is a complex and dynamic process, which can lead to poor product design, increased costs, and delays in delivering the design results. Industry 4.0 provides a new set of opportunities with the emergence of new breakthroughs and cutting - edge technologies that represent great potential for design and prototyping. The use of digital product modeling and simulation tools is more efficient when exploring new products or redesigning products to improve performance [15].

Product geometries are extracted directly from CAD data, offering a digital connection between design and prototyping [30]. 3-D Computer Aided Design (CAD) model of the product is created and simulated using several computer-aided-engineering techniques. CAD data supports the visualization of prototypes in virtual form. The manufacturing process is then created and simulated using computer aids (CAM) [11]. Need to have ability to use data in various formats, by utilizing the cloud platform it's support collaboration between fellow designers and users [17]. The emergence of Virtual Reality (VR) and Augmented Reality (AR) technologies has prompted the development of more intuitive interfaces for product design and modeling [13]. Prototyping with AR has the potential to reduce design and redesign time in early product development [14]. Through Augmented Reality, the design can be visualized in a 1:1 scale so that the design can be reviewed at a more realistic scale and can easily detect flaws in the design. With virtual and augmented prototype technology helps unify the design and visualization that can provide a realistic representation of the product, so as to improve the customer experience and perception [12]. Where with traditional technology this can only be met by making physical prototypes, which require more resources at the time of manufacture. Design digitization can examine product designs from different perspectives, enabling the detection of defects in the initial design. The results of the study [15] which discuss the use of AR in teaching factory learning activities, can reduce 12% of errors in early disan activities and students can do assembling 10% faster. By using AR, Teaching Factory participants have real-scale insight from the designed product and can interact with it.

B. Manufacturing Process in Industry 4.0 Era

Automation systems in industry 4.0, requiring digital skills such as information processing, communication, collaboration, critical thinking, creativity, and problem solving are increasingly demanded in the labor market [31]. Human operators need to know the process that is being automated, so that, at the same time, this knowledge can be continuously updated and the process improved as digital technology develops [19].

1) Cyber physical machine tool: As the main component of any manufacturing systems, machine tools have evolved from a manually operated machine into equipment numerically controlled machine Computerized Numeric Control (CNC). Machine Tool 4.0 enables cyber Physical Machine Tool (CPMT) CPMT is the integration of machine tools, machining processes, computing and networking, in which the embedded computing monitor and control the machining process, with a feedback loop in which the machining process can affect the calculation and vice versa [32]. CPMT consists of four main components: (1) CNC Machine Tool, (2) Data Acquisition Device, (3) Machine Tool Cyber Twin, and (4) Human-Machine Interface Smart (HMI). MT 4.0 defines a new generation of machine tools are smarter, better connected, be widely accessible, more adaptable, and more autonomous [32]. Today's students will work and overcome the network increasingly globalized world, automated, virtualized, compete for jobs in a global market [33]. Technology updates through (CNC) require the operator competency, so that it can intervene to change the program, encode and store in system memory [9]. Make the machine more flexible when operating the production of small batches to a specific customer. Enlarge the scope of the task of the operator to load a program, program, and monitor multiple machines at the same time [20]. CNC related competency such as in research [20] it is important to be improved, especially by establishing training centers CNC connected to the high school.

2) Additive manufacturing: In addition to the development of CNC machining technology, additive manufacturing (AM) is regarded as 4.0 technologies emerging industry with the potential to transform operations and supply chain management significantly. Advance design process, and less production time and lower costs associated with inventory, storage, packaging, and transportation [25]. Additive manufacturing 3D printing refers to physical objects. They can also be used as a digital source, digital design 3D CAD [29]. AM technology with the use of 3D printing originally intended to create a prototype 3D [10]. Along with the development of a 3D printer type and technological developments AM, 3D printing is capable of producing tooling, spare parts, or the final product [25]. To begin the process, a CAD file created in the system and this file is converted into STL file types. The file type STL provides geometrical data required by the 3D printer to create objects [26]. 3D Printing as digital data transfer, remote access, need minimum for human intervention, the ability to develop complex geometry and material intelligent, less wastage, post-process requirements that fewer would help achieve the goal of Industry 4.0 [26].

C. Maintenance

The technology developed in Industry 4.0 and in particular the experience gained through the use of these tools should of course be utilized to improve basic maintenance concepts and management. Monitoring the condition of assets and taking maintenance actions when necessary can avoid damage and possible secondary damage to equipment. That the duties of the operator in maintenance in the article [34] are:

- Maintain basic condition (cleaning, lubricating, checking bolt tightness)
- Maintain operating conditions (proper operation and visual inspection)
- Find damage, primarily through visual inspection and early identification of signs of abnormality during surgery.
- Improve skills such as equipment operation, setup and adjustment, and visual inspection.

4.0 maintenance operator should be able to find information that is relevant in predicting the occurrence by analyzing Big Data appropriately. Required ability to interact with a computer, a digital database access, and analysis of Big Data, [29]. Digitization in the maintenance and upkeep in the Industry 4.0, among others related to predictive maintenance, further combining basic maintenance capabilities and the ability to understand and utilize the data [28].

IV. CONCLUSION

Today's students will work and overcome the network increasingly globalized world, automated, virtualized, compete for jobs in a global market [35]. By mastering the technology developed in the industrial era 4.0 expected students to integrate their knowledge in solving real-world problems. Have knowledge of cutting-edge technology, which involves understanding the processes and skills using media. Presenting the operator 4.0, intelligent and skilled in doing the work is aided by machines as needed [29]. These findings can be used as input for curriculum developers in determining what competencies need to exist in vocational curriculum mechanical machining, in improving the quality of human resources. In order to face the impact of the implementation of new technologies in the industry era 4.0. Although this study describes the interdisciplinary and multidisciplinary technical ability, but the study still has shortcomings that can be improved further research, for example, about the degree to which or how deep the technical ability of vocational students should possess machining techniques.

REFERENCES

[1] Ministry of Industry. (2018). Making Indonesia 4.0 Make National Industry Globally Competitive in the Digital Age . Ministry of Industry. https://kemenperin.go.id/article/19046/Making-Indonesia-4.0-Bikin-Industri-Nasional-Berdaya-Saing-Global-di-Era-Digital

[2] Widiaty, I. (2019). Relevance of Vocational High School Curriculum with the Industrial Needs of Making Batik Competences. Innovation of Vocational Technology Education , 15 (2), 76. https://doi.org/10.17509/invotec.v15i2.19635

[3] Spöttl, G., & Windelband, L. (2021). The 4th industrial revolution–its impact on vocational skills. Journal of Education and Work , 34 (1), 29–52. https://doi.org/10.1080/1639080.2020.1858230

[4] Enke, J., Glass, R., Kreß, A., Hambach, J., Tisch, M., & Metternich, J. (2018). Industrie 4.0 - Competencies for a modern production system: A curriculum for Learning Factories. Procedia Manufacturing , 23 (2017), 267–272. https://doi.org/10.1016/j.promfg.2018.04.028

[5] Lytvyn, A., Lytvyn, V., Rudenko, L., Pelekh, Y., Didenko, O., Muszkieta, R., & ukow, W. (2020). Informatization of technical vocational schools: Theoretical foundations and practical approaches. Education and Information Technologies , 25 (1), 583–609. https://doi.org/10.1007/s10639-019-09966-4

[6] Madsen, ES, Bilberg, A., & Grube Hansen, D. (2016). Industry 4.0 and digitalization call for vocational skills, applied industrial engineering, and less for pure academics. 5th World Conference on Production and Operations Management, 2016 , 0–10.

[7] Fernández-Miranda, SS, Marcos, M., Peralta, ME, & Aguayo, F. (2017). The challenge of integrating Industry 4.0 in the degree of Mechanical Engineering. Procedia Manufacturing , 13 , 1229–1236. https://doi.org/10.1016/j.promfg.2017.09.039

[8] Schallock, B., Rybski, C., Jochem, R., & Kohl, H. (2018). Learning Factory for Industry 4.0 to provide future skills beyond technical training. Procedia Manufacturing , 23 (2017), 27–32. https://doi.org/https://doi.org/10.1016/j.promfg.2018.03.156

[9] Cirillo, V., Rinaldini, M., Staccioli, J., & Virgillito, ME (2021). Technology vs. workers: the case of Italy's Industry 4.0 factories. Structural Change and Economic Dynamics , 56 , 166–183. https://doi.org/10.1016/j.strueco.2020.09.007

[10] Jimeno-Morenilla, A., Azariadis, P., Molina-Carmona, R., Kyratzi, S., & Moulianitis, V. (2021). Technology enablers for the implementation of Industry 4.0 to traditional manufacturing sectors: A review. Computers in Industry , 125 , 103390. https://doi.org/https://doi.org/10.1016/j.compind.2020.103390

[11] Promyoo, R., Alai, S., & El-Mounayri, H. (2019). Innovative Digital Manufacturing Curriculum for Industry 4.0. Procedia Manufacturing , 34 , 1043–1050. https://doi.org/https://doi.org/10.1016/j.promfg.2019.06.092

[12] Nunes, ML, Pereira, air conditioning, and Alves, AC (2017). Smart products development approaches for Industry 4.0. Procedia Manufacturing , 13 , 1215-1222. https://doi.org/https://doi.org/10.1016/j.promfg.2017.09.035

[13] Shen, Y., Ong, SK, & Nee, AYC (2010). Augmented reality for collaborative product design and development. Design Studies , 31 (2), 118–145. https://doi.org/10.1016/j.destud.2009.11.001

[14] Schumann, M., Fuchs, C., Kollatsch, C., & Klimant, P. (2020). Evaluation of augmented reality supported approaches for product design and production processes. Procedia CIRP , 97 , 160–165. https://doi.org/10.1016/j.procir.2020.05.219

[15] Mourtzis, D., Zogopoulos, V., & Vlachou, E. (2018). Augmented Reality supported towards Industry 4.0 Product Design: A Teaching Factory paradigm. Procedia Manufacturing , 23 (2017), 207-212. https://doi.org/10.1016/j.promfg.2018.04.018

[16] Marino, E., Barbieri, L., Colacino, B., Fleri, AK, & Bruno, F. (2021). An Augmented Reality inspection tool to support workers in Industry 4.0 environments. Computers in Industry , 127 , 103412. https://doi.org/10.1016/j.compind.2021.103412

[17] Mourtzis, D., Siatras, V., Angelopoulos, J., & Panopoulos, N. (2020). ScienceDirect ScienceDirect ScienceDirect An Augmented Reality Collaborative Product Design Cloud-Based An Augmented Reality Collaborative Design Platform in the Context of Product Learning Factory Platform in the Context. Procedia Manufacturing , 45 , 546-551. https://doi.org/10.1016/j.promfg.2020.04.076

[18] Krugh, M., & Mears, L. (2021). Pervasive environmental sensing for Industry 4.0 as an educational tool. Procedia Manufacturing , 53 , 790–801. https://doi.org/https://doi.org/10.1016/j.promfg.2021.06.086

[19] Romero, D., Gaiardelli, P., Powell, D., Wuest, T., & Thürer, M. (2019). Rethinking Jidoka under Automation Systems & Learning Perspectives in the Digital Lean Manufacturing World. IFAC-PapersOnLine , 52 (13), 899-903. https://doi.org/https://doi.org/10.1016/j.ifacol.2019.11.309

[20] Ure, OB, & Skauge, T. (2019). Skills and employment under automation: Active adaptation at the local level. International Journal for Research in Vocational Education and Training , 6 (3), 203–223. https://doi.org/10.13152/IJRVET.6.3.1

[21] Liu, C., Vengayil, H., Zhong, RY, & Xu, X. (2018). A systematic development method for cyber-physical machine tools. Journal of Manufacturing Systems , 48 , 13–24. https://doi.org/https://doi.org/10.1016/j.jmsy.2018.02.001

[22] Zhu, Z., & Xu, X. (2020). User-centered information provision of cyber-physical machine tools. Procedia CIRP , 93 , 1546–1551. https://doi.org/10.1016/j.procir.2020.04.091.

[23] Liu, C., Xu, X., Peng, Q., & Zhou, Z. (2018). MTConnect-based Cyber-Physical Machine Tool: a case study. Procedia CIRP , 72 , 492–497. https://doi.org/https://doi.org/10.1016/j.procir.2018.03.059

[24] Deng, C., Guo, R., Zheng, P., Liu, C., Xu, X., & Zhong, RY (2018). From Open CNC Systems to Cyber-Physical Machine Tools: A Case Study. Procedia CIRP , 72 , 1270–1276. https://doi.org/10.1016/j.procir.2018.03.110

[25] Franco, D., Miller Devós Ganga, G., de Santa-Eulalia, LA, & Godinho Filho, M. (2020). Consolidated and inconclusive effects of additive manufacturing adoption: A systematic literature review. Computers & Industrial Engineering , 148 , 106713. https://doi.org/https://doi.org/10.1016/j.cie.2020.106713

[26] Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A., & Ul Haq, MI (2022). 3D printing - A review of processes, materials and applications in industry 4.0. Sustainable Operations and Computers , 3 (September 2021), 33-42. https://doi.org/10.1016/j.susoc.2021.09.004

[27] Reis, TASS, & Campos, FC (2020). Industry 4.0 influences on maintenance operation: a bibliometric analysis. IFAC-PapersOnLine , 53 (2), 10633–10638. https://doi.org/https://doi.org/10.1016/j.ifacol.2020.12.2823

[28] Roy, R., Stark, R., Tracht, K., Takata, S., & Mori, M. (2016). Continuous maintenance and the future – Foundations and technological challenges. CIRP Annals , 65 (2), 667–688. https://doi.org/https://doi.org/10.1016/j.cirp.2016.06.006

[29] Gallo, T., & Santolamazza, A. (2021). Industry 4.0 and human factor: How is technology changing the role of the maintenance operator? Procedia Computer Science , 180 (2019), 388–393. https://doi.org/https://doi.org/10.1016/j.procs.2021.01.364

[30] Mekacher, DL (2019). Augmented Reality (Ar) and Virtual Reality (Vr): the Future of Interactive Vocational Education and Training for People With Handicap. PUPIL: International Journal of Teaching, Education and Learning , 3 (1), 118–129. https://doi.org/10.20319/pijtel.2019.31.118129

[31] Novakova, L. (2020). The impact of technology development on the future of the labor market in the Slovak Republic. Technology in Society , 62 , 101256. https://doi.org/https://doi.org/10.1016/j.techsoc.2020.101256

[32] Liu, C., & Xu, X. (2017). Cyber-physical Machine Tool – The Era of Machine Tool 4.0. Procedia CIRP , 63 , 70–75. https://doi.org/https://doi.org/10.1016/j.procir.2017.03.078

[33] Yoshino, RT, Pinto, MMA, Pontes, J., Treinta, FT, Justo, JF, & Santos, MMD (2020). Educational Test Bed 4.0: a teaching tool for Industry 4.0. European Journal of Engineering Education , 45 (6), 1002–1023. https://doi.org/10.1080/03043797.2020.1832966

[34] Bengtsson, M., & Lundström, G. (2018). On the importance of combining “the new” with “the old” - One important prerequisite for maintenance in Industry 4.0. Procedia Manufacturing , 25 , 118–125. https://doi.org/10.1016/j.promfg.2018.06.065

[35] Kuijpers, M., Meijers, F., & Gundy, C. (2011). The relationship between learning environment and career competencies of students in vocational education. Journal of Vocational Behavior , 78 (1), 21–30. https://doi.org/https://doi.org/10.1016/j.jvb.2010.05.005