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Evaluating Readiness of Vocational Electronics Laboratories for Industry 4.0: Analysis of Facilities, Systems, and Human Resources

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Abstract

This study aims to evaluate the readiness of electronics engineering laboratories in Vocational High Schools (SMK) of Sidoarjo Regency in facing the demands of the Industrial Revolution 4.0. The evaluation focused on four main aspects: laboratory planning, equipment availability, maintenance and management systems, and the competence of laboratory personnel. This study used a descriptive method with a mixed-method approach, involving six vocational schools and respondents from productive teachers, vice principals in the field of infrastructure, and laboratories. Data was obtained through questionnaires, observations, documentation, and in-depth interviews, then analyzed descriptively. The results showed that the average equipment readiness rate was in the "underprepared" category (54.1%), while most schools did not have certified laboratories. Laboratory management is generally still partial and is not systematic, although the usefulness of the laboratory is highly related on by teachers with an average score of 54.4 out of 64. These findings indicated a gap between the availability of facilities, human resource competencies, and the demands of industry-based vocational learning 4.0. The limitations of this study lie in the limited scope of the area and it has not measured the direct impact on student learning outcomes. The practical implications of this study included the importance of strengthening collaboration among schools, industry, and the government in laboratory planning, improving practice facilities, and training and certification of laboratory personnel. Socially, laboratory modernization is an important foundation in producing adaptive and competitive vocational graduates. This study makes an original contribution to mapping the systemic readiness of vocational laboratories in Indonesia.

Keywords: Laboratory evaluation, industry 4.0, vocational education, vocational schools, electronics engineering.

1. Introduction

The rapid development of Information and Communication Technology (ICT) has become the main driver of the Industrial Revolution 4.0, characterized by the integration of cyber-physical systems, the Internet of Things (IoT), and artificial intelligence. This transformation is changing industrial processes from manual systems to interconnected, automation-based, and data-driven decision-making digital systems [1], [2]. The impact of this change is not only felt by the industrial sector but also demands a fundamental transformation of the education system, especially vocational education. The world of work is looking for professionals who are not only proficient in technical skills but also able

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to adapt to disruptive technologies. Therefore, the readiness of the vocational education system is crucial in facing the industrial revolution, which is increasingly complex and rapidly changing.

As a developing country with a large working-age population, Indonesia faces significant challenges in preparing a competent workforce that meets evolving labor market demands. The government, through the Coordinating Ministry for Human Development and Culture, emphasizes the need for human resources who are professional and adaptable to the complexities of technology-based work [3]. Despite these policy directions, several reports consistently highlight the persistence of a digital talent gap, reflected in the limited number of skilled workers in high-tech fields [4]. The Ministry of Industry has promoted the strengthening of competency-based vocational education to address this mismatch [5], however, the gap between policy expectations and actual workforce readiness remains substantial. At the global level, the World Economic Forum projects that while 85 million jobs may be displaced by automation, 97 million new jobs will be created, requiring advanced digital and human-centered skills [6]. These dynamics underscore the urgency for vocational education, particularly at the vocational high school level, not only to enhance curricula, facilities, and management systems, but also to systematically align graduate competencies with the rapidly changing needs of the digital economy.

This condition positions vocational high schools (SMK) as strategically important in preparing graduates who are both work-ready and adaptive to technological changes in industry. Vocational education is designed to produce competent human resources that can respond to labor market needs, as mandated by Presidential Regulation No. 68 of 2022 on the Revitalization of Vocational Education and Training. One of the key indicators of SMK readiness is the availability of practice laboratories that are relevant, functional, and based on up-to-date technologies. At the national level, SMK graduates contribute the highest proportion of unemployment, reaching 9.31% of the total unemployed workforce [7]. Meanwhile, Sidoarjo Regency recognized as the most densely industrialized area in East Java with more than 900 manufacturing companies [8], paradoxically records an open unemployment rate of 8.05% [9], the highest among all districts and municipalities in the province. This paradox indicates that despite being located at the center of industrial activities, SMK graduates in Sidoarjo, as in many other regions, have yet to adequately meet the demands of the labor market, particularly in technology-driven sectors.

Laboratories serve not only as testing facilities but also as platforms for strengthening students' technical competencies and fostering innovation. However, several studies highlight persistent challenges in the readiness of vocational laboratories. For instance, Computer and Network Engineering (TKJ) laboratories in public vocational high schools are generally more prepared, whereas private schools still face considerable shortcomings [10]. Other studies report that the readiness of technology-based science laboratories remains below 50%, underscoring the importance of developing virtual laboratories [11]. The limited number of certified laboratories has also been noted [12] as well as the inadequate infrastructure of automotive workshops despite having established management systems [13]. These findings point to structural problems concerning facilities, maintenance, and human resource capacity within vocational laboratories. Nevertheless, most existing research has concentrated on fields such as automotive and science, leaving electronics engineering relatively underexplored. To date, no comprehensive study has evaluated the readiness of electronics engineering laboratories in vocational education, particularly regarding facilities, management systems, and human resource competencies in responding to the transformation demands of Industry 4.0.

This study evaluates the readiness of electronics engineering laboratories in vocational high schools (SMK) in Sidoarjo Regency to face the Industry 4.0 era. The evaluation encompasses five key aspects: laboratory planning, equipment availability, management and maintenance systems, laboratory usability, and the competence of laboratory personnel. By combining quantitative and qualitative data, the study provides a comprehensive picture of current laboratory conditions. Beyond addressing the research gap, the findings contribute empirically to strengthening vocational education in Indonesia by informing policymakers on improving facilities and developing professional laboratory personnel aligned with digital industry needs.

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2. Method

2.1 Research Design

This study used a descriptive approach with a mixed method to evaluate the readiness of vocational electronics engineering laboratories in supporting industry-based vocational learning 4.0. This study employed a convergent parallel mixed methods design, in which quantitative and qualitative data are collected simultaneously, analyzed separately, and then integrated to provide a comprehensive understanding of the readiness of electronics engineering laboratories [14]. Quantitative data were obtained through checklists and closed-ended questionnaires, while qualitative data were gathered via interviews and open-ended questionnaires. This approach allowed the findings from both types of data to complement each other, enhancing the overall validity and depth of the study.

2.2 Research Setting and Participants

This study was conducted in Sidoarjo Regency by involving the entire population of vocational high schools offering the Electronics Engineering program, namely SMKN 1 Sidoarjo, SMKN 1 Jabon, SMK YPM 8 Sidoarjo, SMK Antartika 2 Sidoarjo, SMK YPM 4 Taman, and SMK Krian 2 Sidoarjo. A total sampling approach was applied [15], including all key personnel from these schools as participants. Participants comprised Deputy Principals of Infrastructure (planning aspects), Productive Teachers (laboratory usability), and Laboratory Personnel (competency and management aspects) (Table 1). Although the total number of participants is relatively small, it represents the entire population of relevant staff, providing a comprehensive perspective on laboratory readiness.

Table 1. Number of Participants per School

School	Deputy Principals (Infrastructure)	Productive Teachers	Laboratories
SMKN 1 Sidoarjo	1	4	1
SMKN 1 Jabon	1	3	1
SMK YPM 8 Sidoarjo	1	2	1
SMK Antartika 2 Sidoarjo	1	2	1
SMK YPM 4 Taman	1	1	1
SMK Krian 2 Sidoarjo	1	3	1
Total	6	15	6

2.3 Instruments

Data was collected through questionnaires, observations, documentation, and interviews. The aspects analyzed included planning, equipment availability, management and maintenance systems, laboratory usability, and the competence of laboratory personnel. The instruments are prepared based on Regulation of the Minister of Education and Culture Number 34 of 2018 and vocational laboratory norms for the competencies of audio video engineering, industrial electronics, and mechatronics.

Table 2. Instruments

Aspects	Instruments	Subjects
Planning	Interview	Deputy Principals (Infrastructure)
Equipment avaibility	Checklist Questionnaire	Researcher (Observation)
Maintenance and management	Interview	Laboratories

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Laboratory usability	Close-ended Questionnaire	Productive Teachers
Competency of laboratory personnel	Open-ended Questionnaire	Laboratories

All instruments underwent content validation by two experts in education, technology, and vocational training, who confirmed that the instruments were suitable for use without revision in terms of content and statement construction.

Construct validity and reliability testing were applied only to the laboratory usability questionnaire, as it is the only instrument analyzed with statistical techniques. The checklist for equipment availability was analyzed quantitatively, but only in aggregate form, comparing the total actual score with the ideal score to determine readiness levels. Other instruments, including interviews and open-ended questionnaires, are qualitative in nature, and their validity is ensured through content validation and method triangulation.

A pilot test of the laboratory usability questionnaire was conducted with 30 productive teachers. The sample consisted of 30 respondents from 12 vocational high schools in East Java, including Surabaya, Malang, Pasuruan, Kediri, Ponorogo, Gresik, and Mojokerto. This coverage reflected the diversity of both public and private schools across urban and semi-urban areas.

Construct validity was assessed using Exploratory Factor Analysis (EFA) on 16 items rated on a 4-point Likert scale. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) value was 0.561 and Bartlett's Test of Sphericity was significant ($\chi^2 = 238$, df = 120, $p < .001$), indicating sampling adequacy [16]. Three factors with eigenvalues greater than 1 were extracted (see Figure 1), accounting for 48.7% of the total variance. Model fit indices showed that the chi-square criterion was met ($\chi^2 = 92.4$, df = 75, $p = 0.085$), whereas RMSEA (0.081) did not meet the acceptable threshold (< 0.08). Reliability analysis indicated good internal consistency (Cronbach's $\alpha = 0.817$) [16]. Overall, the instrument demonstrated acceptable validity and reliability for further use.

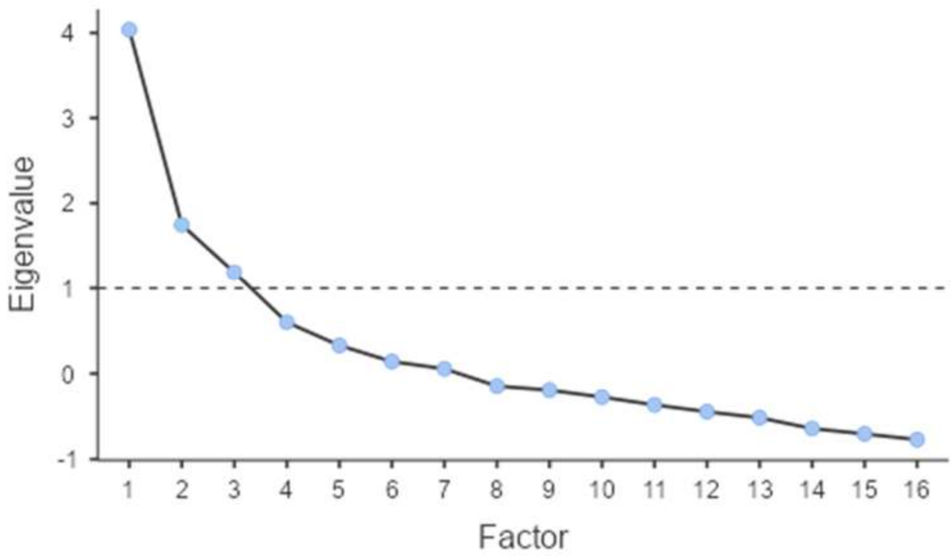

Figure. 1 Scree Plot

Reliability testing was conducted separately for each factor. Factor 1 demonstrated good internal consistency with a Cronbach's alpha of 0.771, indicating that its items reliably measured the intended construct. Factor 2 showed moderate reliability ($\alpha = 0.631$), which is acceptable but suggests that further refinement or the addition of items may be needed to strengthen the scale. In contrast, Factor 3 exhibited poor reliability ($\alpha = 0.375$), indicating that the items were not consistent and this factor should be revised or reconsidered. Despite the variation across subscales, the overall instrument achieved a Cronbach's alpha of 0.817, which reflects good reliability at the scale level.

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2.4 *Quantitative Data Analysis*

Quantitative data were analyzed using descriptive statistics in the form of percentages. For checklist-based aspects, such as equipment availability, the total actual score was compared with the ideal score using the following formula:

$$P = \frac{Real\ score}{Ideal\ score} \times 100\%\ [17]$$

Explanation:

P = percentage number

Skor riil = actual laboratory state score

Skor ideal = score set by the government

After the percentage results were obtained, then the interpretation of the obtained score was carried out. The interpretation follows the guidelines below [18]:

Table 3. Interpretation Guidelines

Percentage Range	Category
76% - 100%	Highly Prepared
56% - 75%	Ready
40% - 55%	Less Prepared
0% - 39%	Not Ready

Example of calculation: suppose an aspect consists of 10 items with an ideal total score of 40. The actual score obtained from the checklist is 28. The readiness percentage is calculated as:

$$P = \frac{28}{40} \times 100\% = 70\%$$

This result indicated that the laboratory is in the Ready category (56–75%).

To provide clarity on how the readiness percentages were calculated, a summary of the checklist items is presented in Table 4. The number of items varied according to sub-specialization, reflecting the different requirements of audio-video electronics, industrial electronics, and mechatronics.

Table 4. Number of Items in the Laboratory Availability Checklist

Sub-specialization	Schools	Infrastructure	Facilities	Total Items
Audio-Video Electronics (TAV)	SMKN 1 Sidoarjo, SMK YPM 4 Taman	1	26	27
Industrial Electronics (TEI)	SMKN 1 Jabon, YPM 8 Sidoarjo, SMK Krian 2 Sidoarjo	2	36	38
Mechatronics (TM)	SMK Antartika 2 Sidoarjo	2	61	63

For the laboratory usability questionnaire, responses were converted into attitude categories using mean-based score ranges and standard deviations [19], the categorization is shown in Table 5:

Table 5. Category of Data Grouping of Laboratory Usability Questionnaire

Interval	Interval Values	Category
$Mi + 1.5\ SDi < x \leq Mi + 3\ SDi$	$52 < x \leq 64$	Strongly agree
$Mi < x \leq Mi + 1.5\ SDi$	$40 < x \leq 52$	Agree
$Mi - 1.5\ SDi < x \leq Mi$	$28 < x \leq 40$	Disagree
$Mi - 3\ SDi \leq x \leq Mi - 1.5\ SDi$	$16 \leq x \leq 28$	Strongly Disagree

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Explanation:

Mi = Ideal mean (1/2 × (highest score + lowest score))
SDi = Standard deviation (1/6 × (highest score − lowest score))

This approach ensured that both checklist-based and questionnaire-based data are quantified consistently, allowing the readiness of laboratories to be evaluated in a comparable manner.

In addition, to examine the relationship between laboratory availability (checklist-based scores) and laboratory usability (questionnaire-based scores), Spearman's rank-order correlation was employed. This non-parametric method is particularly suitable when the data do not meet the assumptions of normality and when variables are measured at an ordinal [20].

2.5 Qualitative Data Analysis

Qualitative data were collected via semi-structured interviews and open-ended questionnaires with key informants. Interviews focused on planning, management systems, and laboratory personnel competencies. Qualitative data were analyzed using thematic analysis, with informant answers organized into predefined themes based on the research aspects [21]. Data trustworthiness was ensured through method triangulation, by comparing interview findings with laboratory planning documents and field observations, providing a reliable and comprehensive interpretation of the results.

3. Result and discussion

This study aims to evaluate the readiness of the electronics engineering laboratory at SMK Sidoarjo Regency in facing the demands of the industrial era 4.0. Data were obtained from six vocational schools through questionnaires, observations, documentation, and interviews. Evaluation was carried out on five aspects: planning, availability of equipment, maintenance and management, laboratory usability, and competence of laboratory personnel.

3.1 Laboratory planning

The planning of electronics engineering laboratories in Sidoarjo Regency demonstrates efforts to align with Industry 4.0, although the implementation is uneven across schools. SMKN 1 Jabon, for instance, has taken concrete steps by procuring advanced technology-based equipment such as robotics and solar-powered automatic watering systems. As the Vice Principal for Facilities and Infrastructure explained: "*Last year, we procured new equipment aligned with technological developments, such as robotics. A student robotics community has also produced innovations, including automatic garbage cans and solar-powered watering systems*."

In contrast, other schools such as SMKN 1 Sidoarjo and SMK Krian 2 remain in the early stages of facility development. One informant described the improvement process as gradual:

> "Currently, the Electronics Engineering laboratory is being developed towards Industry 4.0 standards. Nevertheless, the improvements are still implemented in stages, or as locally phrased in Javanese, 'in installments,' meaning gradually over time..." [Interview with the Deputy Principal for Facilities and Infrastructure at Krian 2 Vocational School, Sidoarjo].

Meanwhile, SMK YPM 8 Sidoarjo emphasized the importance of curriculum alignment with industrial needs through routine synchronization: "*We regularly synchronize the curriculum with industry requirements, particularly in the Electronics Engineering program...*" [Interview with the Vice Principal for Infrastructure at SMK YPM 8 Sidoarjo].

3.2 Equipment availability

Analysis of the availability of laboratory equipment is carried out based on quantitative data from questionnaires in the form of checklists (checks) developed based on electronic engineering equipment standards. The results of the analysis showed that only one of the six vocational schools is included in the "Very Ready" category, namely SMKN 1 Sidoarjo with a readiness level of 79.7%. Meanwhile, five

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other schools are in the "Less Ready" category, namely SMKN 1 Jabon (55.3%), SMK YPM 8 Sidoarjo (50.5%), SMK YPM 4 Taman (50.0%), SMK Antartika 2 Sidoarjo (48.6%), and SMK Krian 2 Sidoarjo (40.5%). In aggregate, the average readiness of laboratory equipment from the six vocational schools reached 54.1%, which placed laboratory conditions in the "Less Ready" category to support learning based on industrial technology 4.0.

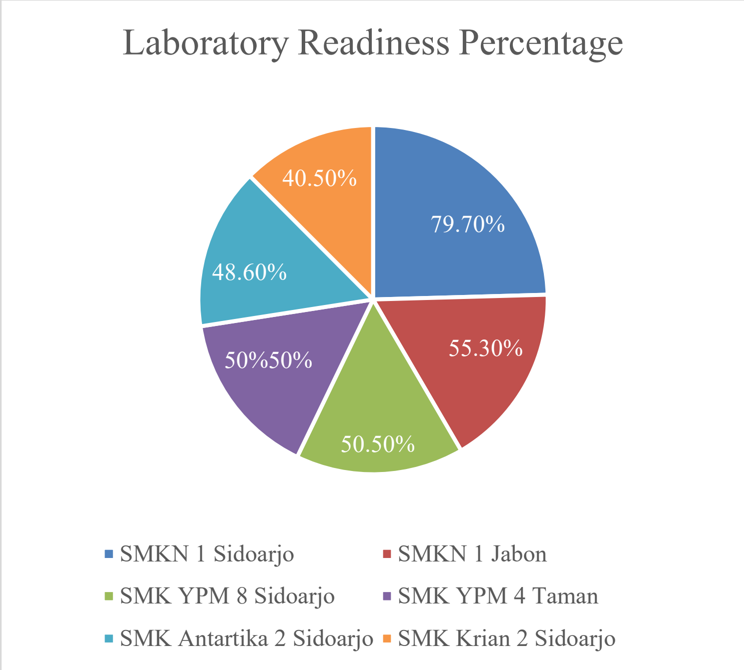

Figure. 2 Readiness Scores of Electronics Labs by School (n = 6)

3.3 Maintenance and management

Electronics engineering laboratory maintenance policies and practices show variation between schools. SMKN 1 Sidoarjo carries out maintenance on a scheduled basis every two to three months, or at least twice per semester. A flexible approach is applied by SMKN 1 Jabon, adjusting to the frequency of student practice; usually the check is carried out once a month if there are no practical activities. A systematic approach is applied by SMK YPM 8 Sidoarjo through daily, weekly, monthly, and yearly schedules, adjusting to the condition of each tool. The maintenance model based on usage intensity is seen at SMK Krian 2 Sidoarjo, with daily checks for frequently used equipment and general maintenance carried out every one to three months.

The laboratory management mechanism in each school shows awareness to maintain the feasibility of the equipment function, although it is not yet completely uniform. Maintenance procedures at SMKN 1 Sidoarjo include periodic checks, equipment calibration, and reporting damage to the head of the department. Labs handle minor repairs, while major damage is coordinated with outside parties. The schedule for using the laboratory is arranged in harmony with the school learning schedule, under the coordination of the head of the department.

The implementation of maintenance at SMKN 1 Jabon includes charging, lubrication, and checking cables. Inventory management has been carried out digitally through Microsoft Excel, while the allocation of laboratory use is adjusted to teachers' productive schedules. Similar practices are implemented by SMK YPM 8 Sidoarjo, with routine checks and calibrations, as well as the ability to self-repair by laboratories. If the tool does not allow repair, then new procurement is the next step. The inventory is compiled based on the needs of teaching materials and practices, and laboratory scheduling involves collaboration between the head of the department, the curriculum field, and student affairs.

A different approach can be seen at SMK Krian 2 Sidoarjo, which prioritizes daily preventive maintenance of computer devices, equipped with periodic inventory reports every semester. Defective equipment is assembled for proposed removal or replacement. The Curriculum Waka sets the laboratory schedule, while the laboratory is responsible for preparing equipment according to the needs that have been set. All of these findings show that although there is no standard system between schools,

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laboratory management efforts have been carried out functionally and adaptively based on the context of each institution. The importance of facility management as a supporting factor for learning is reflected in the practice, as affirmed by Suharto et al. [22].

3.4 Laboratory usability

The measurement of laboratory usefulness was carried out through the distribution of questionnaires to productive teachers of electronics engineering. The instrument consists of 16 statements using a four-point Likert scale, with a score range between 1 and 4. The total number of respondents was 15 productive teachers from six vocational schools that were the subject of the study. Data analysis was carried out using SPSS software version 29.

Table 6. Descriptive Statistics of Laboratory Usability

Category	Value
Mean	54.40
Standard deviation	6.033

Table 7. Results of Laboratory Usability Questionnaire Analysis

Interval Values	Category	Frequency
$52 < x \leq 64$	Strongly agree	10 (67%)
$40 < x \leq 52$	Agree	5 (33%)
$28 < x \leq 40$	Disagree	0
$16 \leq x \leq 28$	Strongly Disagree	0
Total		15

Based on the results of the analysis of the usability category, as many as 10 respondents (67%) were in the "Strongly Agree" category and 5 respondents (33%) were in the "Agree" category. No respondents stated "Disagree" or "Strongly Disagree". This category refers to the interpretation of laboratory usability data according to the value of the interval that has been set.

The average score of 54.40 puts the perception of productive teachers in the category of "Strongly Agree", indicating that electronics engineering laboratories are considered to have high usefulness in supporting the learning process. Although there are still variations in scores between respondents, the frequency distribution shows that the majority of teachers give positive assessments of laboratory functions in their respective schools.

Table 8. Descriptive Statistics of Laboratory Usability Scores by School

Schools	N (productive teacher)	Mean	Standard deviation
SMKN 1 SIDOARJO	4	57	0,6
SMKN 1 JABON	3	46	2,5
SMK YPM 8 SIDOARJO	2	60	2,1
SMK YPM 4 TAMAN	1	62	0
SMK KRIAN 2 SIDOARJO	3	56	6,4
SMK ANTARTIKA 2 SIDOARJO	2	52	4,9

Table 8 presents the descriptive statistics of the laboratory usability questionnaire for each school, including the number of productive teachers (N), mean scores, and standard deviations. The mean scores varied among schools, ranging from 46 at SMKN 1 Jabon to 62 at SMK YPM 4 Taman, indicating differences in teachers' perceptions of laboratory usability. To further examine whether laboratory usability was associated with laboratory readiness, a Spearman's rank-order correlation was conducted. The analysis revealed a very weak positive association ($\rho = 0.058$, df = 4, $p = 0.913$), which was not statistically significant. This finding indicates that higher availability of laboratory facilities does not necessarily translate into higher perceived usability, suggesting that other factors such as laboratory management or teacher competence may have greater influence.

3.5 Competency of laboratory personnel

The measurement of laboratory competence was carried out through an open questionnaire distributed to six laboratory workers from each school. The questions in the questionnaire cover three main aspects, namely the possession of a laboratory competency certificate (K1), a certificate for the use of the latest technology (K2), and an Occupational Safety and Health (K3) certificate. The results obtained were compiled in the form of percentages based on the responses of each respondent.

Most laboratories do not have formal certification in these three aspects. Only one laboratory from SMK YPM 8 Sidoarjo stated that he had a laboratory competency certificate and a certificate on the use of the latest technology but did not have a K3 certificate. Laboratories from SMK Krian 2 Sidoarjo are recorded as having a K3 certificate and a certificate in the use of the latest technology but do not yet have a laboratory competency certificate. Meanwhile, four laboratory technicians from the other school do not have any of the three types of certifications.

In general, these results showed that the level of ownership of laboratory competency certificates is still very low. The average percentage of competence based on the three aspects measured only reached 16.7%. This percentage places laboratory competencies in the category of "Not Ready" in supporting the management of industrial 4.0-based electronics engineering laboratories. The absence of certification in most laboratories indicates the need to increase the capacity of technical personnel through formal training and industry-based certification programs.

3.6 Discussion

The evaluation of electronics engineering laboratories in Sidoarjo revealed both progress and persistent disparities. While some schools, such as SMKN 1 Jabon, have begun integrating robotic technology and renewable energy into their planning, others remain in partial stages of implementation or focus only on curriculum synchronization without industry involvement. These variations highlight the importance of institutional structures that support systematic planning aligned with Industry 4.0. Successful TVET institutions are those that align laboratory development with industry needs and multiskill competency design [23], [24]. However, the majority of schools studied have not yet achieved such integration, reflecting a gap between vision and practice. Further note that future education systems must be inclusive and responsive to industry demands, underscoring the urgency of designing laboratory planning based on local data and multifaceted competencies [25].

A major finding of this study is the low average readiness of laboratory facilities, which reached only 54.1%. This places most schools in the “underprepared” category, revealing a mismatch between program design and real implementation. Disparities are influenced by funding constraints, institutional status, and access to industry partnerships [22]. Private schools experience greater funding pressures compared to public schools, which receive BOS (School Operational Assistance). Similar inconsistencies have been reported in other contexts, such as SMKN 5 Bandung, where facilities often fall short of minimum vocational standards [26]. These findings point to local disparities that may also reflect broader challenges, though further research with larger and more diverse samples is needed to confirm systemic patterns. The importance of equitable budget allocation based on actual school needs has also been emphasized [27], and the availability of facilities has been confirmed as a determining factor for successful learning processes [28].

Beyond quantity, the quality and relevance of laboratory equipment to Industry 4.0 is a critical issue. Most schools have not yet met the minimum standards for technology-based practices. The presence of Industry 4.0 equipment is a core indicator of vocational readiness [29], and its integration enhances both technical skills and learning outcomes relevant to labor market demands [30]. The Directorate of Vocational Schools also stresses proportional ratios of equipment as a prerequisite for effective learning. Therefore, procurement strategies must prioritize functional suitability, utilization, and alignment with industrial standards.

Laboratory management emerged as another challenge. Only two of the six schools had structured maintenance schedules, with most still relying on reactive approaches. The absence of SOPs and systematic protocols reflects weak management cultures. Applying Total Quality Management (TQM) principles such as continuous improvement, customer focus, and fact-based management has been shown to improve educational facility quality [31], while reactive maintenance increases costs and reduces functionality [32]. Digitalized systems further ensure efficiency, accuracy, and transparency in

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facility management [33]. Strengthening management with data-driven and technology-based systems is therefore essential.

Despite equipment and management gaps, teachers' perceptions of laboratory usefulness were relatively positive, with 67% acknowledging their importance for hands-on learning. This optimism suggests functional reliance on laboratories, even when equipment falls short of Industry 4.0 standards. Teachers often compensate by adapting and improvising practical activities. However, this mismatch between positive perceptions and limited facilities creates cognitive dissonance. The effectiveness of virtual laboratories depends heavily on pedagogical integration [34], and teacher capacity is key to bridging facility limitations and achieving relevant learning [35]. Strengthening pedagogical competence and providing technological support are therefore vital for laboratory optimization.

Another critical aspect is the role of laboratory personnel. Only 16.7% of laboratories reported staff with relevant competency certifications, which is insufficient given the complexity of Industry 4.0 tools. This lack of certification indicates that professional development for laboratory staff is not yet a priority at the school level. Yet, laboratory personnel play a central role in safety, functionality, and supporting vocational learning [36]. Technical training and certification are essential components of vocational laboratory development [37]. In addition, other study emphasized the importance of technical training for laboratory workers as a key component in a modern vocational education system [30]. Therefore, improving the competence of laboratories must be an integral part of the strategy to strengthen vocational laboratories as a whole.

In summary, this evaluation reveals a significant imbalance between institutional visions for Industry 4.0 and actual implementation in the field. Although some schools demonstrate progress, most remain constrained by limited equipment, weak management, and underqualified personnel. These findings affirm that laboratory transformation must be designed as a strategic, data-driven agenda involving collaboration between teachers, laboratory staff, and industry. Achieving this transformation requires balancing infrastructure improvement, human resource capacity, and technological integration aligned with real labor market needs.

This study has several limitations. First, three different versions of the availability checklist were used according to sub-specializations, which may affect comparability. Second, the limited sample size did not allow for the application of advanced statistical methods such as confirmatory factor analysis (CFA) or partial least squares structural equation modeling (PLS-SEM) to validate the latent construct of readiness. Despite these limitations, the study contributes by offering an in-depth evaluation of laboratory readiness from both availability and usability perspectives, identifying key disparities, and proposing data-based and collaborative strategies to strengthen vocational laboratory development.

4. Conclusion

This study highlights the condition of electronics engineering laboratories in vocational schools across Sidoarjo Regency and their readiness for Industry 4.0-based learning. While planning aligns with the needs of the digital era, implementation varies among schools due to differences in equipment availability, maintenance practices, and human resource capacity. Laboratory personnel competence remains a concern, with only 16.7% certified, and management practices are not yet fully systematic, indicating areas for improvement.

This research contributes to the literature on vocational education readiness by providing empirical insights into factors influencing the transformation of laboratories for technology-driven learning. Practically, it offers guidance for schools, policymakers, and industry partners by identifying priorities for enhancing laboratory facilities, developing human resources, and implementing supportive policies, including structured training, systematic maintenance, and technology integration. The novelty of this study lies in the fact that, to date, no comprehensive study has evaluated the readiness of electronics engineering laboratories in vocational education, particularly regarding facilities, management systems, and human resource competencies in responding to the transformation demands of Industry 4.0. Additionally, this study combines quantitative readiness assessment with qualitative perspectives, providing a comprehensive understanding that goes beyond previous research focusing primarily on infrastructure or equipment availability.

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Based on the findings and conclusions of this study, several recommendations are proposed to enhance the readiness of vocational electronics laboratories in supporting Industry 4.0-based learning.

Table 9. Recommendations

Timeframe	Recommended Actions	Main Actors	Estimated Resources
Short-term (1–2 years)	1. Conduct regular needs assessment of equipment based on Industry 4.0 standards. 2. Provide training workshops for laboratory staff on the use and maintenance of existing equipment. 3. Optimize scheduling and management of lab usage to improve usability. 4. Strengthen collaboration with local industries for equipment support.	School management, Laboratory staff, Local industry	Low–Medium
Medium-term (3–5 years)	1. Upgrade laboratory facilities with priority equipment aligned to Industry 4.0 (automation, IoT-based tools). 2. Establish systematic maintenance and management systems with clear SOPs. 3. Enhance professional development of teachers through industry internships and certification programs. 4. Expand partnerships with universities and industry for joint projects.	Education authorities, Schools, Industry partners	Medium–High
Long-term (5+ years)	1. Develop smart laboratories integrating virtual/augmented reality as complementary tools. 2. Institutionalize continuous certification for laboratory staff and teachers in line with technological advances. 3. Secure sustainable funding models (government–industry–school collaboration). 4. Position vocational schools as regional centers of excellence for Industry 4.0-based laboratory practices.	Government, Schools, Industry associations	High

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