



# Developing Green Skills through the Teaching Factory Learning Model to Support Sustainable Development Goals (SDGs)

Tiara Maulida Yanti<sup>1</sup>, Tuti Suartini<sup>1\*</sup>, Dimas Aulia Saputra<sup>1</sup>, Mustika Nuramalia Handayani<sup>2</sup>, Saripudin<sup>1</sup>

<sup>1</sup>Program Study of Technology and Vocational Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.

<sup>2</sup>Program Study of Agro-Industrial Technology Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.

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Corresponding Author:

Name Tuti Suartini

[tutisuartini@upi.edu](mailto:tutisuartini@upi.edu)

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**Abstract:** Vocational education in Indonesia faces challenges in preparing graduates who are aligned with the needs of industries transitioning toward a green economy. This study aims to examine the effectiveness of integrating green skills into the Teaching Factory (TeFa) learning model in the Agricultural Product Processing Program at SMKN PP Lembang. The study employed a quasi-experimental approach using a one-group pretest-posttest design involving 31 students. The intervention was implemented through the modification of TeFa work instructions by embedding five green skill dimensions: environmental awareness, innovation, communication, adaptability, and waste management. Data were collected through pretest and posttest assessments and student perception questionnaires, and were enriched by input from industry assessors as contextual validation of competency applicability in the workplace. The results showed that the students' mean score increased from 63.23 to 84.62, with an N-Gain score of 0.57, indicating moderate effectiveness. The most notable improvements were found in environmental awareness and innovation. These findings indicate that integrating green skills into TeFa work instructions is effective in improving student competencies and strengthening the relevance of vocational learning to sustainability-oriented industrial demands.

**Keywords:** APHP; Food industry; Green skills; N-Gain; Teaching factory; TVE

## Introduction

The global transition toward a circular economy has intensified the demand for workers who are not only technically competent but also capable of applying environmentally responsible practices in production processes. Industries increasingly require graduates who can demonstrate resource efficiency, waste minimization, compliance with environmental standards, and accurate process documentation as part of everyday work performance. In addition to these technical and procedural abilities, cross-functional competencies such as innovation, communication, and adaptability have become increasingly important in supporting green productivity and workplace resilience (Fitriyanto et al., 2022; Muaddab et al., 2024). Recent studies further show that green skills need to be understood not merely as narrow environmental

techniques, but as competencies that must be connected to broader sustainability-oriented performance and workplace transformation (Albertz & Pilz, 2025; Montanari et al., 2023). This shift has placed vocational education in a strategic position, as it is expected to prepare graduates who are able to respond to industrial transformation while contributing to sustainability goals. In the context of vocational education, this challenge is closely related to job readiness, since the gap between educational outcomes and workplace expectations remains a persistent issue in vocational schools (Costa et al., 2025). In parallel, green education literature also emphasizes that sustainability-oriented learning should be systematically organized through curriculum, teaching materials, and methods, rather than treated as incidental environmental messaging (Matlubah et al., 2025).

### How to Cite:

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In Indonesia, the Teaching Factory (TeFa) model has been widely recognized as an authentic learning approach that integrates industrial standards, quality culture, and real production activities into school-based learning (Cahyani et al., 2024; Fitriani et al., 2022; Irwanto, 2024). Previous studies have shown that successful TeFa implementation depends on the alignment of curriculum, standard operating procedures, measurable job sheets, and strong industry partnerships (Irwanto, 2025; Suwandi et al., 2023). Other studies also indicate that TeFa effectiveness is influenced by the quality of planning, production-unit management, industrial cooperation, and the use of job sheets that structure student performance in authentic learning settings (Chasovy et al., 2024; Dwikurniangsih, 2025; Widiatna et al., 2025). In addition, TeFa has been associated with contextual production experience, improved entrepreneurship readiness, and stronger workplace orientation in vocational education (Purba et al., 2024; Susilowati et al., 2024). However, the existing literature still indicates that vocational learning outcomes have not fully met industrial competency demands, particularly in relation to green job readiness (Isnandar et al., 2024; Muaddab et al., 2024). This concern is reinforced by recent evidence showing that green skills development in vocational education still tends to be uneven across cognitive, interpersonal, and intrapersonal domains, which suggests that classroom and production practices have not yet consistently translated sustainability demands into observable student competence (Saputra et al., 2026).

One important reason for this gap is that TeFa implementation often emphasizes production quality and technical performance, while green skill indicators are not yet systematically embedded in the operational instruments that directly guide student practice, such as work instructions and job sheets. As a result, environmentally oriented competencies may be discussed at the curricular level but remain weakly translated into observable production behavior. This issue is especially relevant in agricultural and food-processing contexts, where production learning is expected not only to build technical competence and business awareness, but also to foster efficiency, responsibility, and sustainable processing behavior in authentic practice (Pinatik et al., 2025). More broadly, vocational learning studies suggest that project-based and contextual production models can improve competence only when intended outcomes are translated into explicit daily activities, practical guidance, and assessable routines rather than left at the conceptual level (Hulyadi et al., 2025; Sukmawati et al., 2024). Comparable work on experiential learning factories also indicates that authentic, competency-based environments become more meaningful when

practical tasks clearly bridge theory, procedure, and performance (Rantschl et al., 2025).

This issue highlights the importance of focusing on work instructions as an operational entry point for green skills integration. In TeFa-based production learning, work instructions function not only as technical guides but also as instruments that structure how students perform tasks, monitor quality, follow procedures, and document production activities. Therefore, if green skill indicators such as utility efficiency, material optimization, waste reduction, and GHP or SSOP documentation are explicitly incorporated into work instructions, these competencies can be observed, practiced, and assessed more consistently during production activities (Cahyani et al., 2024; Fitriani et al., 2022; Irwanto, 2024). This perspective is in line with Handayani's framework, which emphasizes that green skills should be infused into learning outcomes, materials, activities, and assessment systems, rather than treated as additional or separate content (Handayani, 2021, 2023). It is also supported by international scholarship showing that vocational education requires clearer green innovation skill profiles, stronger curriculum mainstreaming for sustainability, and better integration between emerging competencies and pedagogical design (Shamzuzoha et al., 2022; Wickramasinghe & Wickramasinghe, 2026). At the same time, successful implementation depends on teacher readiness and the availability of pedagogical models that can connect sustainability-oriented competencies with authentic vocational learning processes (Sourgiadaki & Karkalacos, 2023; Vitalocca et al., 2026).

Based on this background, the present study addresses a more specific gap by examining how green skill indicators can be operationalized through modified TeFa work instructions in the Agricultural Product Processing (APHP) program. The novelty of this study lies in its focus on translating green skills into concrete production guidance used in school-based TeFa practice and in evaluating the resulting changes in students' competencies through a pre-test and post-test design. Unlike previous studies that discuss TeFa implementation or green skills integration at a broader conceptual or managerial level, this study investigates how green competencies can be embedded directly into the instructional instruments that shape students' daily production behavior. The study focuses on five dimensions, namely environmental awareness, innovation, communication, adaptability, and waste management. Therefore, this research is important because it provides empirical evidence on how school-based vocational learning can more concretely align with sustainability-oriented industrial demands through operational changes in teaching and production practice. In a broader sense, this relevance also resonates

with recent discussions on teaching methods for building human capital for the twin transition, where sustainability and technological change increasingly require skill-based instructional redesign rather than conventional content delivery alone (Hofmann et al., 2026).

**Method**

This study employed a quasi experimental quantitative design using a one group pre test and post test approach to examine changes in students’ green skills after the integration of green skill indicators into Teaching Factory (TeFa) work instructions. The intervention was implemented in the school based TeFa learning environment. Input from industry assessors during Field Work Practice (PKL) was included only as contextual support to enrich the interpretation of

students’ competency development in authentic workplace settings, rather than as the primary basis for measuring the effectiveness of the intervention. This design was selected because it enabled the researchers to compare students’ competency conditions before and after the instructional intervention in a more controlled school based setting. The overall research procedure is presented in Figure 1.

The methodological orientation followed the evaluation framework commonly used in TeFa implementation, which emphasizes quality culture reinforcement, alignment of learning processes with industrial standards, and traceability in production practices (Cahyani et al., 2024; Fitriani et al., 2022; Irwanto, 2024). These principles guided the development of the intervention, the preparation of research instruments, the data collection procedures, and the interpretation of learning outcomes.



**Figure 1.** Research methodology flowchart

The participants were 31 students enrolled in the Agricultural Product Processing (APHP) vocational program at SMK Negeri Pertanian Pembangunan Lembang, West Java. The students were directly involved in school based TeFa production activities across three product lines, namely dim sum, bakery products, and yogurt, which were developed in collaboration with industry partners. These activities were designed to simulate real industrial practices and were carried out in accordance with Good Hygiene Practices (GHP), Sanitation Standard Operating Procedures (SSOP), and other relevant quality assurance procedures. After completing the TeFa phase, the same students undertook PKL in industry settings, where assessor feedback was collected to provide contextual insights into the applicability of the targeted competencies.

Data were collected using two complementary instruments to capture both foundational understanding and students’ perceived development of green skills. The first instrument was a brief cognitive test consisting of 10 items. This test was intended to assess students’ basic conceptual understanding of environmentally responsible practices embedded in the production

process. Each correct answer was scored 1, and each incorrect answer was scored 0. Because the cognitive test served only as an initial measure of conceptual understanding, it was complemented by a broader questionnaire to better reflect the multidimensional nature of green skills.

The second instrument was a green skills questionnaire administered through Google Forms using a Likert scale ranging from 1 to 5. The questionnaire represented five dimensions of green skills, namely environmental awareness, innovation skills, communication skills, adaptability in green jobs, and waste management. These dimensions were derived from previous studies on green skills integration in vocational education and TeFa based learning processes (Cahyani et al., 2024; Fitriani et al., 2022; Fitriyanto et al., 2022; Handayani, 2021; Irwanto, 2025).

To ensure content validity, both instruments were reviewed by experts in productivity, food processing, and quality assurance. The validation process focused on relevance, clarity, and alignment between the instrument items and operational indicators such as resource efficiency, compliance with GHP and SSOP, reduction of off spec products, waste sorting and

minimization, safe rework practices, and documentation procedures. Revisions were made based on expert feedback before the instruments were administered.

The data analysis was conducted to identify changes associated with the intervention. Pre test and post test scores were analyzed using descriptive statistics and normalized gain (N Gain) to determine the extent of students' improvement after the integration of green skill indicators into TeFa work instructions. Questionnaire data were analyzed descriptively to identify patterns of perceived development across the five green skill dimensions. In addition, feedback from industry assessors during PKL was used as contextual information to strengthen the discussion regarding the relevance of students' competencies in workplace settings.

Through this approach, the study sought to provide empirical evidence on the potential of integrating green skills into TeFa work instructions to strengthen vocational students' competencies. The findings were expected to contribute to the improvement of school based vocational learning practices and to support the broader effort to align vocational education with the competency demands of sustainability oriented industries.

## Result and Discussion

This section presents the findings of the study and discusses their implications by comparing students' performance before and after the intervention. The discussion focuses on changes in students' cognitive achievement and the development of green skills as reflected in student and industry perspectives. The interpretation is supported by relevant literature to explain how the integration of green skill indicators into Teaching Factory (TeFa) work instructions may strengthen vocational competency development.

### *Students' Cognitive Achievement on TeFa Product Job Sheets*

The analysis of 31 students showed an improvement in cognitive scores after the intervention. The mean pre-test score increased from 64.23 to 84.62 in the post-test, with an N-Gain value of 0.57, which falls into the moderate category. This result indicates that the integration of green skill indicators into TeFa work instructions was associated with a meaningful improvement in students' conceptual understanding of environmentally responsible production practices. In the context of vocational education, such improvement is important because TeFa is designed not only to strengthen technical competence but also to embed industrial work culture, quality awareness, and process discipline into daily learning activities (Cahyani et al., 2024; Fitriani et al., 2022; Irwanto, 2025; Suwandi et al.,

2023). Similar findings in international vocational education research also show that competence-based and practice-oriented training can strengthen learners' conceptual understanding and technical competence when learning is closely connected to authentic task performance (Kayitare & Twahirwa, 2026; Qi et al., 2026).

From a curriculum perspective, these findings support the argument that green skills need to be systematically integrated into learning outcomes, learning materials, practical tasks, and assessment rubrics so that they are not treated as additional content, but as an integral part of vocational competence formation (Handayani, 2023). The moderate N-Gain score suggests that students were able to internalize several green production principles introduced through the revised work instructions, including resource efficiency, waste awareness, process documentation, and continuous improvement in production activities. This interpretation is consistent with international studies showing that sustainability-oriented vocational education becomes more meaningful when competencies are translated into structured learning designs, operational guidance, and clearly defined competency frameworks rather than being left at the level of broad policy discourse (Ortiz, 2025; Ye et al., 2024). It is also supported by research emphasizing that sustainable vocational systems require clear links between curricular intention, practical implementation, and measurable competence development (Storonyanska et al., 2025).

At the same time, the cognitive findings should be interpreted with caution. The cognitive test in this study consisted of only 10 items distributed across five green skill dimensions, meaning that each dimension was represented by a limited number of questions. As a result, the test was more appropriate for capturing general conceptual tendencies than for making strong claims about detailed mastery in each domain. Therefore, the cognitive results were complemented by questionnaire data and contextual input from industry assessors to obtain a broader understanding of students' green skill development.

Overall, the cognitive improvement indicates that embedding green skill indicators into TeFa job sheets can help strengthen students' understanding of environmentally oriented work practices. This finding is relevant to the broader challenge of reducing the gap between vocational school learning and industrial competency demands, particularly in sectors that are increasingly shaped by sustainability principles and green production expectations (Isnandar et al., 2024; Muaddab, 2024; Muaddab et al., 2024). Comparative TVET studies also underline that the alignment between vocational learning and sustainable development

depends on how effectively practical competence, pedagogical innovation, and labor market relevance are integrated within training systems (Okoye et al., 2025).

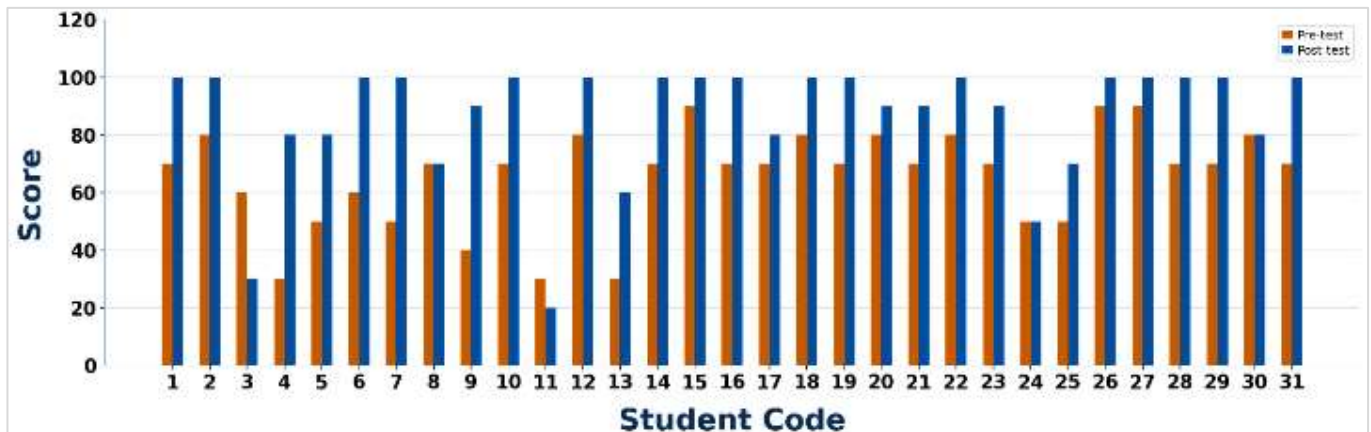


Figure 2. Pre-test and post-test cognitive scores of students

*Development of Green Skills from the Student Perspective*

The student questionnaire showed positive changes across all five dimensions of green skills after the intervention. The strongest improvements were found in environmental awareness and communication skills, followed by adaptability in green jobs and innovation skills, while waste management showed improvement but remained the lowest among the five dimensions. This pattern suggests that the intervention was particularly effective in strengthening students' awareness, interaction, and responsiveness within environmentally oriented production activities, while procedural aspects related to waste management still required further reinforcement. This tendency is in line with international studies showing that sustainability-related competencies develop more effectively when active learning, contextual problem solving, and applied instructional methods are embedded in vocational learning environments (Díaz-Lauzurica & Moreno-Salinas, 2025).

The most prominent change was observed in environmental awareness, which increased from 3.8% before the intervention to 71.8% afterward. Communication skills also increased from 39.1% to 76.0%, followed by adaptability in green jobs from 14.1% to 73.1%, innovation skills from 20.5% to 71.0%, and waste management from 20.5% to 58.3%. These results indicate that the integration of green skill indicators into learning activities did not only affect students' understanding, but also shaped how they perceived their own environmentally responsible behavior in production settings.

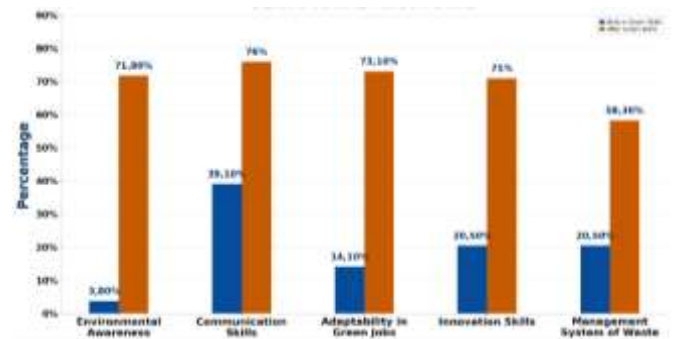


Figure 3. Student perspective on green skill development before and after the intervention

The improvement in environmental awareness can be interpreted as a direct outcome of learning activities that explicitly linked production tasks with the principles of resource efficiency, cleanliness, waste reduction, and process responsibility. This finding is in line with (Handayani, 2021, 2023), who argues that green skills are more likely to develop when they are infused into core learning components rather than delivered as separate moral messages. In vocational settings, repeated exposure to environmentally oriented procedures can gradually shape students' ecological sensitivity and work habits. This interpretation is also supported by studies on sustainability education showing that teacher readiness, sustainability knowledge, and instructional self-efficacy strongly influence the extent to which sustainability principles are meaningfully translated into classroom and practice-based learning (Ghazali et al., 2024; Yang et al., 2024).

Substantial progress was also found in communication skills and adaptability in green jobs. These two aspects are closely connected to the collaborative and situational nature of TeFa learning. Daily briefings, production coordination, explanation of

work procedures, and feedback on quality and environmental performance appear to function as practical arenas in which students learn to communicate clearly and adapt to dynamic work conditions. This result supports previous studies emphasizing that vocational graduates are increasingly expected to combine technical competence with soft skills and adaptive capacity in order to meet workplace demands in sustainability-oriented industries (Fitriyanto et al., 2022; Isnandar et al., 2024). This is consistent with broader research on vocational training and the future of work, which highlights the growing importance of adaptability, applied communication, and cross-functional competence in sustainability-oriented workplaces (Chigbu & Makapela, 2025).

Innovation skills also showed considerable improvement, indicating that the learning design may have encouraged students to think beyond routine execution and become more responsive to process improvement opportunities. In TeFa contexts, even small improvements related to material use, work steps, cleanliness, or waste reduction can represent meaningful forms of innovation. This interpretation aligns with studies suggesting that authentic production-based learning can stimulate problem solving, initiative, and continuous improvement, which are essential elements of both entrepreneurial competence and green productivity (Fitriani et al., 2022; Suwandi et al., 2023). It also resonates with international work showing that design-oriented thinking and circular economy implementation depend on the development of practical improvement habits, systems awareness, and sustainability-sensitive decision making in real work processes (Sakao et al., 2024).

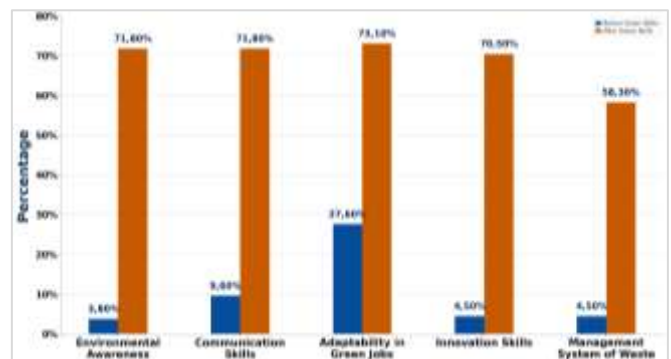
Waste management, although improved, remained the weakest dimension from the student perspective. This result should not be interpreted as a failure of the intervention, but rather as an indication that procedural green skills require more intensive practice and more specific assessment mechanisms. Waste management is not only a matter of awareness, but also involves technical consistency in sorting, measuring, recording, labeling, and evaluating waste generated during production. Previous studies have likewise shown that procedural implementation is often more difficult to strengthen than attitudes or general awareness in green vocational education (Muaddab, 2024; Muaddab et al., 2024). This observation is consistent with recent discussions showing that sustainable vocational systems require stronger attention to operational efficiency, safety, resource use, and procedural control in order to ensure that sustainability principles are enacted rather than merely understood (Chen et al., 2026).

Taken together, the student perspective demonstrates that the intervention contributed

positively to the development of green skills across multiple dimensions. However, the uneven pattern of improvement also suggests that green skill development is multidimensional and that some domains, especially waste management, need more structured procedural reinforcement than others.

*Development of Green Skills from the Industry Perspective*

Feedback from industry assessors showed a pattern that generally confirmed the student responses. Industry viewed the students as demonstrating stronger environmental awareness, better communication, higher adaptability, and improved innovation after the intervention. This convergence between school-based and workplace-based perspectives strengthens the interpretation that the competencies developed through TeFa were relevant to actual industrial settings, even though PKL data in this study were used only as contextual support rather than as the main basis for causal inference. This pattern is consistent with research showing that sustainable performance in vocational institutions is influenced not only by curriculum content, but also by organizational support, management systems, and the degree to which sustainability principles are embedded in operational practice (Efendi & Hidayat, 2025).



**Figure 4.** Industry perspective on students' green skill development before and after the intervention

From the industry perspective, environmental awareness increased from 3.8% to 71.8%, communication skills from 9.6% to 71.8%, adaptability in green jobs from 27.6% to 73.1%, innovation skills from 4.5% to 70.5%, and waste management from 4.5% to 58.3%. Although the magnitude of change varied across dimensions, the overall trend indicates that students were increasingly able to translate school-based learning into workplace behavior. Industry assessors particularly noted improvement in behaviors related to workplace cleanliness, resource conservation, and responsiveness to environmentally sensitive production practices.

The increase in innovation skills from the industry perspective is also important. In industrial settings,

innovation is often reflected not through large inventions, but through practical suggestions and small adjustments that improve efficiency, reduce waste, or support better process flow. The finding that students became more capable of proposing environmentally relevant improvements suggests that TeFa learning may have helped foster a mindset of continuous improvement, which is highly valued in production environments (Fitriani et al., 2022; Suwandi et al., 2023). This interpretation is compatible with international literature showing that circular and sustainable production transitions require workers who are able to contribute not only technical execution, but also practical innovation, problem recognition, and process refinement in real organizational settings (Sakao et al., 2024).

Communication and adaptability were likewise seen as improving in meaningful ways. These competencies are essential because green industrial practices often depend on coordination, compliance, and rapid adjustment to changing procedures, materials, or quality standards. The improvement reported by industry assessors supports the view that TeFa can function as a preparatory environment in which students rehearse workplace behavior before entering more complex industrial contexts (Cahyani et al., 2024; Irwanto, 2024; Isnandar et al., 2024). Similar findings in international vocational research indicate that labor market relevance, transferable skills, and sustainable development orientation become stronger when vocational systems deliberately connect training structures with evolving workplace demands (Okoye et al., 2025; Storonianska et al., 2025).

As in the student perspective, waste management remained the least developed dimension from the industry perspective. Industry assessors observed progress in basic habits such as sorting and saving materials, but they also indicated that students still needed stronger procedural consistency in documentation, labeling, and simple internal control related to waste handling. This finding is consistent with the literature showing that waste management competence requires not only awareness but also repeated technical practice, measurable indicators, and performance monitoring in authentic production settings (Fitriani et al., 2022; Muaddab, 2024; Muaddab et al., 2024). It also reflects broader concerns in sustainability education that institutional effectiveness depends on the operationalization of sustainability through repeated practice, clear criteria, and supportive instructional ecosystems (Silina-Jasjukevičá et al., 2025; Ye et al., 2024).

In summary, the results from both student and industry perspectives indicate that the integration of green skill indicators into TeFa work instructions

contributed to meaningful competency development. The most visible strengths were found in environmental awareness, communication, adaptability, and innovation, while waste management emerged as the dimension requiring the most improvement. These findings suggest that TeFa can serve as an effective learning model for integrating sustainability-related competencies into vocational education, provided that procedural domains are supported by more specific indicators, repeated practice, and closer monitoring.

## Conclusion

The integration of green skill indicators into Teaching Factory (TeFa) work instructions was associated with a substantial improvement in students' competencies, as reflected in the increase in the mean score from 63.23 to 84.62 and an N-Gain of 0.57, which indicates moderate effectiveness. The findings show that the intervention contributed positively to the development of students' green skills, particularly in environmental awareness, innovation, communication, and adaptability, while waste management remained the dimension requiring stronger procedural reinforcement. Supported by contextual input from industry assessors, these results suggest that integrating green skills into school-based TeFa learning can strengthen the relevance of vocational education to sustainability-oriented industrial demands. Therefore, future implementation should place greater emphasis on structured waste management practices, clearer operational indicators, and more consistent monitoring to support balanced green skill development across all dimensions.

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## Author Contributions

Conceptualization, T.M.Y. and T.S.; methodology, T.M.Y. and T.S.; software, T.M.Y.; validation, T.M.Y., T.S., D.A.S., M.N.H., and S.; formal analysis T.M.Y. and D.A.S.; investigation, T.M.Y., T.S., D.A.S., M.N.H., and S.; resources, T.M.Y., D.A.S., M.N.H., and S.; data curation, T.M.Y., and D.A.S.; writing - original draft, T.M.Y.; writing - review and editing, T.M.Y., T.S., D.A.S., and M.N.H., and S; visualization, T.M.Y., and D.A.S.;

supervision, T.M.Y., D.A.S., M.N.H., and S.; project administration, T.M.Y. and T.S. All authors have read and agreed to the published version of the manuscript. All authors have read and agreed to the published version of the manuscript.

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### Conflicts of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

### References

- Albertz, A., & Pilz, M. (2025). International Journal of Educational Development Green skills at Industrial Training Institutes in India: An exploratory study of VET teachers' subjective theories. *International Journal of Educational Development*, 118(September), 103406. <https://doi.org/10.1016/j.ijedudev.2025.103406>
- Cahyani, S., Rila, D., Miyono, N., & Pendidikan, M. (2024). Evaluasi Program Teaching Factory dalam Membentuk Budaya Mutu di SMK. *Jurnal Inovasi Pembelajaran Di Sekolah*, 5(1), 62–70. <https://doi.org/10.51874/jips.v5i1.221>
- Chasovy, A., Jalinus, N., & Wulansari, R. E. (2024). Analysis of the Implementation of the Teaching Factory Program in Vocational High School. *Jurnal Penelitian Pendidikan IPA*, 10(7), 4364–4375. <https://doi.org/10.29303/jppipa.v10i7.7569>
- Chen, D., Hou, J., & Zheng, Q. (2026). Management of Vocational Education Systems Through Virtual Reality-Based Pre-Training: Evidence from Learning Readiness and Skill Transfer. *Sustainability*, 18(5), 2236. <https://doi.org/10.3390/su18052236>
- Chigbu, B. L., & Makapela, S. L. (2025). Journal of Open Innovation : Technology, Market, and Complexity AI in education, sustainability, and the future of work: An integrative review of industry 5.0, education 5.0, and work 5.0. *Journal of Open Innovation: Technology, Market, and Complexity*, 11(4), 100645. <https://doi.org/10.1016/j.joitmc.2025.100645>
- Costa, T., Irazu, L., Lopez, A., Perussello, C., Quinn, F., Crowley, Q. G., McMahon, H., & Holden, N. M. (2025). Addressing the Demand for Green Skills : Bridging the Gap Between University Outcomes and Industry Requirements. *Sustainability*, 17, 2732. <https://doi.org/10.3390/su17062732>
- Díaz-Lauzurica, B., & Moreno-Salinas, D. (2025). Active Learning Methodologies for Increasing the Interest and Engagement in Computer Science Subjects in Vocational Education and Training. *Education Sciences*, 15(8), 1–33. <https://doi.org/10.3390/educsci15081017>
- Dwikurniangsih, Y. (2025). Developing A Teaching Factory Management Model to Improve Entrepreneurship Programs and Industry-Based Student Competencies in Vocational High School. *Jurnal Penelitian Pendidikan IPA*, 11(8), 161–168. <https://doi.org/10.29303/jppipa.v11i8.12277>
- Efendi, H., & Hidayat, H. (2025). The Relationship Between Digital Literacy and Emotional Intelligence on Vocational High School Students ' Work Readiness. *Jurnal Penelitian Pendidikan IPA*, 11(4), 499–505. <https://doi.org/10.29303/jppipa.v11i4.10628>
- Fitriani, N. L., Bukit, M., & Mujdalipah, S. (2022). Teaching Factory Learning Management to Improve the Quality of Learning in Study Programs APHP Vocational. *EDUFORTECH*, 7(1), 62–84. <https://doi.org/10.17509/edufortech.v7i1.44980>
- Fitriyanto, M. N., Salahudin, A., & Anugrah, C. (2022). Determinant Factors Of Green Skills Information Technology Students. *Bitnet: Jurnal Pendidikan Teknologi Informasi*, 7(1). <https://doi.org/10.33084/bitnet.v7i1.3364>
- Ghazali, M. B., Makrakis, V. G., Kostoulas-Makrakis, N., Yakob, N., Ahmad Rashid, R. A., Othman, W., & Fitriyanto, N. A. (2024). Predicting Teacher's Information and Communication Technology-Enabled Education for Sustainability Self-Efficacy. *Sustainability (Switzerland)*, 16(13). <https://doi.org/10.3390/su16135323>
- Handayani, M. N. (2021). *infusi kurikulum, pengembangan green skills, sekolah menengah kejuruan, curriculum infusion, green skills development, vocational school*. Universitas Pendidikan Indonesia. Retrieved from <http://repository.upi.edu/id/eprint/6579>
- Handayani, M. N. (2023). *Desain kurikulum SMK pertanian dengan infusi green skills*. Deepublish.
- Hofmann, A., Dukovska-popovska, I., Acerbi, F., Terzi, S., & Sassanelli, C. (2026). Teaching methods for building human capital for the twin transition : a skill-based approach. *Technology in Society*, 85(May 2025), 103172. <https://doi.org/10.1016/j.techsoc.2025.103172>
- Hulyadi, Suryati, Azmi, I., Prayogi, S., & Verawati, N. N. S. P. (2025). Project-based teaching factory in the chemical cleaning industry to enhance students ' soft skills and entrepreneurial intention. *Social Sciences & Humanities Open*, 12(August), 102221. <https://doi.org/10.1016/j.ssaho.2025.102221>
- Irwanto. (2024). *Modul pengelolaan TEFA*. Universitas Sultan Ageng Tirtayasa.
- Irwanto. (2025). *Proses Pembelajaran TEFA di Sekolah*

- Menengah Kejuruan Berbasis Teknologi Industri. *Jurnal Pendidikan Indonesia*, 5(3). <https://doi.org/10.59818/jpi.v5i3.1422>
- Isnandar, I., Muliadi, M., Nurmalasari, R., & Maula, P. I. (2024). Identifikasi Dimensi Skill Lulusan Pendidikan Vokasi Dengan Kebutuhan Keterampilan Kerja Di Industri. *Learning: Jurnal Inovasi Penelitian Pendidikan Dan Pembelajaran*, 4(2), 335–345. <https://doi.org/10.51878/learning.v4i2.2903>
- Kayitare, P. ., & Twahirwa, J. . (2026). Evaluating the efficacy of competence-based training on trainee's conceptual understanding, skill development, and market-driven opportunities at Nyamirama Technical Secondary School. *Discover Education*. <https://doi.org/10.1007/s44217-026-01358-4>
- Matlubah, H., Rahman, S. A., & Andi, R. (2025). The Potency and Urgency of Implementing Green Education in Sumenep Madura. *Jurnal Penelitian Pendidikan IPA*, 11(2), 365–374. <https://doi.org/10.29303/jppipa.v11i2.10080>
- Montanari, S., Agostini, E., & Francesconi, D. (2023). Are We Talking about Green Skills or Sustainability Competences? A Scoping Review Using Scientometric Analysis of Two Apparently Similar Topics in the Field of Sustainability. *Sustainability*, 15(19). <https://doi.org/10.3390/su151914142>
- Muaddab, H. (2024). Promoting Green Skill and Green Vocational Education for A Circular Economy : A Literature Review. *Journal Of Education: Development And Review (JEDAR)*, 01(January), 8–20. Retrieved from <https://pub.ruangrosadi.com/jurnal-ilmiah/index.php/jedar/article/view/2>
- Muaddab, H., Zunitasari, I., & Martha, J. A. (2024). Problematika Green Skill Terhadap Kesiapan. *Research and Development Journal Of Education*, 10(1), 460–470. <https://doi.org/10.30998/rdje.v10i1.23324>
- Okoye, M. C., Hui, X., & David, A. M. (2025). Comparative analysis of technical and vocational education and training systems in China and Sub-Saharan Africa for sustainable development. *Discover Education*, 4, 535. <https://doi.org/10.1007/s44217-025-00965-x>
- Ortiz, E. J. M. (2025). An Integrated Competency-Based Framework for Employability and the Sustainability of Higher Education. *Sustainability*, 17, 1–23. <https://doi.org/10.3390/su172210340>
- Copyright:
- Pinatik, H. F., Tooy, D., & Rumambi, D. P. (2025). Analysis of the Potential of Fresh Fruit Health Drink Agroindustry for Creative Food Business Education for Agricultural Students in Manado City. *Jurnal Penelitian Pendidikan IPA*, 11(3), 564–572. <https://doi.org/10.29303/jppipa.v11i3.10638>
- Purba, S., Purba, E. M., Panjaitan, K., Hasan, A., & Ginting, L. M. (2024). Analysis of the Implementation of the Contextual Science Teaching Factory Learning Model at the Medan City Center of Excellence Vocational School. *Jurnal Penelitian Pendidikan IPA*, 10, 74–81. <https://doi.org/10.29303/jppipa.v10iSpecialIssue.7973>
- Qi, Z., Wang, J., Du, Y., & Zhang, X. (2026). The effect of blended learning approaches on vocational school students' practical skills performance and learning behaviors: virtual simulations or hands-on activities while accessing instructional videos. *Instructional Science*, 54(39), 1–23. <https://doi.org/10.1007/s11251-026-09793-4>
- Rantschl, M., Ramsauer, C., Wolf, M., Herst, P., & Magana, A. J. (2025). Reality Immersive learning factories for promoting experiential manufacturing education and STEM competency development. *Computers & Education: X Reality Journal*, 7(July). <https://doi.org/10.1016/j.cexr.2025.100125>
- Sakao, R. T., Bocken, N., Nasr, N., Umeda, Y., & En, R. (2024). Implementing circular economy activities in manufacturing for environmental sustainability. *CIRP Annals - Manufacturing Technology*, 73(2), 457–481. <https://doi.org/10.1016/j.cirp.2024.06.002>
- Saputra, D. A., Suartini, T., Yanti, T. M., Harja, S. L., & Damayanti, S. A. (2026). From Classroom to Industry : What Truly Improves Green Skills in Indonesian Vocational High Schools ? *Jurnal Penelitian Pendidikan IPA*, 12(1), 53–68. <https://doi.org/10.29303/jppipa.v12i1.13244>
- Shamzzuzoha, A., Chavira, P. C., Kekäle, T., Kuusniemi, H., & Jovanovski, B. (2022). Identified necessary skills to establish a center of excellence in vocational education for green innovation. *Cleaner Environmental Systems*, 7, 100100. <https://doi.org/10.1016/j.cesys.2022.100100>
- Silina-Jasjukevič. (2025). Promoting Effective Vocational Education and Training Teacher' s Professional Development and Its Transfer to Practice : A Systematic Review. *Education S*, 15(5), 596. <https://doi.org/10.3390/educsci15050596>
- Sourgiadaki, M., & Karkalakos, S. (2023). “ GreenComp ” as a tool for examining motivation of vocational teachers to create learning opportunities for the green transition. *SN Social Sciences*, 3(7), 1–27. <https://doi.org/10.1007/s43545-023-00699-3>
- Storonyanska, I., Benovska, L., Patytska, K., Ivashko, O., & Chulipa, I. (2025). Redesigning Sustainable Vocational Education Systems to Respond to Global Economic Trends and Labor Market Demands: Evidence from EU Countries on SDGs. *Sustainability*, 17(21), 9530.

- <https://doi.org/10.3390/su17219530>
- Sukmawati, F., Cahyono, B. T., Santoso, E. B., Prihatin, R., & Juwita, R. (2024). Implementation of Project Based Learning Model in Vocational High School : A systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, 10(12), 890–901. <https://doi.org/10.29303/jppipa.v10i12.8847>
- Susilowati, S., Evawati, D., Karyanto, Y., & Asmaul, R. (2024). Quick Analysis of The Applied Teaching Factory in The Independent Learning Curriculum Towards the Readliness of Enterpreneurship. *Jurnal Penelitian Pendidikan IPA*, 10(11), 9087–9096. <https://doi.org/10.29303/jppipa.v10i11.9256>
- Suwandi, A., Muktiarni, Fitriyani, E., & Setiad, R. P. (2023). Implementasi Program Teaching Factory ( Tefa ) Berbasis Unit Kewirausahaan Siswa Di Smk Kepariwisataan Bandung. *Jurnal Ilmiah Global Education*, 4(4), 2215–2226. <https://doi.org/10.55681/jige.v4i4.1398>
- Vitalocca, D., Suherman, A., Rohendi, D., Yulia, C., & Abdullah, A. G. (2026). Integrating computational thinking and green skills in vocational education through the bridging learning green informatics framework. *Discover Education*, 5, 99. <https://doi.org/10.1007/s44217-025-01095-0>
- Wickramasinghe, G. L. D., & Wickramasinghe, V. (2026). Implementation of sustainability into training , upskilling , and reskilling curricula of technical and vocational education and training in south and southeast Asia. *Discover Sustainability*, 7, 511. <https://doi.org/10.1007/s43621-026-02917-3>
- Widiatna, A. D., Utami, P. P., & Kemal, I. (2025). Implementing and Managing the Teaching Factory Learning Model at Vocational Schools. *Jurnal Penelitian Pendidikan IPA*, 11(5), 341–351. <https://doi.org/10.29303/jppipa.v11i5.10944>
- Yang, W., Chinedu, C. C., Chen, W., Saleem, A., Ogunniran, M. O., Ñacato Estrella, D. R., & Vaca Barahona, B. R. (2024). Building Capacity for Sustainability Education: An Analysis of Vocational Teachers' Knowledge, Readiness, and Self-Efficacy. *Sustainability (Switzerland)*, 16(9). <https://doi.org/10.3390/su16093535>
- Ye, J. H., He, Z., Bai, B., & Wu, Y. F. (2024). Sustainability of Technical and Vocational Education and Training ( TVET ) along with Vocational Psychology. *Behavioral Sciences*, 14, 859. <https://doi.org/10.3390/bs14100859>