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The Effectiveness of Scientific Creativity-Based Teaching Factory in Improving Vocational Students' Soft Skills: A Mixed Methods Approach in Renewable Energy Engineering

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Abstract

This study aimed to examine the effectiveness of scientific creativity-based Teaching Factory in improving vocational students' soft skills in the Renewable Energy Engineering Program. The study employed a sequential explanatory mixed methods design with a quasi-experimental pretest-posttest control group design. The participants were 44 Grade XI students, consisting of 22 students in the experimental group and 22 students in the control group. Quantitative data were collected using a soft skills scale covering communication, collaboration, problem solving, responsibility, and adaptability. Qualitative data were obtained through semi-structured interviews with students and a vocational teacher. The results showed that the experimental group's soft skills score increased from 67.45 to 85.50, while the control group increased from 60.77 to 67.36. The experimental group achieved a moderate N-gain of 0.55, whereas the control group obtained a low N-gain of 0.15. ANCOVA indicated a significant group effect after controlling for pretest scores, $F(1, 41) = 147.92$, $p < .001$. The qualitative findings revealed that the improvement in soft skills was supported by students' engagement in real problem identification, group work, idea communication, solar-panel lighting system testing, technical problem solving, product revision, reflection, and teacher feedback. This approach has the potential to strengthen contextual, collaborative, and workplace-oriented vocational learning, although its implementation requires adequate learning materials, practical facilities, and consistent teacher guidance at school.

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INTRODUCTION

Vocational education plays a strategic role in preparing graduates who are able to participate productively in the world of work. This role has become increasingly important because technological development, changes in job structures, and industrial demands require graduates who not only master technical skills but are also able to communicate, work in teams, solve problems, and adapt to dynamic work situations. Thus, vocational education can no longer be understood merely as a pathway for practical skills training, but as a learning system that connects knowledge, technical skills, work experience, and the development of professional attitudes. Several studies have shown that the quality of vocational education is closely related to work readiness, employability, and the successful transition of students from school to the workplace, particularly when the learning process is aligned with industrial needs and real work experience (Kamaliah et al., 2018; Qin, 2024; Yousfani et al., 2021).

In the Indonesian context, vocational high schools are among the main institutions responsible for preparing middle-level workers across various fields of expertise. However, the readiness of vocational graduates cannot be measured solely by their ability to perform technical procedures or use work equipment. Business and industry sectors also require nontechnical competencies, such as communication, collaboration, problem solving, responsibility, discipline, and adaptability. These competencies are commonly referred to as soft skills and are an important factor in graduates' success in entering and remaining in the workplace. Several studies have shown that soft skills make an important contribution to the work readiness of vocational graduates and, in many situations, distinguish graduates who are merely able to complete technical tasks from those who are able to develop within complex work environments (Febriyana et al., 2023; Hartanto, 2017; Robles, 2012; Wulaningrum & Hadi, 2019).

Despite their importance, the development of soft skills in vocational learning is still often positioned as an implicit goal. Students are indeed involved in practical activities, but these activities are not always deliberately designed to develop communication, teamwork, problem solving, responsibility, and adaptability. In many vocational learning settings, the achievement of technical competence remains more dominant than the development of measurable and observable soft skills. This condition may create a gap between the competencies developed at school and those expected by the workplace. Nurrohmawati et al. (2023) emphasized that a skills mismatch among vocational graduates may occur when soft skills development is not systematically integrated into the learning process. This is consistent with Okoye and Nkanu (2020), who positioned soft skills as one of the essential requirements for technical and vocational education graduates to work effectively in industrial environments.

The need to integrate technical skills and soft skills has become increasingly relevant in the Renewable Energy Engineering Program. The renewable energy sector has developed in response to the need for sustainable energy, the reduction of dependence on fossil fuels, and growing attention to environmental issues. Vocational education in this field needs to prepare students to understand the principles and applications of solar, hydro, and wind energy technologies, including the design, installation, testing, maintenance, and troubleshooting of energy systems. However, work in the renewable energy sector does not only require the ability to install or operate technical systems. Graduates also need to be able to work in teams, communicate with users or partners, adjust designs to local conditions, and make decisions based on data and evaluation results. Therefore, renewable energy education requires a learning approach that is oriented not only toward technical procedures but also toward contextual problem solving and the development of socio-professional competencies (Fang et al., 2021; Lee et al., 2025; Mueller et al., 2020).

One approach considered relevant for bridging school-based learning and workplace needs is Teaching Factory. Teaching Factory provides learning experiences that resemble industrial production processes within the school environment. Through this approach, students do not merely participate in laboratory or workshop practice that is separated from the work context, but are involved in a sequence of activities that is closer to industrial processes, such as work planning, role distribution, the use of tools and materials, production, quality control, evaluation, and product improvement. This approach provides opportunities for students to experience work situations that require coordination, communication, responsibility, and problem solving. Previous studies have shown that Teaching Factory can improve vocational students' work readiness and competencies when implemented with adequate support for instructional planning, practical facilities, and student engagement (Indramayanti et al., 2024; Irfan et al., 2024; Tanjung et al., 2025; Wahjusaputri & Bunyamin, 2022).

However, the implementation of Teaching Factory does not automatically produce transformative learning. In certain practices, Teaching Factory may shift into routine production activities that emphasize only compliance with procedures and task completion. If students merely follow teacher instructions or imitate industrial workflows without opportunities to analyze problems, propose ideas, test alternatives, and revise products, then the potential of Teaching Factory to develop soft skills becomes limited. Prastiantomo et al. (2023) cautioned that project- or production-based activities need to be accompanied by explicit assessment, feedback, and reflection so that they do not stop at technical collaborative work. Therefore, the success of Teaching Factory as a vocational learning approach depends strongly on the quality of its pedagogical design, not merely on the existence of production activities at school.

In this context, scientific creativity becomes an important element that can strengthen Teaching Factory. Scientific creativity can be understood as the ability to use scientific and technological knowledge flexibly to generate new solutions, modify designs, test alternatives, evaluate results, and improve products based on evidence. In the field of renewable energy, scientific creativity may emerge when students adjust the position of solar panels to lighting conditions, analyze why a system does not function, select appropriate components, or improve a design based on testing results. Integrating scientific creativity into Teaching Factory enables learning to be oriented not only toward production, but also toward scientific thinking, technical innovation, and reflection on the quality of solutions. Studies related to project-based learning, STEM, and Teaching Factory have shown that creativity and problem solving are more likely to develop when students are confronted with authentic problems, given opportunities to explore ideas, and involved in the process of evaluating and revising products (Dhani & Kristiani, 2021; Muliyati et al., 2023; Riwayani et al., 2024; Roemintoyo et al., 2021; Samsuri et al., 2024).

Scientific creativity-based Teaching Factory has the potential to develop soft skills because learning takes place through technical activities that simultaneously require social interaction and decision making. Students need to identify problems, express ideas, discuss alternative solutions, divide tasks, test their work, face technical challenges, receive feedback, and make revisions. These activities allow communication to develop functionally because students need to explain ideas and work results. Collaboration develops because the project requires coordination among group members. Problem solving and adaptability develop because students encounter conditions that do not always match the initial plan. Responsibility develops because the success of the product depends on each group member's contribution. Thus, soft skills are not positioned as additional content, but become part of a structured vocational learning experience.

Although Teaching Factory, soft skills, and renewable energy learning have been widely discussed in the literature, studies that specifically integrate scientific creativity-based Teaching Factory to improve vocational students' soft skills in the Renewable Energy Engineering Program remain limited. Some Teaching Factory studies have focused on work readiness, technical competence, or strengthening school-industry relationships. Other studies have discussed scientific creativity and project-based learning, but few have positioned them as a pedagogical basis for Teaching Factory in the context of renewable energy. In fact, renewable energy provides a rich learning context for integrating technical skills, scientific creativity, and soft skills because students can work on real problems such as solar panel systems, the use of local energy, system efficiency, and technological adaptation to the environment. This gap forms the main basis for the present study.

Research Objectives and Questions

This study aimed to analyze the effectiveness of scientific creativity-based Teaching Factory in improving vocational students' soft skills in the Renewable Energy Engineering Program. The soft skills examined in this study included communication, collaboration, problem solving, responsibility, and adaptability. In addition to quantitatively examining the effectiveness of the approach, this study also aimed to explain how learning experiences in scientific creativity-based Teaching Factory contributed to the improvement of students' soft skills.

Based on these objectives, this study addressed the following research questions.

1. How effective is scientific creativity-based Teaching Factory in improving vocational students' soft skills in the Renewable Energy Engineering Program?
2. How do learning experiences in scientific creativity-based Teaching Factory contribute to the improvement of students' communication, collaboration, problem solving, responsibility, and adaptability?

Novelty of the Study

The novelty of this study lies in the explicit integration of Teaching Factory, scientific creativity, and soft skills development in the context of the Renewable Energy Engineering Program. Previous studies have shown that Teaching Factory can strengthen vocational students' work readiness and competencies through learning that brings the school environment closer to industrial work processes (Indramayanti et al., 2024; Tanjung et al., 2025). However, most of these studies still position Teaching Factory primarily as a production simulation model, a strategy for strengthening technical competence, or a link-and-match approach with industry. The present study differs because it does not merely position Teaching Factory as a semi-realistic production environment, but also as a pedagogical space for developing scientific creativity and soft skills simultaneously.

This study also differs from research that emphasizes creativity in Teaching Factory in general. Samsuri et al. (2024), for example, linked scientific creativity-based Teaching Factory with soft skills and sustainable entrepreneurship. However, the present study extends that focus to a more specific context, namely the Renewable Energy Engineering Program through a project based on a solar-panel lighting system. This context is important because renewable energy learning requires students not only to understand installation and system testing procedures, but also to identify real problems, adjust designs to environmental conditions, work in groups, and make decisions based on technical evaluation results.

Therefore, the main novelty of this study can be formulated in three aspects. First, this study applies Teaching Factory not only as a production-based approach but as a scientific creativity-based approach through activities involving problem identification, solution design, testing, analysis of technical constraints, and product revision. Second, this study positions soft skills as explicitly designed learning outcomes, including communication, collaboration, problem solving, responsibility, and adaptability, rather than as incidental outcomes of vocational practice. Third, this study presents renewable energy as a vocational learning context that connects technical skills, scientific creativity, and soft skills through a contextual project closely related to the needs of the school environment.

METHODS

Research Design

This study employed a mixed methods approach with a sequential explanatory design. This design was selected because the study aimed not only to examine the effectiveness of scientific creativity-based Teaching Factory in improving students' soft skills, but also to explain the learning experiences that contributed to these changes. In accordance with the principles of a sequential explanatory design, quantitative data were collected and analyzed first, followed by qualitative data collection to deepen the interpretation of the quantitative findings (Creswell, 2009).

In the quantitative phase, the study used a quasi-experimental pretest-posttest control group design. Two groups were involved, namely an experimental group and a control group. The experimental group participated in learning using scientific creativity-based Teaching Factory, whereas the control group received expository learning. Both groups were given a pretest before the treatment and a posttest after the learning activities were completed. The pretest was administered to identify students' initial soft skills and to provide a statistical basis for controlling possible initial differences between the experimental and control groups.

Students were assigned to the research groups based on existing classes or learning groups at the school. Thus, the treatment assignment was conducted at the class level rather than at the individual level. This characteristic made the study more appropriately understood as quasi-experimental because the researcher did not fully control the individual grouping of students. Therefore, data analysis did not rely solely on posttest comparisons or improvement scores, but also used analysis of covariance (ANCOVA) to control pretest scores as a covariate. This strategy was used to provide a more cautious estimate of the effectiveness of the approach and to reduce the influence of initial score differences between groups.

The qualitative phase was conducted after the initial analysis of the quantitative data. Qualitative data were obtained through semi-structured interviews with students and a vocational teacher. The interviews were used to explore students' experiences during the scientific creativity-based Teaching Factory project, including collaboration dynamics, idea communication, technical problem-solving strategies, product revision, and the supporting and inhibiting factors in the implementation of the approach. Thus, the qualitative data served to explain the learning mechanisms that may have contributed to the improvement of students' soft skills.

Research Participants

The study was conducted at State Vocational High School 1 Pringgabaya with Grade XI students in the Renewable Energy Engineering Program, specializing in Solar, Hydro, and Wind Energy Engineering (TESHA). This context was selected because the characteristics of the program were aligned with the objectives of the study. The Renewable Energy Engineering Program requires students to master technical competencies in solar, hydro, and wind energy while also developing soft skills such as communication, collaboration, problem solving, responsibility, and adaptability. The learning characteristics of this field also allow the implementation of contextual projects that are consistent with the principles of Teaching Factory and scientific creativity.

The number of participants in the quantitative phase was 44 students. A total of 22 students were in the experimental group and 22 students were in the control group. All participants were Grade XI students in the same vocational program. In the experimental group, there were 14 male students and 8 female students. In the control group, there were 21 male students and 1 female student. Based on age, the participants ranged from 16 to 18 years old, with the majority being 17 years old.

In addition to students, one vocational teacher who was directly involved in the learning implementation was also included as a qualitative informant. The teacher provided information regarding learning readiness, implementation of the approach, student responses, observed changes in soft skills, implementation barriers, and factors supporting the success of the learning process. Student informants in the qualitative phase were selected purposively from the experimental group by considering variations in learning experiences and changes in soft skills during the project.

Implementation Procedure

The study was conducted through five main stages: learning preparation, pretest, treatment implementation, posttest, and qualitative data collection. During the preparation stage, the researchers prepared learning materials for both the experimental and control groups. The materials for the experimental group included a scientific creativity-based Teaching Factory project scenario, student worksheets, group role distribution, tools and practical materials, and a soft skills assessment rubric. The teacher who implemented the learning activities was given orientation regarding the characteristics of the approach so that the activities would not stop at procedural practice, but would also facilitate problem identification, idea generation, testing, problem solving, product revision, and reflection.

The next stage was the pretest. The initial measurement of soft skills was administered to both the experimental and control groups before the treatment began. The pretest data were used to describe students' initial conditions and to serve as the basis for analyzing the initial equivalence between groups. Because the study involved intact classes, pretest information was important to ensure that the interpretation of effectiveness was not based solely on students' final conditions after learning.

During the implementation stage, the experimental group participated in scientific creativity-based Teaching Factory through a renewable energy project involving the development of a solar-panel lighting system. The activity began with orientation to a real problem, namely the need for lighting in the school environment. Students then worked in groups to observe the problem, discuss alternative solutions, prepare a work plan, divide roles, prepare tools and materials, install components, test the system, and evaluate their work. When technical problems occurred, such as the lamp not turning on or the connections not functioning properly, students were guided to inspect the circuit, check polarity, battery, cables, and controller, and then make improvements based on the inspection results. At the end of the activity, students reflected on the work process and revised the product based on testing results and teacher feedback.

The control group received expository learning on the topic of renewable energy. Learning was conducted through teacher explanation, question-and-answer sessions, demonstrations, and routine exercises. The material was aligned with the learning topic and the time allocation was equivalent to that of the experimental group. However, the control group did not experience scientific creativity-based Teaching Factory, such as contextual production projects, exploration of alternative designs, project-based role distribution, systematic product testing, product revision, and structured reflection on soft skills.

After all learning activities were completed, both groups were given a posttest. This final measurement was used to identify changes in students' soft skills after the treatment. In the final stage, semi-structured interviews were conducted with students in the experimental group and the vocational teacher. Student interviews focused on their experiences in identifying project problems, working in groups, communicating ideas, dealing with technical challenges, revising products, and perceiving changes in their soft skills. The teacher interview focused on implementation readiness, student responses, changes in communication, collaboration, problem solving, learning barriers, and factors supporting the implementation of the approach.

Instruments and Data Collection

Quantitative data were collected using a soft skills scale administered during the pretest and posttest. This instrument was used to measure five dimensions of soft skills: communication, collaboration, problem solving, responsibility, and adaptability. The scores for each dimension were summed to obtain the total soft skills score, ranging from 0 to 100. The total score was used to assess students' soft skills before and after learning. The interpretation of soft skills scores was based on three categories. Scores from 0 to 59 were categorized as low, scores from 60 to 79 as moderate, and scores from 80 to 100 as high. These categories were used to interpret students' achievement in the pretest and posttest. Meanwhile, improvement in soft skills was analyzed using normalized gain (N-gain).

Before use, the soft skills instrument was reviewed to ensure the alignment between the items and the indicators being measured. The communication dimension included the ability to express opinions, ask questions, engage in discussions, and present work results. The collaboration dimension included the ability to share roles, help group members, and complete tasks collectively. The problem-solving dimension included the ability to identify problems, analyze causes, and try alternative solutions. The responsibility dimension included the commitment to completing tasks and maintaining the quality of work. The adaptability dimension included the ability to adjust actions, accept feedback, and improve results based on evaluation.

Qualitative data were collected through semi-structured interviews. The student interview guide covered experiences in participating in the scientific creativity-based Teaching Factory project, group work processes, idea communication, technical challenges, product revision, and perceived changes in soft skills. The teacher interview guide covered learning readiness, student responses, observed changes in soft skills, implementation barriers, and factors supporting the success of the approach. Interview data were used to strengthen and explain the quantitative findings, particularly regarding the learning processes that contributed to the improvement of students' soft skills.

Data Analysis

Quantitative data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to calculate the mean (M), standard deviation (SD), minimum score, maximum score, N-gain, and the distribution of score categories and N-gain categories. N-gain was calculated using the following formula:

$$\textit{N-gain} = (\textit{posttest score} - \textit{pretest score}) \,/\, (\textit{maximum score} - \textit{pretest score})$$

The maximum score used was 100. The N-gain categories were determined as follows: an N-gain of less than 0.30 was categorized as low, an N-gain between 0.30 and less than 0.70 was categorized as moderate, and an N-gain of 0.70 or higher was categorized as high. For dimension-level analysis, N-gain was calculated based on group means because one dimension contained maximum pretest scores, making individual dimension-level N-gain calculations unstable for the entire dataset.

Before examining the effectiveness of the approach, the pretest scores of the experimental and control groups were compared using an independent-samples t-test. This test was used to examine the initial equivalence of students' soft skills between the two groups. The improvement of soft skills within each group was analyzed using a paired-samples t-test. Furthermore, differences in improvement between the experimental and control groups were analyzed using an independent-samples t-test on N-gain scores.

Because the pretest results indicated initial differences between the experimental and control groups, the main analysis of effectiveness was conducted using ANCOVA. In this analysis, the posttest score was treated as the dependent variable, the learning group as the independent variable, and the pretest score as the covariate. ANCOVA was used to test whether the difference in posttest scores between the experimental and control groups remained significant after controlling for initial scores. The assumptions of ANCOVA included residual normality using the Shapiro-Wilk test, homogeneity of residual variance using Levene's test, and homogeneity of regression slopes through the interaction test between pretest scores and group. ANCOVA was also applied to each soft skills dimension to examine the effect of the approach on communication, collaboration, problem solving, responsibility, and adaptability.

Effect sizes were reported to strengthen the interpretation of the findings. Cohen's d was used to assess the magnitude of differences between groups in the pretest and N-gain scores. The paired-samples effect size (dz) was used to describe the magnitude of improvement within each group in the paired-samples t-test. Partial eta squared (η_p^2) was used in ANCOVA to indicate the proportion of variance in posttest scores explained by group differences after controlling for pretest scores.

Qualitative data were analyzed using thematic analysis. The analysis stages included repeated reading of interview data, initial coding, grouping codes into provisional themes, and determining final themes. The themes developed included real problem identification, collaboration in the project, creative idea communication, technical problem solving, product revision based on evaluation, implementation readiness, implementation barriers, and supporting factors for the approach. The qualitative findings were then integrated with the quantitative findings to explain how learning experiences in scientific creativity-based Teaching Factory contributed to the improvement of students' soft skills.

Ethical Approval

This study was conducted after obtaining permission from Universitas Pendidikan Mandalika and State Vocational High School 1 Pringgabaya. Before data collection, the principal, teacher, and students were informed about the purpose of the study, implementation procedures, forms of participant involvement, and the use of research data. Participants' identities were kept confidential by using anonymous codes in data processing and reporting. Participants were also given the right to refuse or withdraw from the study without academic consequences. Interviews and documentation were conducted after obtaining consent from the participants involved.

RESULTS AND DISCUSSION

Scientific creativity-based Teaching Factory showed a stronger pattern of improvement in students' soft skills than expository learning. This difference was reflected in changes in total scores, the distribution of achievement categories, *N*-gain improvement in each soft skills dimension, and inferential test results after students' initial scores were statistically controlled. Qualitative findings from students and the teacher also indicated that the improvement in soft skills was related to learning experiences involving real projects, group work, idea communication, technical problem solving, product evaluation, and product revision.

The measurement results showed that both groups experienced an increase in soft skills scores after learning, but the improvement in the experimental group was greater than that in the control group. The experimental group, which participated in scientific creativity-based Teaching Factory, increased from a pretest mean score of 67.45 to a posttest mean score of 85.50. Thus, the soft skills achievement of the experimental group shifted from the moderate category to the high category. Meanwhile, the control group, which received expository learning, increased from 60.77 to 67.36 but remained in the moderate category. The descriptive statistics of students' total soft skills scores are presented in Table 1.

Table 1. Descriptive statistics of students' total soft skills scores

Group	*n*	Pretest *M* ± *SD*	Category	Posttest *M* ± *SD*	Category	*N*-gain *M* ± *SD*	Category
Experimental	22	67.45 ± 3.40	Moderate	85.50 ± 4.26	High	0.55 ± 0.13	Moderate
Control	22	60.77 ± 6.35	Moderate	67.36 ± 3.63	Moderate	0.15 ± 0.14	Low

The data in Table 1 show that scientific creativity-based Teaching Factory produced a stronger improvement than expository learning. This difference was evident not only in the posttest scores but also in the *N*-gain values. The experimental group obtained a mean *N*-gain of 0.55, which was in the moderate category, whereas the control group obtained an *N*-gain of 0.15, which was in the low category. Substantively, these findings indicate that production project-based learning linked to scientific creativity provides broader learning opportunities for students to develop communication, collaboration, problem solving, responsibility, and adaptability.

The improvement in the control group should still be acknowledged. Expository learning can help students understand the material, follow demonstrations, and complete routine exercises. However, this improvement was more limited because students did not experience the full project work process, such as real problem identification, design exploration, project-based role distribution, product testing, revision, and structured reflection on soft skills. This difference reinforces the view that soft skills in vocational education cannot be sufficiently developed through explanation or ordinary technical exercises alone, but require learning situations that involve social interaction, work responsibility, and authentic problem solving. This finding is consistent with studies emphasizing that vocational graduates' employability is influenced by the combination of technical skills and soft skills, not only one of them (Robles, 2012; Okoye & Nkanu, 2020; Wulaningrum & Hadi, 2019).

To clarify the difference in improvement patterns between the experimental and control groups, the mean pretest and posttest scores are visualized in Figure 1. Figure 1 shows a different pattern of improvement between the two groups. Although both groups showed increased scores after learning, the increase in the experimental group was sharper than that in the control group. This indicates that scientific creativity-based Teaching Factory was more capable of promoting changes in students' soft skills achievement than expository learning.

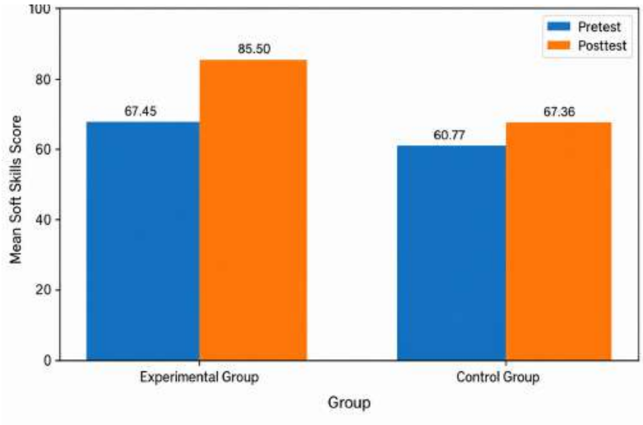

Figure 1. Mean pretest and posttest soft skills scores in the experimental and control groups

Category distribution analysis was used to examine changes in students' soft skills achievement at the individual level. The results showed that all students in the experimental group were in the moderate category before the treatment. After participating in scientific creativity-based Teaching Factory, 20 students, or 90.91%, reached the high category, while 2 students, or 9.09%, remained in the moderate category. In the control group, 5 students, or 22.73%, were in the low category at the pretest, and 17 students, or 77.27%, were in the moderate category. After expository learning, all students in the control group were in the moderate category, but none reached the high category. The distribution of students' total soft skills score categories is presented in Table 2.

Table 2. Distribution of students' total soft skills score categories

Group	Stage	Low	Moderate	High	Total
Experimental	Pretest	0 std. or 0.00%	22 std. or 100.00%	0 std. or 0.00%	22
	Posttest	0 std. or 0.00%	2 std. or 9.09%	20 std. or 90.91%	22
Control	Pretest	5 std. or 22.73%	17 std. or 77.27%	0 std. or 0.00%	22
	Posttest	0 std. or 0.00%	22 std. or 100.00%	0 std. or 0.00%	22

The distribution pattern in Table 2 shows that the improvement in the experimental group did not occur only at the group mean level, but was also experienced by most students individually. In contrast, expository learning was able to move students from the low category to the moderate category, but was not strong enough to push students' achievement into the high category. In other words, scientific creativity-based Teaching Factory had a stronger driving effect on the transformation of students' soft skills achievement.

In addition to the distribution of total score categories, students' improvement was also analyzed using *N*-gain categories. The distribution of students' soft skills *N*-gain categories is presented in Table 3.

Table 3. Distribution of students' soft skills ***N*-gain** categories

Group	Low	Moderate	High	Total
Experimental	0 std. or 0.00%	18 std. or 81.82%	4 std. or 18.18%	22
Control	18 std. or 81.82%	4 std. or 18.18%	0 std. or 0.00%	22

Table 3 shows that no student in the experimental group was in the low *N*-gain category. A total of 18 students, or 81.82%, were in the moderate category, and 4 students, or 18.18%, reached the high category. In contrast, in the control group, 18 students, or 81.82%, were in the low category, and only 4 students, or 18.18%, were in the moderate category. No students in the control group reached the high *N*-gain category.

To visually show the difference in improvement distribution, the *N*-gain categories in the experimental and control groups are presented in Figure 2.

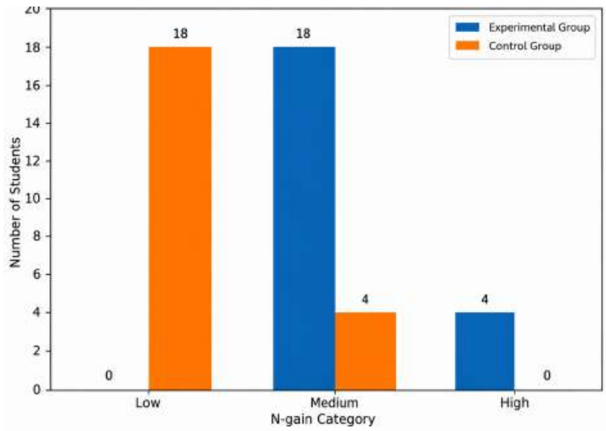

Figure 2. Distribution of students' soft skills *N*-gain categories

Figure 2 reinforces that scientific creativity-based Teaching Factory produced a more even and stronger pattern of improvement among students. Most students in the experimental group were in the moderate *N*-gain category, and some reached the high category. In contrast, most students in the control group were in the low category. This finding provides a basis for arguing that real project-based learning does not benefit only a few students, but has the potential to facilitate soft skills improvement among most members of the class.

Dimension-level analysis was conducted to determine whether soft skills improvement occurred across all measured aspects. The five dimensions analyzed were communication, collaboration, problem solving, responsibility, and adaptability. The results showed that all dimensions in the experimental group improved with moderate *N*-gain. In the control group, all dimensions also improved, but remained in the low *N*-gain category. The descriptive statistics of soft skills by dimension are presented in Table 4.

Table 4. Descriptive statistics of soft skills by dimension

Dimension	Group	Pretest *M* ± *SD*	Posttest *M* ± *SD*	*N*-gain	Category
Communication	Experimental	13.50 ± 0.96	17.00 ± 0.98	0.54	Moderate
	Control	12.32 ± 1.29	13.55 ± 1.14	0.16	Low
Collaboration	Experimental	14.27 ± 0.88	17.73 ± 1.12	0.60	Moderate
	Control	13.09 ± 1.74	13.73 ± 1.35	0.09	Low
Problem solving	Experimental	13.05 ± 1.00	16.68 ± 1.46	0.52	Moderate
	Control	10.95 ± 2.34	12.14 ± 2.42	0.13	Low
Responsibility	Experimental	14.09 ± 1.57	17.32 ± 1.09	0.55	Moderate
	Control	13.95 ± 1.62	15.00 ± 1.35	0.17	Low
Adaptability	Experimental	12.55 ± 1.60	16.77 ± 1.69	0.57	Moderate
	Control	10.45 ± 2.52	12.95 ± 1.62	0.26	Low

In the experimental group, all soft skills dimensions were in the moderate *N*-gain category. The highest *N*-gain was found in the collaboration dimension at 0.60, followed by adaptability at 0.57, responsibility at 0.55, communication at 0.54, and problem solving at 0.52. This pattern indicates that the solar-panel lighting project provided sufficient opportunities for students to coordinate in groups, adjust actions to field conditions, take responsibility for their respective roles, express ideas, and solve technical problems based on testing results.

The collaboration dimension showed the highest N-gain in the experimental group. This can be understood because scientific creativity-based Teaching Factory required students to work in groups, divide roles, agree on work steps, prepare tools and materials, install components, and evaluate the results of their work. Such activities encouraged positive interdependence among group members. Students did not work only individually, but had to ensure that each member's work contributed to the success of the product as a whole.

The adaptability dimension also showed strong improvement. In the renewable energy project, students encountered technical situations that did not always proceed as planned. When the lamp did not turn on or the panel position was not optimal, students needed to adjust strategies, recheck the circuit, repair connections, and change component positions based on evaluation results. Adaptability developed because students directly experienced situations that required changes in action, not merely because they received explanations about the importance of flexibility at work.

Problem solving developed through practical activities that required technical reasoning. When the system did not function, students needed to check cable connections, polarity, battery, controller, and other components. This process required the ability to diagnose the causes of problems, test possible solutions, and determine corrective actions. Thus, problem solving did not develop through memorizing procedures, but through experiences in overcoming technical challenges in a real project. This finding supports the view that project-based learning and Teaching Factory can become spaces for developing scientific creativity when students are involved in designing, testing, evaluating, and revising products (Dhani & Kristiani, 2021; Roemintoyo et al., 2021; Samsuri et al., 2024).

The improvement in communication can be understood from students' need to express ideas, ask questions, discuss, report testing results, and present products. Communication in this context was functional because it emerged from the need to complete the project. Students spoke not merely to fulfill the teacher's instructions, but because they needed to explain ideas, agree on designs, clarify mistakes, and communicate work results. The same applies to the responsibility dimension. Students did not merely complete routine exercises, but had to ensure that their part of the work contributed to the success of the group product. However, responsibility as a work habit still requires longer habituation, teacher supervision, and a clear assessment mechanism. To compare improvement across dimensions, the mean N-gain of the experimental and control groups is presented in Figure 3.

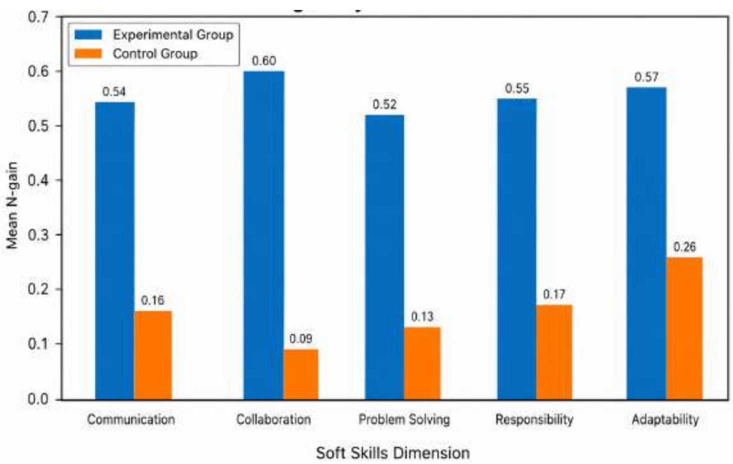

Figure 3. Mean N-gain of soft skills by dimension

Figure 3 shows that the experimental group obtained higher N-gain than the control group across all dimensions. The largest N-gain difference was found in collaboration, followed by problem solving, communication, responsibility, and adaptability. This pattern indicates that scientific creativity-based Teaching Factory most strongly influenced socio-interactive dimensions, particularly collaboration and communication, because the project required students to coordinate intensively during planning, implementation, testing, and revision.

Before the effectiveness of the approach was tested, the pretest scores of the experimental and control groups were compared to examine initial equivalence. The independent-samples *t*-test showed a significant difference between the experimental and control groups in pretest scores, $t(42) = 4.35$, $p < .001$, with $d = 1.31$. The experimental group had higher initial scores than the control group. The results of the pretest score comparison are presented in Table 5.

Table 5. Results of pretest soft skills score between the experimental and control groups

Comparison	Exp. pretest $M \pm SD$	Cont. pretest $M \pm SD$	t	df	p	d	Decision
Experimental vs. control	67.45 ± 3.40	60.77 ± 6.35	4.35	42	< .001	1.31	Significantly different

The finding in Table 5 is methodologically important. Because the two groups were not fully equivalent at the beginning of the study, the interpretation of effectiveness cannot rely only on posttest or *N*-gain comparisons. The initial difference may influence final achievement. Therefore, ANCOVA was used to control the pretest score as a covariate. This approach makes the interpretation of the results more cautious and consistent with the characteristics of a quasi-experimental study.

Before ANCOVA was conducted, assumption tests were performed to ensure residual normality, homogeneity of residual variance, and homogeneity of regression slopes. The results of the ANCOVA assumption tests are presented in Table 6.

Table 6. Results of ANCOVA assumption tests for total soft skills scores

Assumption	Statistic	p	Decision
Residual normality	Shapiro-Wilk $W = 0.969$	.278	Met
Homogeneity of residual variance	Levene's $F = 1.073$	.306	Met
Homogeneity of regression slopes	$F = 0.077$	.783	Met

Table 6 shows that the residuals were normally distributed, the residual variances were homogeneous, and there was no violation of the homogeneity of regression slopes. Therefore, the use of ANCOVA was considered appropriate to test posttest score differences after controlling for pretest scores.

A paired-samples *t*-test was used to examine the improvement in soft skills from pretest to posttest within each group. The results of the paired-samples *t*-test are presented in Table 7.

Table 7. Results of paired-samples ***t***-test for total soft skills scores

Group	Pretest $M \pm SD$	Category	Posttest $M \pm SD$	Category	t	df	p	dz
Experimental	67.45 ± 3.40	Moderate	85.50 ± 4.26	High	15.62	21	< .001	3.33
Control	60.77 ± 6.35	Moderate	67.36 ± 3.63	Moderate	4.57	21	< .001	0.98

Based on Table 7, both groups experienced a significant increase in soft skills scores from pretest to posttest. In the experimental group, the increase from 67.45 to 85.50 was significant,

$t(21) = 15.62$, $p < .001$, $dz = 3.33$. In the control group, the increase from 60.77 to 67.36 was also significant, $t(21) = 4.57$, $p < .001$, $dz = 0.98$. Nevertheless, the improvement in the experimental group was more substantively meaningful because it was accompanied by a shift in category from moderate to high. In the control group, the statistically significant increase did not result in a change in achievement category. This indicates that statistical significance needs to be interpreted together with achievement categories, effect sizes, and the learning context.

The difference in improvement between the experimental and control groups was tested using an independent-samples *t*-test on *N*-gain scores. The results of the *N*-gain comparison are presented in Table 8.

Table 8. Results of between-group comparison of N-gain

Variable	**Experimental *M* ± *SD***	**Control *M* ± *SD***	***t***	***df***	***p***	***d***
N-gain	0.55 ± 0.13	0.15 ± 0.14	9.56	42	< .001	2.88

Table 8 shows that the experimental group obtained a significantly higher *N*-gain than the control group. The value of $d = 2.88$ indicates a large effect. However, because the pretest scores differed significantly, the *N*-gain results should still be interpreted together with ANCOVA so that the interpretation of the approach's effectiveness is stronger and does not ignore differences in students' initial conditions.

ANCOVA was conducted to examine the difference in posttest scores between the experimental and control groups after controlling for pretest scores. The ANCOVA results for posttest soft skills scores are presented in Table 9.

Table 9. ANCOVA results for posttest soft skills scores

Source of variance	***F***	***df***	***p***	η_p^2
Pretest	0.43	1, 41	.513	.010
Group	147.92	1, 41	< .001	.783

Table 9 shows that after controlling for pretest scores, the posttest difference between the experimental and control groups remained significant, $F(1, 41) = 147.92$, $p < .001$, $\eta_p^2 = .783$. The adjusted posttest mean of the experimental group was 85.23, whereas that of the control group was 67.63. This result strengthens the evidence that scientific creativity-based Teaching Factory contributed to the improvement of students' soft skills after differences in initial ability were controlled. However, because the study used existing classes and not full individual randomization, causal interpretation must still be stated cautiously. This finding indicates strong effectiveness in the context of this study, but it does not mean that all variation in the results can be explained solely by the treatment. Class factors, student characteristics, teacher readiness, and facility support may also influence learning outcomes.

ANCOVA was also conducted for each soft skills dimension to examine the consistency of the effect of the approach. The ANCOVA results by soft skills dimension are presented in Table 10.

Table 10. ANCOVA results by soft skills dimension

Dimension	**Experimental adj. mean**	**Control adj. mean**	***F***	***p***	η_p^2
Communication	16.97	13.58	85.22	< .001	.675
Collaboration	17.71	13.74	92.14	< .001	.692
Problem solving	16.77	12.05	44.66	< .001	.521
Responsibility	17.31	15.01	38.72	< .001	.486
Adaptability	16.73	13.00	43.52	< .001	.515

Table 10 shows that the experimental group had higher adjusted means than the control group across all soft skills dimensions. All differences were significant with strong effect sizes. The largest effects were found in collaboration and communication. These results indicate that scientific creativity-based Teaching Factory not only improved soft skills in general, but also had an impact on each measured dimension. The largest effects on collaboration and communication can be explained by the nature of the project, which required intensive interaction. Students needed to share information, express suggestions, agree on task distribution, and present work results. The effects on problem solving and adaptability emerged because students faced technical challenges requiring rechecking, strategy adjustment, and design revision. Meanwhile, responsibility developed because each student held a specific role in completing the product.

Qualitative findings from students indicated that the improvement in soft skills was related to real project-based learning experiences. The solar-panel lighting project began with the identification of lighting needs in the school environment. This context made learning closer to students' lives and their field of expertise. Students did not merely receive material about renewable energy, but were asked to connect the material with real needs, discuss solutions, and produce a product that could be tested. A summary of the students' qualitative findings is presented in Table 11.

Table 11. Summary of students' qualitative findings

Theme	Main finding	Related soft skills dimensions	Interpretation
- Real problem identification through the project	Students observed lighting needs in the school environment and proposed a solar-panel lamp as a solution.	Problem solving, communication	Students learned to recognize contextual problems and communicate renewable energy-based solutions.
- Collaboration in project implementation	Students divided tasks, prepared tools and materials, installed components, recorded measurement results, and tested the lamp.	Collaboration, responsibility	The project encouraged students to carry out roles and help one another in practical work.
- Creative idea communication	Students expressed ideas about the installation location and panel tilt to obtain optimal sunlight.	Communication, adaptability	Students practiced communicating technical ideas and adjusting designs based on discussion.
- Technical problem solving	Students encountered a problem when the lamp did not turn on, then checked cable connections, polarity, battery, and controller.	Problem solving, adaptability	Students learned to diagnose causes of problems and try solutions based on circuit inspection.

Theme	Main finding	Related soft skills dimensions	Interpretation
- Product revision based on evaluation	Students repaired the circuit, tidied the connections, and adjusted component positions after receiving feedback.	Adaptability, responsibility	Students showed readiness to accept feedback and improve product quality.
- Integrated development of soft skills	Students felt more confident in speaking, working together, expressing opinions, solving practical problems, and taking responsibility.	All dimensions	Project activities were perceived as supporting the integrated development of soft skills.

The findings in Table 11 show that soft skills developed through a series of interconnected activities. Problem identification encouraged problem solving and communication. Role distribution encouraged collaboration and responsibility. Technical challenges encouraged problem solving and adaptability. Product evaluation and revision encouraged students to accept feedback and improve the quality of their work. Thus, the improvement in soft skills was not the result of a single activity, but of the whole learning experience that combined real contexts, group work, technical exploration, and reflection.

In addition to student data, the teacher interview provided information about implementation readiness, student responses, changes in learning behavior, barriers, and supporting factors for the approach. A summary of the teacher's qualitative findings is presented in Table 12.

Table 12. Summary of the teacher's qualitative findings

Focus of finding	Main result	Implication for the approach
- Implementation readiness	The teacher needed to prepare a real problem scenario, student worksheets, role distribution, tools and materials, and a soft skills assessment rubric.	The approach requires systematic planning so that project implementation is effective and measurable.
- Student responses to the project	Students were more interested because the solar-panel project was directly related to real conditions and the TESHA field.	Project relevance can increase student participation.
- Changes in communication	Students began to ask questions, discuss, express opinions, and present work results more confidently.	The approach provides broader interaction opportunities than expository learning.
- Changes in collaboration	Students learned to divide roles, help one another, and solve problems together.	The approach supports collaboration, but supervision is still needed to ensure that all students are involved.

Focus of finding	Main result	Implication for the approach
- Changes in problem solving	Students learned to check circuits, measure voltage, discuss the causes of problems, and try solutions.	The project trained analytical and systematic thinking in practical problem situations.
- Implementation barriers	Barriers included limited practice time, limited tools and materials, varied initial student abilities, and the need for intensive supervision.	Implementation requires adequate facilities, time, and teacher guidance.
- Supporting factors	Project relevance to TESHA, the school environment as a real problem context, student enthusiasm, teacher support, student worksheets, and rubrics were supporting factors.	The approach is easier to implement when the project is aligned with vocational competencies and learning materials are available.

The findings in Table 12 indicate that scientific creativity-based Teaching Factory cannot be understood as an approach that automatically succeeds merely because it uses projects or a production atmosphere. Its effectiveness depends on the quality of learning design. Without a clear scenario, role distribution, rubrics, and reflection, project activities may become ordinary practical work oriented only toward products. This note is consistent with Prastiantomo et al. (2023), who emphasized that project activities require explicit assessment and feedback in order to genuinely become a space for soft skills development.

The integration of quantitative and qualitative data shows that the improvement in soft skills in the experimental group can be explained by the active, contextual, collaborative, and reflective nature of the learning process. Quantitatively, the experimental group showed an increase in total scores, a category shift from moderate to high, better *N*-gain, and significant ANCOVA results after controlling for pretest scores. Qualitatively, students and the teacher explained that this improvement was related to real problem identification, group discussion, role distribution, circuit testing, technical problem solving, product revision, and reflection. The integration of quantitative and qualitative findings is presented in Table 13.

Table 13. Integration of quantitative and qualitative findings

Quantitative finding	Supporting qualitative finding	Meaning of the result
- The experimental group improved from the moderate category to the high category.	Students were involved in a real project involving the identification of lighting needs and the solar-panel lamp solution.	The contextual project provided space for students to develop soft skills through real problems.
- The control group remained in the moderate category.	The control learning did not explicitly include scientific creativity-based TEFA project experiences.	Expository learning can improve scores, but it was not strong enough to move achievement into the high category.
- The experimental group's *N*-gain was in the moderate category,	Students divided tasks, discussed, tested the system,	Project activities provided active learning experiences

Quantitative finding	Supporting qualitative finding	Meaning of the result
whereas the control group's *N*-gain was low.	corrected errors, and revised the product.	that supported soft skills improvement.
- Communication and collaboration showed strong effects.	Students expressed ideas, asked questions, discussed, worked in groups, and presented results.	Social interaction in the project became an important mechanism for strengthening communication and collaboration.
- Problem solving and adaptability increased significantly.	Students faced technical challenges such as the lamp not turning on, incorrect cable connections, and panel positions that needed adjustment.	Technical challenges became learning spaces for diagnosing problems and adjusting actions.
- Responsibility increased in the experimental group.	Each student had a task in the group and shared responsibility for the quality of the project outcome.	Role distribution encouraged individual and collective responsibility.
- The effectiveness of the approach remained evident after pretest scores were controlled through ANCOVA.	The teacher emphasized the importance of student worksheets, rubrics, real problem scenarios, facilities, and guidance.	Soft skills improvement was related to structured learning design, not merely ordinary practical activities.

Based on the integration in Table 13, the mechanism of soft skills improvement can be explained through three main processes. First, the real problem context gave students clear reasons to communicate, collaborate, and seek solutions. Second, the technical project encouraged students to face uncertainty, errors, and the need for revision, thereby developing problem solving and adaptability. Third, the group work structure and product demands helped students learn to take responsibility for their roles and the quality of the work.

The results of this study support the idea that vocational learning needs to be designed as an authentic and pedagogical work experience. Teaching Factory provides a production framework that brings students closer to industrial situations, while scientific creativity enriches the approach with exploration, testing, evaluation, and improvement activities. The combination of both ensures that learning does not stop at compliance with procedures, but also promotes students' ability to think, interact, and adapt. This finding is consistent with studies stating that Teaching Factory can improve vocational students' competencies when implemented through activities that require collaboration, communication, and problem solving (Indramayanti et al., 2024; Irfan et al., 2024; Tanjung et al., 2025; Wahjusaputri & Bunyamin, 2022).

In the context of the Renewable Energy Engineering Program, this approach has particular relevance. Renewable energy requires students to understand technical systems while also being able to adapt solutions to environmental conditions and user needs. The solar-panel lighting project provides an example of how technical competence can be connected with real problems at school. Through this project, students learned that energy system installation requires not only knowledge of components but also the ability to work in teams, diagnose faults, adjust designs, and take responsibility for results. This is consistent with the view that renewable energy education should connect technical knowledge, contextual problem solving, and awareness of environmental needs (Fang et al., 2021; Lee et al., 2025; Mueller et al., 2020).

Nevertheless, the findings of this study should be interpreted proportionally. The difference in pretest scores between the experimental and control groups indicates that the initial conditions of the two groups were not fully equivalent. The use of ANCOVA helped control this difference, and the results still showed a significant group effect. However, the quasi-experimental design with intact classes did not allow full control over all external variables. Therefore, the more appropriate claim is that scientific creativity-based Teaching Factory showed strong effectiveness in improving students' soft skills in the context of this study after initial differences were statistically controlled.

In addition, the qualitative results showed that the effectiveness of the approach was influenced by implementation readiness. The teacher needed to prepare project scenarios, tools and materials, student worksheets, role distribution, rubrics, and supervision strategies. Without such support, Teaching Factory may become routine practical activity that provides limited opportunities for exploration and reflection. Thus, the success of the approach is determined not only by the concept of Teaching Factory or scientific creativity, but also by the quality of implementation, teacher capacity, availability of facilities, and a learning culture that encourages students' active participation.

Overall, the results of this study show that scientific creativity-based Teaching Factory can serve as an effective vocational learning alternative for developing students' soft skills in the Renewable Energy Engineering Program. This approach works through project experiences that connect real problems, group work, idea communication, technical testing, problem solving, product revision, and reflection. Thus, soft skills are not treated as additional outcomes outside technical competence, but are developed directly through contextual and meaningful vocational activities.

CONCLUSION

Scientific creativity-based Teaching Factory showed stronger effectiveness than expository learning in improving vocational students' soft skills in the Renewable Energy Engineering Program. This was reflected in the experimental group's achievement, which increased from the moderate category to the high category, while the control group remained in the moderate category. The experimental group obtained a moderate *N*-gain, whereas the control group obtained a low *N*-gain. The ANCOVA results also showed that the difference in soft skills achievement between the experimental and control groups remained significant after controlling for pretest scores. Thus, this approach can be considered a potential vocational learning strategy for developing students' soft skills in a more structured manner.

The improvement in students' soft skills occurred because scientific creativity-based Teaching Factory provided active, contextual, collaborative, and reflective learning experiences. The solar-panel lighting project gave students opportunities to identify real problems, express ideas, divide roles, test systems, deal with technical challenges, improve designs, and evaluate work results. These processes contributed to the development of communication, collaboration, problem solving, responsibility, and adaptability. In other words, soft skills in this study did not emerge merely as incidental outcomes of vocational practice, but developed through a learning design that deliberately integrated technical activities, scientific creativity, and social interaction.

The findings of this study indicate that vocational learning in renewable energy needs to be designed not only to train students' mastery of technical procedures, but also to develop their ability to work, think, and adapt in situations resembling real workplace conditions. However, the results should be interpreted cautiously because this study used intact classes and the initial scores of the two groups were not fully equivalent. Although the initial differences were statistically controlled through ANCOVA, broader generalization of the findings still requires further testing with larger samples, different schools, and more diverse vocational program contexts.

RECOMMENDATIONS

The implementation of scientific creativity-based Teaching Factory should be designed as vocational learning that explicitly integrates technical skills and soft skills through real projects, such as solar-panel lighting systems or other simple renewable energy technologies. Teachers and schools need to prepare problem scenarios, student worksheets, role distribution, practical tools and materials, safety procedures, soft skills assessment rubrics, and sufficient time so that the activities do not become merely ordinary technical practice. Soft skills such as communication, collaboration, problem solving, responsibility, and adaptability should be assessed using clear indicators and structured feedback. Future studies are recommended to involve larger samples, different schools, longer implementation periods, and more diverse measurement methods, such as direct observation, performance rubrics, peer assessment, and project portfolios, so that stronger evidence of the approach's effectiveness can be obtained and tested in broader vocational education contexts.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Declaration of Interest

The author declares no conflict of interest.

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