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A Scientific Creativity-Based Teaching Factory Model to Improve Vocational High School Students' Soft Skills in the Renewable Energy Engineering Program

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Abstract

This study aimed to examine the effectiveness of a scientific creativity-based Teaching Factory (TEFA) model in improving vocational high school students' soft skills in the Renewable Energy Engineering Program and to identify the factors supporting such improvement. The study employed a mixed-methods approach with an explanatory sequential design. The quantitative phase involved 44 eleventh-grade TESHA students at SMK Negeri 1 Pringgabaya, divided into an experimental group ($n = 22$) and a control group ($n = 22$). The experimental group participated in scientific creativity-based TEFA learning through a solar panel lamp project, while the control group received expository instruction. Quantitative data were collected using a soft skills scale administered as a pretest and posttest, and were analyzed using descriptive statistics, N-gain, t-tests, ANCOVA, and effect size analysis. The qualitative phase was conducted through semi-structured interviews with students and a teacher to explain the factors influencing changes in students' soft skills. The results showed that the soft skills scores of the experimental group increased from the moderate to the high category, whereas those of the control group remained in the moderate category. The mean N-gain of the experimental group was in the moderate category, while that of the control group was in the low category. The ANCOVA results indicated a significant difference in posttest scores between the two groups after controlling for pretest scores. Improvements were observed across all dimensions of soft skills, namely communication, teamwork, problem solving, responsibility, and adaptability. The qualitative findings revealed that the improvement in soft skills was supported by authentic projects, role distribution, communication of ideas, resolution of technical problems, product revision, student worksheets, assessment rubrics, and teacher guidance. Therefore, the scientific creativity-based TEFA model is effective in improving the soft skills of vocational high school students in the Renewable Energy Engineering Program.

Keywords: Teaching factory; Scientific creativity; Soft skills; Renewable energy engineering; Vocational education

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INTRODUCTION

Vocational education is widely regarded as one of the main foundations supporting students' transition from school to the more complex world of adulthood and work. Through vocational education, students do not merely learn theoretical concepts but are also equipped with practical skills that are directly related to labour market needs. Previous studies have shown that practical competence is a core goal of vocational education and is closely associated with career readiness and the quality of graduates' future lives (Qin, 2024; Kusuma et al., 2023). In this context, vocational education should not be positioned as a "second track" of education, but rather as an important pathway for developing competencies that determine personal and professional success.

In many countries, including Indonesia, vocational education is also considered a strategy for reducing youth unemployment and increasing the productive participation of the working-age population. Vocational education and training (VET) systems are reported to contribute to employability when training outcomes are aligned with the expectations of business and industry. Several studies have highlighted that students’ involvement in real work experiences and industry-based training is associated with higher motivation, better graduation outcomes, and smoother school-to-work transitions. At the same time, these outcomes depend strongly on the quality of program design and the intensity of industry involvement (Kamaliah et al., 2018; Yousfani et al., 2021). This means that vocational education has the potential to become a vital pathway for students’ lives, but this potential cannot be realized without serious planning and implementation.

In Indonesia, vocational education at the secondary level is mainly implemented through vocational high schools, known as Sekolah Menengah Kejuruan (SMK), which offer various expertise programs aligned with the needs of industrial sectors. SMKs are expected to serve as a frontline institution in preparing middle-level workers with specific competencies in fields such as manufacturing, services, technology, and energy. In recent years, SMK development has increasingly been directed toward strengthening school-industry alignment and narrowing the gap between competencies taught at school and competencies required in the workplace. However, various reports also indicate that the quality of program implementation and facilities varies considerably across SMKs, meaning that not all students receive ideal vocational learning experiences.

One strategic expertise program in SMKs is Renewable Energy Engineering, particularly the concentration in Solar, Hydro, and Wind Energy Engineering (TESHA). This program has emerged in line with national policy targets to increase the share of renewable energy in the national energy mix, from approximately 12.16% in 2021 to 23% in 2025 and 31% in 2050. These targets require the availability of a workforce capable of mastering solar energy technologies, such as the design and maintenance of photovoltaic systems, small-scale hydropower, and wind energy systems, including their integration with digital technologies such as the Internet of Things (IoT). The TESHA curriculum in SMKs is designed to train students to design, assemble, operate, and maintain renewable energy systems. Nevertheless, several studies have also identified challenges such as limited practical infrastructure, teachers’ incomplete mastery of current technologies, and teaching materials that are not yet fully contextualized according to developments in the renewable energy industry.

In the context of TESHA expertise, vocational education is insufficient if it only emphasizes technical mastery. Students who will later work in the renewable energy sector will engage with multidisciplinary teams, communicate with clients, technicians, and other stakeholders, and solve complex and dynamic field problems. Therefore, soft skills such as communication, teamwork, problem solving, creativity, and adaptability are highly crucial. Studies in engineering and energy sectors emphasize that graduates’ success in the workplace is strongly influenced by the combination of technical competence and soft skills, rather than by either one alone (Robles, 2012; Okoye & Nkanu, 2020). In other words, TESHA graduates who are technically competent but weak in soft skills may face difficulties adapting to real work environments.

Despite their importance, several studies indicate that the soft skills of vocational high school students in Indonesia remain relatively low and have not been developed systematically. Many expertise programs place greater emphasis on achieving minimum curriculum-based technical competencies, while soft skills training tends to be implicit and unstructured. Empirical reports show weaknesses among SMK graduates in communication, teamwork, and critical thinking (Wulaningrum & Hadi, 2019; Febriyana et al., 2023). Similar concerns have also been raised by industry. Companies often perceive SMK graduates as lacking teamwork ability, initiative, and flexibility in responding to change. In several surveys, almost all industries identify soft skills as a determining factor in recruitment and promotion, yet they consider schools insufficiently capable of meeting these expectations.

The relatively low level of soft skills among SMK students is not solely attributable to the students themselves, but also to the structure and practice of learning. Many vocational teachers have not received sufficient training to integrate soft skills into vocational learning, and instructional approaches are often still teacher-centred and based on rigid work procedures. Although innovations such as project-based learning have begun to be implemented and have been shown to support soft skills development through group work and authentic problem solving, their implementation remains uneven and is often constrained by limited time, facilities, and school culture (Pradipta et al., 2021; Firdaus et al., 2023). This condition indicates the need for a vocational learning model that is explicitly designed to strengthen soft skills while maintaining the quality of technical competence.

One approach that has been widely developed in Indonesian vocational education is the Teaching Factory (TEFA). In simple terms, Teaching Factory can be understood as a learning model that brings industrial work environments and procedures into schools, allowing learning to take place in a “miniature factory” or semi-realistic production environment. Through TEFA, students are involved in the production flow, from receiving orders, planning work, managing materials and equipment, to quality control and customer service. In this way, learning does not stop at artificial technical practice but moves closer to actual industrial practice. Previous studies have shown that students’ involvement in TEFA can improve work readiness and their understanding of industrial demands, although its quality and success depend strongly on the design and implementation in each school (Indramayanti et al., 2024; Tanjung et al., 2025).

Teaching Factory essentially provides a rich space for soft skills development. In a TEFA environment, students are required to communicate with peers and “clients,” organize work in teams, resolve conflicts, and make decisions when facing production problems. These activities have the potential to strengthen communication, teamwork, responsibility, and leadership skills. Several studies have reported that the implementation of TEFA can improve students’ soft skills, particularly when accompanied by learning strategies that emphasize reflection, discussion, and structured feedback (Vitriani et al., 2023; Wahjusaputri & Bunyamin, 2022). However, some reports also show that TEFA implementation in certain schools remains formalistic, merely imitating industrial procedures without providing sufficient space for students to explore, solve problems, and innovate. In such situations, the potential of TEFA to genuinely develop soft skills becomes limited.

At this point, the concept of scientific creativity becomes relevant. Scientific creativity refers to the ability to generate meaningful new ideas in science and technology contexts, combine existing knowledge in unconventional ways, design original solutions to real problems, and reflect critically on the results of one’s work. In the field of renewable energy, scientific creativity is reflected, for example, in students’ ability to adapt photovoltaic system designs to specific geographical and social conditions or to modify micro-hydro systems according to local water flow characteristics. If designed with real problem-based tasks and innovative projects, the TEFA model has strong potential to foster such scientific creativity (Roemintoyo et al., 2021; Riwayani et al., 2024).

However, this potential is not automatically realized. Many TEFA implementations still emphasize the reproduction of standard operating procedures rather than encouraging students to experiment or design alternative solutions. Students are more often asked to follow predetermined steps rather than being challenged to ask questions, test ideas, or make modifications. Yet, several studies have emphasized that learning environments that provide room for exploration, experimentation, and interdisciplinary collaboration are more effective in developing scientific creativity (Muttaqien, 2020; Muliyati et al., 2023). In other words, the success of Teaching Factory in developing soft skills and scientific creativity depends largely on how teachers and schools design the learning experiences within it, not merely on the label “TEFA” itself.

In the context of the Renewable Energy Engineering Program with a TESHA concentration, a scientific creativity-based Teaching Factory has the potential to become an important foundation for addressing students’ low soft skills. Production activities and projects related to solar, hydro, and wind energy can be designed as real problem-solving contexts that require teamwork, intensive communication, role negotiation, and collective decision-making. At the same time, students are encouraged to propose new ideas, modify designs, and evaluate the effectiveness of the solutions they develop. This process is expected to simultaneously strengthen students’ scientific creativity and soft skills. Nevertheless, empirical studies that specifically examine the effectiveness of a scientific creativity-based Teaching Factory model in the TESHA context at vocational high schools remain relatively limited.

Based on the above discussion, this study seeks to address this gap by implementing a scientific creativity-based Teaching Factory (TEFA) model to improve vocational high school students’ soft skills in the Renewable Energy Engineering Program. More specifically, this study addresses the following two research questions.

1. How effective is the scientific creativity-based Teaching Factory (TEFA) model in improving vocational high school students’ soft skills in the Renewable Energy Engineering Program?
2. How do learning factors in the scientific creativity-based Teaching Factory (TEFA) model contribute to the improvement of vocational high school students’ soft skills in the Renewable Energy Engineering Program?

LITERATURE REVIEW

Soft Skills

The discussion of soft skills in vocational education has emerged in response to changes in labour market demands, which no longer require only the mastery of technical skills. On the one hand, industry needs workers who are technically competent; on the other hand, it also requires the ability to communicate, collaborate, and adapt in dynamic work environments. This condition has led to the view that vocational education needs to integrate soft skills explicitly into the curriculum, rather than treating them merely as a “side effect” of technical learning. However, this normative recognition has not always been followed by consistent classroom practice, resulting in a gap between policy rhetoric and classroom reality.

Soft skills generally include communication, teamwork, problem solving, time management, and adaptability. Several studies have emphasized that these competencies are strongly correlated with graduates’ employability and are often considered more decisive than formal academic achievement when individuals enter the workplace. However, Nurrohmawati et al. (2023) found that vocational graduates still frequently experience skills mismatch, particularly because soft skills training has not become a systematic focus. This condition contributes to high levels of unemployment or, at least, unstable employment among vocational high school graduates. Thus, the narrative that vocational education “automatically” produces work-ready graduates needs to be viewed more critically when non-technical aspects remain neglected.

The Teaching Factory model is often promoted as one strategy to bridge this gap. In practice, Teaching Factory creates a learning environment that imitates industrial production settings, allowing students to experience social interaction, time pressure, and more realistic task complexity. Irfan et al. (2024) and Indramayanti et al. (2024) showed that students’ direct involvement in production activities within a simulated industrial environment can strengthen collaboration and communication skills. However, this effectiveness depends heavily on how students' roles are designed. If students are positioned only as "technical operators" who follow teacher instructions without opportunities for negotiation and reflection, the potential for soft skills development becomes limited.

The literature also highlights the importance of more innovative pedagogical frameworks for embedding soft skills into vocational education. Teaching Factory is considered compatible with project-based learning, in which students work in teams, manage real projects, and take responsibility for outputs that have consequences for "customers" or school partners (Jaya, 2025; Mentari et al., 2021). Such activities theoretically create opportunities for the development of communication, leadership, and problem-solving skills. However, Prastiantomo et al. (2023) cautioned that without assessment design and explicit feedback on soft skills, project activities may easily shift into merely shared technical work, rather than becoming a reflective socio-cognitive learning space.

The concept of Outcome-Based Education (OBE) is often associated with efforts to clarify graduate profiles and learning outcomes, including soft skills. Within this framework, Teaching Factory and other instructional methods are expected to target competencies that are explicitly formulated and measurable, both technical and non-technical (Jaya, 2025). However, several studies have also highlighted structural constraints, such as limited facilities, learning resources, and teachers' capacity to design and assess soft skills validly (Diwangkoro & Soenarto, 2020; Kafi & Harjanto, 2024). In many vocational high schools, learning remains heavily focused on hard skills, leaving soft skills in the "implicit" domain.

In addition to internal school factors, alignment with industry needs also determines the relevance of soft skills training. Tanjung et al. (2025) emphasized that vocational curricula need to be developed through continuous dialogue with the workplace, because industry expectations regarding soft skills continue to change along with organizational and technological dynamics. Without a strong feedback mechanism, schools risk teaching soft skills normatively but not in ways that reflect actual work situations. Therefore, the literature on soft skills in vocational education points to one main message: the importance of soft skills integration is widely acknowledged, but its implementation requires pedagogical transformation, teacher capacity building, and more serious partnerships with industry, rather than simply adding slogans to curriculum documents.

Renewable Energy Engineering Program

The Renewable Energy Engineering Program has emerged as a response to the climate crisis and the global need for more sustainable energy systems. At the international level, the transition from fossil energy to renewable energy is viewed as a key strategy for reducing carbon emissions and strengthening energy security (Hidayah et al., 2025). In Indonesia, the target of achieving a 23% renewable energy share in the national energy mix by 2025 (Lavi, 2021) is often cited as an important rationale for education and training in the renewable energy sector. However, policy targets do not automatically ensure the availability of work-ready human resources. Therefore, this expertise program should be understood not only as a technical response but also as an effort to build the institutional capacity of vocational education.

The Renewable Energy Engineering Program is generally designed to equip students with knowledge and skills related to solar, wind, and hydro energy systems, including energy efficiency and sustainable design. The curriculum commonly covers the design and installation of photovoltaic systems, the use of small-scale wind and water flow potential, and the maintenance and troubleshooting of installed systems. The approach is multidisciplinary, combining concepts from physics, engineering, environmental studies, and elements of energy economics (Mueller et al., 2020). Ideally, the depth and breadth of this material enable students to recognize the relationship between technology and its ecological and social impacts. In practice, however, the extent of interdisciplinary integration depends heavily on teachers' readiness and background, as well as the availability of supporting facilities in schools.

The use of pedagogical frameworks such as project-based learning (PBL) and Teaching Factory has been identified as an effort to bring renewable energy issues into real contexts. Through PBL, for example, students can be involved in designing solar panel systems for school or community facilities or in examining micro-hydro potential in the surrounding environment (Halada et al., 2016; Fang et al., 2021). Such activities are considered capable of strengthening not only technical skills but also critical thinking and collaboration. However, there is a risk of "symbolic projects" when tasks are designed merely to fulfil administrative curriculum requirements without adequate monitoring of technical quality or the sustainability of project outcomes in the community.

Several studies have reported that students' involvement in real projects contributes to the development of creativity and readiness to face industrial challenges (Salzman et al., 2016). Activities that have direct impact on the community may also foster students' sense of responsibility and social engagement with energy and environmental issues (Hidayah et al., 2025). However, these positive claims need to be balanced with the observation that not all schools have access to community or industry partners capable of consistently supporting real projects. In many cases, projects remain limited to simulations in school workshops.

Collaboration with the energy industry is believed to be a key factor in maintaining curriculum relevance and facilitating authentic learning experiences. Such collaboration usually takes the form of internships, industrial visits, or joint projects that allow students to interact directly with actual technologies and work cultures (Shuman et al., 2005). However, the literature also reminds us that school-industry relationships are not always symmetrical. In some cases, industry involvement remains ceremonial, without sustained commitment, which limits its pedagogical impact. In addition, the capacity of local industries in renewable energy is not evenly distributed across regions, meaning that opportunities for internships and authentic projects are not always available to all students.

Another dimension that has begun to receive attention is the importance of entrepreneurial skills in renewable energy programs. Voss et al. (2015) and Reave (2004) emphasized that graduates should not only be prepared as "technical workers," but also as future innovators and entrepreneurs capable of creating new solutions in the energy sector. This is relevant because many renewable energy opportunities exist at small and medium scales, such as household solar panel installation, village energy systems, and maintenance services. However, adding entrepreneurial content to an already dense curriculum is not simple. This demand may result in an overloaded curriculum if it is not supported by an integrative learning design. Thus, the literature on the Renewable Energy Engineering Program portrays an initiative that is strategic in policy and substantive terms, but that also faces substantial implementation challenges, particularly regarding resources, partnerships, and the consistency of pedagogical approaches.

Scientific Creativity-Based Teaching Factory

Teaching Factory (TEFA) has been introduced as an approach that connects schools and industry by creating learning environments that resemble real production processes. In the context of vocational education, TEFA is claimed to integrate theoretical learning, practical training, and industrial work culture into a unified learning experience. Students do not only complete structured practical tasks but also engage in a production cycle that includes planning, implementation, quality control, and service to "customers." However, the claim that TEFA automatically produces work-ready and innovative graduates needs to be examined critically by looking at the actual learning design implemented in classrooms and workshops.

Previous studies have shown that Teaching Factory has strong potential to develop a combination of technical and non-technical skills. Students' involvement in real production activities requires them to collaborate, communicate, and solve problems within certain time and resource constraints (Indramayanti et al., 2024; Tanjung et al., 2025). If properly facilitated, this environment can serve as a training space for leadership, conflict management, and decision-making. However, when TEFA activities are reduced to a simple "order-production-delivery" pattern without pedagogical reflection, students risk becoming cheap labour in a "school factory," rather than learners who develop higher-order thinking capacities.

Scientific creativity has recently been viewed as an important dimension to be integrated into Teaching Factory, particularly in expertise programs related to science and technology, such as renewable energy. In this context, scientific creativity is not merely understood as spontaneous "creative ideas," but as the ability to combine scientific knowledge with imagination to design new solutions, modify designs, and critically evaluate outcomes. In solar energy projects, for instance, scientific creativity is reflected when students are able to adjust panel configurations to local conditions or optimize systems within cost and space limitations. Samsuri et al. (2024) emphasized that the success of Teaching Factory depends heavily on how students' scientific creativity is developed and orchestrated within the learning process. This statement implicitly criticizes TEFA practices that only emphasize compliance with standard operating procedures without creating space for exploration.

Several studies have suggested that TEFA can become a medium for developing scientific creativity when integrated with project-based learning and authentic problem solving (Roemintoyo et al., 2021; Dhani & Kristiani, 2021). Students are encouraged to analyse needs, design alternative solutions, test products, and revise them based on data and feedback. These activities require the flexible use of scientific and technological concepts, so creativity is not detached from scientific foundations. Nevertheless, the literature also emphasizes that such activities require time, facilities, and a school culture that supports experimentation. Without these conditions, teachers tend to return to procedural practice patterns that are easier to manage but less cognitively challenging.

Interaction with industry in the TEFA model is often considered capable of enriching students' scientific creativity because it exposes them to current practices and real problems in the field (Sari & Silviana, 2020; Pertiwi & Ahmad, 2018). However, such interaction can also restrict creativity if industry only emphasizes compliance with standards without allowing room for student modification or innovation. In this regard, teachers and schools play an important role as mediators who balance the demand for compliance with the pedagogical need to foster creative and critical thinking. The renewable energy context actually offers many open-ended problems, such as system optimization in remote villages, integration with IoT, and adaptation to specific environmental conditions. The challenge lies in translating these problems into TEFA tasks that are structured but still allow room for exploration.

Furthermore, the literature on STEM and interdisciplinary learning shows that scientific creativity develops more effectively in learning environments that encourage inquiry, exploration, and experimentation (Muttaqien, 2020; Muliyati et al., 2023). If these principles are integrated into TEFA, the Teaching Factory workshop or laboratory functions not only as a production space but also as an "innovation laboratory," where students can safely and purposefully test their ideas within certain boundaries. This, of course, requires a shift in the teacher's role from instructor to facilitator and co-designer of learning. Such a shift is not always easy because it involves professional culture and teachers' workload.

Therefore, a scientific creativity-based Teaching Factory should not be understood merely as a technical variation of TEFA, but as a design orientation that deliberately combines production goals with the development of scientific creativity and soft skills. In the context of the Renewable Energy Engineering Program in vocational high schools, this model offers opportunities to connect solar, hydro, and wind energy projects with authentic problem-solving activities that require teamwork, communication, and innovation. However, the literature also indicates that the success of such a model is not automatic. It depends on teacher readiness, the quality of industry partnerships, school policy support, and the availability of resources. Further research is therefore important to examine the extent to which a scientific creativity-based

Teaching Factory can truly improve students' soft skills and to identify the factors influencing its successful implementation in practice.

METHOD

Research Design

This study employed a mixed-methods approach with an explanatory sequential design as proposed by Creswell (2009). In this design, quantitative data collection and analysis were conducted first to examine the effectiveness of the scientific creativity-based Teaching Factory (TEFA) model on students' soft skills. Subsequently, qualitative data were collected and analysed to further explain the factors that supported or hindered the improvement of students' soft skills during the implementation of the model. Thus, the quantitative data were used to show patterns of change and differences in soft skills scores, while the qualitative data were used to interpret how learning experiences based on TEFA and scientific creativity contributed to these changes.

In the quantitative phase, the study used a pretest-posttest control group design, with group assignment conducted at the class or learning-group level. The experimental group received the treatment in the form of a scientific creativity-based TEFA model, while the control group received expository instruction. Both groups were given an initial measurement, or pretest, before the treatment and a final measurement, or posttest, after the learning process was completed. The research design is presented in Table 1.

Table 1. Research design

Group	Pretest	Treatment	Posttest
Experimental	O_1	Scientific creativity-based TEFA model	O_2
Control	O_1	Expository instruction	O_2

Note: O_1 = initial measurement of soft skills; O_2 = final measurement of soft skills

This design was used to compare changes in soft skills between the experimental and control groups. Because students were assigned based on existing classes, randomization was conducted at the class level rather than at the individual level. Therefore, pretest scores were analysed to determine the initial equivalence of the groups. If initial differences were found, pretest scores were statistically controlled using analysis of covariance (ANCOVA), so that the interpretation of model effectiveness did not rely solely on posttest or gain score comparisons.

The qualitative phase was conducted after the initial quantitative analysis had been completed. Qualitative data were used to explain the factors influencing the improvement of students' soft skills, particularly in the experimental group. The qualitative information was obtained through semi-structured interviews with students and a teacher. The interviews focused on students' experiences during the project, group-work dynamics, communication of ideas, technical problem solving, product revision, and the supports and challenges encountered during the implementation of the scientific creativity-based TEFA model.

Participants

The participants of this study were eleventh-grade students in the Renewable Energy Engineering Program, with a concentration in Solar, Hydro, and Wind Energy Engineering (TESHA), at SMK Negeri 1 Pringgabaya. This context was selected because the Renewable Energy Engineering Program requires the mastery of both technical competence and soft skills, particularly communication, teamwork, problem solving, responsibility, and adaptability. In addition, the learning characteristics of this expertise program are relevant to the implementation of a project-based Teaching Factory model integrated with scientific creativity.

The quantitative participants consisted of 44 students, divided into two groups: 22 students in the experimental group and 22 students in the control group. The experimental group participated in scientific creativity-based TEFA learning, while the control group received expository instruction. The characteristics of the participants are presented in Table 2.

Table 2. Characteristics of research participants

Characteristic	Experimental (n = 22)	Control (n = 22)	Total (N = 44)
Class	XI TESHA	XI TESHA	XI TESHA
Expertise program	Renewable Energy Engineering	Renewable Energy Engineering	Renewable Energy Engineering
Male	14 students or 63.64%	21 students or 95.45%	35 students or 79.55%
Female	8 students or 36.36%	1 student or 4.55%	9 students or 20.45%
Age 16 years	1 student or 4.55%	7 students or 31.82%	8 students or 18.18%
Age 17 years	20 students or 90.91%	14 students or 63.64%	34 students or 77.27%
Age 18 years	1 student or 4.55%	1 student or 4.55%	2 students or 4.55%

In addition to the students, one productive-subject teacher involved in the implementation of the learning process also served as a qualitative informant. The teacher provided information about the readiness of model implementation, students' responses, observed changes in students' soft skills, implementation challenges, and supporting factors in applying the scientific creativity-based TEFA model. Student informants in the qualitative phase were selected purposively from the experimental group by considering variations in their learning experiences and changes in soft skills during the learning process.

Model Implementation Procedure

The model implementation procedure was designed to align with the experimental design and the characteristics of the Renewable Energy Engineering Program. The study was carried out through several stages: preparation, pretest, learning implementation, posttest, and qualitative data collection.

The first stage was preparation. At this stage, the researchers prepared learning materials for both the experimental and control groups. The learning materials for the experimental group included a scientific creativity-based TEFA project scenario, student worksheets, group-role assignments, practical tools and materials, and a soft skills assessment rubric. The teacher who implemented the learning received an orientation on the principles of scientific creativity-based TEFA so that the learning process would not focus only on procedural practice, but would also facilitate problem identification, idea communication, problem solving, testing, revision, and reflection.

The second stage was the pretest. The pretest was administered to both the experimental and control groups before the treatment began. The purpose of the pretest was to identify the initial condition of students' soft skills in both groups. The pretest results were also used as a basis for statistically controlling initial differences in the data analysis.

The third stage was learning implementation. In the experimental group, learning was conducted through the scientific creativity-based TEFA model using a renewable energy project in the form of a solar panel lamp. The learning began with problem orientation, namely the identification of lighting needs 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 failing to turn on or incorrect wiring connections, students were guided to recheck the circuit, inspect the polarity, battery, cables, and controller, and then make improvements. At the end of the activity, students reflected on and revised the product based on testing results and teacher feedback.

In the control group, learning was conducted using an expository approach. The teacher delivered the material through explanation, question and answer sessions, demonstrations, and routine exercises. The material was still related to renewable energy topics and was adjusted to a time allocation comparable to that of the experimental group. However, the control group did not receive scientific creativity-based TEFA learning experiences, such as contextual production projects, design exploration, project-based role distribution, product testing, systematic revision, or structured soft skills reflection.

The fourth stage was the posttest. The posttest was administered to both groups after all learning activities had been completed. The posttest was used to determine changes in students' soft skills after the treatment in each group.

The fifth stage was qualitative data collection. Semi-structured interviews were conducted with students from the experimental group and with the productive-subject teacher. Student interviews were intended to explore their experiences in identifying project problems, working in teams, communicating creative ideas, resolving technical problems, revising products, and experiencing changes in their soft skills. Teacher interviews were intended to explore the readiness of model implementation, students' responses, changes in communication, teamwork, problem solving, implementation challenges, and supporting factors in applying the model.

Data Collection and Instruments

Quantitative data were obtained through a soft skills scale administered before and after the learning process. The soft skills scale was used to measure five dimensions: communication, teamwork, problem solving, responsibility, and adaptability. Each dimension produced a score, which was then summed to obtain a total soft skills score ranging from 0 to 100. This total score was used to examine students' soft skills achievement before and after the treatment.

The interpretation of soft skills scores was based on score categories ranging from 0 to 100. Scores of 0-59 were categorized as low, scores of 60-79 as moderate, and scores of 80-100 as high. These categories were used to interpret students' soft skills achievement in the pretest and posttest. Meanwhile, improvement in soft skills was analysed separately using gain and N-gain.

Before being used in the study, the soft skills instrument was reviewed to ensure the suitability of its items with the indicators of the dimensions being measured. The communication dimension included the ability to express opinions, ask questions, engage in discussion, and present results. The teamwork dimension included the ability to share roles, assist group members, and complete tasks collaboratively. The problem-solving dimension included the ability to identify problems, analyse causes, and try out solutions. The responsibility dimension included students' seriousness in completing tasks and maintaining the quality of their work. The adaptability dimension included the ability to adjust actions, accept feedback, and improve results based on evaluation.

Qualitative data were obtained through semi-structured interviews. The student interview guide included questions about students' experiences in participating in the scientific creativity-based TEFA project, group-work processes, idea communication, technical challenges, product revision, and perceived changes in soft skills. The teacher interview guide included questions about the readiness of model implementation, students' responses, observed changes in soft skills, implementation challenges, and factors supporting the success of the model.

Data Analysis

Quantitative data were analysed using descriptive and inferential statistics. Descriptive analysis was used to calculate the mean, standard deviation, minimum score, maximum score, gain, N-gain, and the distribution of score and N-gain categories. Gain was calculated from the difference between posttest and pretest scores. N-gain was calculated using the following formula:

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

The maximum score used was 100 for the total soft skills score. The N-gain category was classified as low if N-gain < 0.30, moderate if 0.30 ≤ N-gain < 0.70, and high if N-gain ≥ 0.70. For dimensional analysis, N-gain was calculated based on group means because one dimension contained a maximum pretest score, making the calculation of individual N-gain scores by dimension not fully stable across all data.

Before testing the effectiveness of the model, an independent-samples t-test was conducted to examine differences in pretest scores between the experimental and control groups. This test was used to determine whether the two groups had equivalent initial soft skills. Subsequently, the improvement of soft skills within each group was analysed using paired-samples t-tests. Differences in improvement between the groups were analysed using independent-samples t-tests on gain and N-gain scores.

Because the pretest scores of the experimental and control groups differed significantly, the main analysis of model effectiveness was conducted using analysis of covariance (ANCOVA). In the ANCOVA, the posttest score was used as the dependent variable, the learning group as the independent variable, and the pretest score as the covariate. This analysis was used to examine differences in posttest scores between the experimental and control groups after statistically controlling for initial score differences. The assumptions for ANCOVA included residual normality tested using the Shapiro-Wilk test, homogeneity of residual variance tested using Levene’s test, and homogeneity of regression slopes tested through the interaction between pretest score and group. In addition to ANCOVA on the total score, ANCOVA was also conducted for each soft skills dimension to determine the effectiveness of the model on communication, teamwork, problem solving, responsibility, and adaptability.

In addition to statistical significance, effect sizes were also reported. Cohen’s d was used to determine the strength of differences between groups in pretest, gain, and N-gain scores. The effect size dz was used in paired-samples t-tests to describe the magnitude of improvement within each group. Partial eta squared 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 analysed using thematic analysis. The analysis process began with repeated reading of the interview results, assigning initial codes to relevant data segments, grouping codes into preliminary themes, and then formulating final themes. The analysed themes included real project-based problem identification, collaboration in project implementation, communication of creative ideas, technical problem solving, product revision based on evaluation, implementation readiness, implementation challenges, and supporting factors of the model. The qualitative findings were then integrated with the quantitative findings to explain why and how the scientific creativity-based TEFA model contributed to the improvement of students’ soft skills.

Research Ethics Approval

This study obtained permission from Universitas Pendidikan Mandalika as the researchers’ institution and implementation approval from SMK Negeri 1 Pringgabaya as the research site. Before the study was conducted, the school principal, teacher, and students were informed about the research objectives, implementation procedures, forms of participant involvement, and the use of research data. The identities of all participants were kept confidential through the use of anonymous codes in data processing and reporting. Participants were given the right to refuse or withdraw from the study without any academic consequences. All forms of documentation and interviews were conducted after obtaining consent from the participants involved.

RESULTS

Description of Students’ Total Soft Skills Scores

Soft skills were measured through pretest and posttest assessments in both the experimental and control groups. The experimental group participated in learning through the scientific creativity-based Teaching Factory model, while the control group received expository instruction. The total soft skills score ranged from 0 to 100 and covered five dimensions, namely communication, teamwork, problem solving, responsibility, and adaptability. The interpretation of soft skills scores used three categories: low for scores of 0-59, moderate for scores of 60-79, and high for scores of 80-100. The descriptive statistics of students' total soft skills scores are presented in Table 3.

Table 3. Descriptive statistics of students' total soft skills scores

Group	n	Pretest M ± SD	Category	Posttest M ± SD	Category	Gain M ± SD	N-gain M ± SD	N-gain category
Experimental	22	67.45 ± 3.40	Moderate	85.50 ± 4.26	High	18.05 ± 5.42	0.55 ± 0.13	Moderate
Control	22	60.77 ± 6.35	Moderate	67.36 ± 3.63	Moderate	6.59 ± 6.76	0.15 ± 0.14	Low

As shown in Table 3, the mean pretest score of the experimental group was 67.45, which was in the moderate category. This score increased to 85.50 in the posttest, placing it in the high category. In the control group, the mean pretest score was 60.77, also in the moderate category, and increased to 67.36 in the posttest, remaining in the moderate category. Thus, a shift in soft skills achievement category occurred only in the experimental group, from moderate to high.

In terms of score improvement, the experimental group obtained a mean gain of 18.05, while the control group obtained a mean gain of 6.59. The N-gain score of the experimental group was 0.55, categorized as moderate, while that of the control group was 0.15, categorized as low. These results indicate that the improvement in soft skills was stronger in the experimental group than in the control group. The comparison of mean pretest and posttest scores in both groups is visualized in Figure 1.

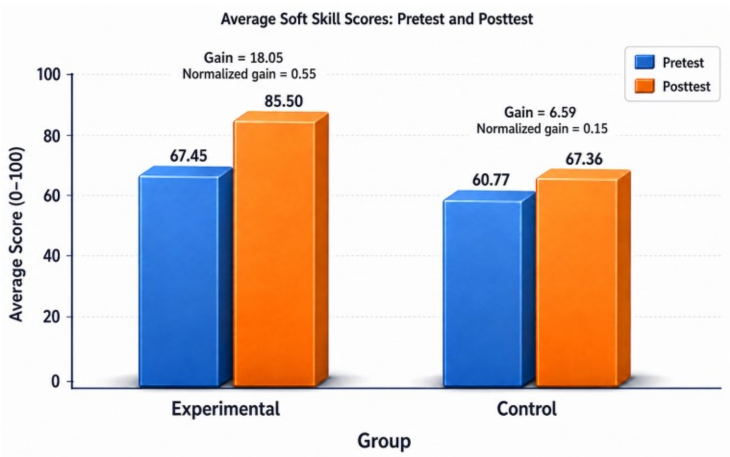

Figure 1. Mean pretest and posttest scores of soft skills

Based on Figure 1, both groups showed an increase in mean soft skills scores from pretest to posttest, but the increase in the experimental group was much greater than that in the control group. The experimental group increased from 67.45 to 85.50, with a gain of 18.05 and an N-gain of 0.55. The control group increased from 60.77 to 67.36, with a gain of 6.59 and an N-gain of 0.15. This visualization clarifies that the scientific creativity-based Teaching Factory model produced stronger changes in soft skills achievement than expository instruction.

Distribution of Pretest and Posttest Score Categories

The distribution of score categories was analysed to determine changes in students' individual soft skills achievement. The distribution of pretest and posttest score categories in the experimental and control groups is presented in Table 4.

Table 4. Distribution of students' total soft skills score categories

Group	Stage	Low	Moderate	High	Total
Experimental	Pretest	0 or 0%	22 or 100%	0 or 0%	22
	Posttest	0 or 0%	2 or 9.09%	20 or 90.91%	22
Control	Pretest	5 or 22.73%	17 or 77.27%	0 or 0%	22
	Posttest	0 or 0%	22 or 100%	0 or 0%	22

As shown in Table 4, all students in the experimental group were in the moderate category at the pretest stage. After participating in the scientific creativity-based Teaching Factory learning, 20 students, or 90.91%, moved to 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 pretest, while 17 students, or 77.27%, were in the moderate category. After expository instruction, all students in the control group were in the moderate category, but none reached the high category.

These findings indicate that scientific creativity-based TEFA learning not only increased the mean score but also encouraged students to move from the moderate to the high category. In the control group, expository instruction was able to move some students from the low to the moderate category, but it was not sufficient to help students reach the high category.

Distribution of N-gain Categories

N-gain categories were used to assess the level of score improvement from pretest to posttest. The N-gain categories were classified as low if N-gain < 0.30, moderate if 0.30 ≤ N-gain < 0.70, and high if N-gain ≥ 0.70. The distribution of N-gain categories is presented in Table 5.

Table 5. Distribution of students' soft skills N-gain categories

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

Based on Table 5, no students in the experimental group were in the low N-gain category. Most students, namely 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, 4 students or 18.18% were in the moderate category, and no students reached the high category. These results strengthen the previous descriptive findings, indicating that the improvement in students' soft skills in the experimental group was better than that in the control group. This difference was evident not only in the mean scores but also in the distribution of individual improvement. The distribution of N-gain categories is visualized in Figure 2.

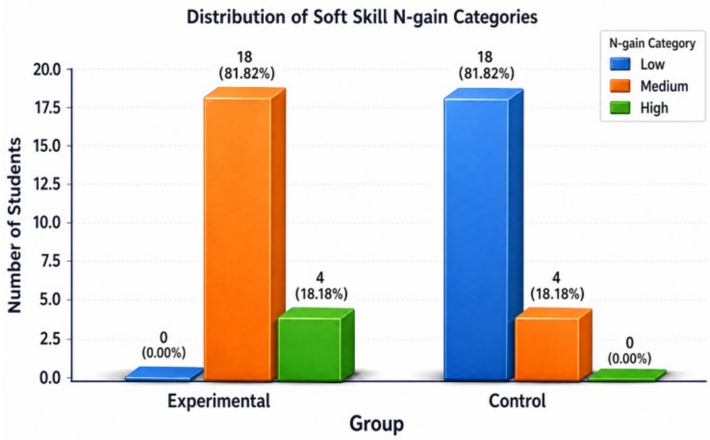

Figure 2. Distribution of soft skills N-gain categories

Based on Figure 2, the distribution of N-gain categories shows different patterns of improvement between the experimental and control groups. In the experimental group, 18 students were in the moderate category and 4 students were in the high category, while no students were in the low category. Conversely, in the control group, 18 students were in the low category and only 4 students were in the moderate category. No students in the control group reached the high category. This visualization indicates that the improvement in soft skills in the experimental group was not only higher on average but also better at the individual level.

Improvement in Soft Skills by Dimension

The next analysis was conducted on the five dimensions of soft skills: communication, teamwork, problem solving, responsibility, and adaptability. This analysis was necessary because improvement in total soft skills scores does not necessarily indicate the same pattern of improvement across each dimension. The descriptive statistics of soft skills by dimension are presented in Table 6.

Table 6. Descriptive statistics of soft skills by dimension

Dimension	Group	Pretest M ± SD	Posttest M ± SD	Gain M ± SD	N-gain	N-gain category
Communication	Exp.	13.50 ± 0.96	17.00 ± 0.98	3.50 ± 1.44	0.54	Moderate
	Control	12.32 ± 1.29	13.55 ± 1.14	1.23 ± 1.57	0.16	Low
Teamwork	Exp.	14.27 ± 0.88	17.73 ± 1.12	3.45 ± 1.57	0.60	Moderate
	Control	13.09 ± 1.74	13.73 ± 1.35	0.64 ± 2.06	0.09	Low
Problem solving	Exp.	13.05 ± 1.00	16.68 ± 1.46	3.64 ± 1.62	0.52	Moderate
	Control	10.95 ± 2.34	12.14 ± 2.42	1.18 ± 3.59	0.13	Low
Responsibility	Exp.	14.09 ± 1.57	17.32 ± 1.09	3.23 ± 1.93	0.55	Moderate
	Control	13.95 ± 1.62	15.00 ± 1.35	1.05 ± 1.84	0.17	Low
Adaptability	Exp.	12.55 ± 1.60	16.77 ± 1.69	4.23 ± 2.18	0.57	Moderate
	Control	10.45 ± 2.52	12.95 ± 1.62	2.50 ± 2.97	0.26	Low

Note: N-gain for each dimension was calculated based on group means because one dimension contained a maximum pretest score, making individual N-gain calculation by dimension not fully stable across all data.

As shown in Table 6, all dimensions of soft skills in the experimental group improved with moderate N-gain categories. The greatest improvement in the experimental group was found in adaptability, with a gain of 4.23, followed by problem solving with 3.64, communication with 3.50, teamwork with 3.45, and responsibility with 3.23.

In the control group, all dimensions also improved, but they were in the low N-gain category. The greatest improvement in the control group was found in adaptability, with a gain of 2.50, while the lowest improvement was found in teamwork, with a gain of 0.64. Thus, expository instruction produced more limited improvement across all dimensions of soft skills.

These findings indicate that the scientific creativity-based Teaching Factory model had a more consistent effect across the five dimensions of soft skills. Adaptability and problem solving improved because students were confronted with technical challenges during the project, such as checking circuits, adjusting components, and improving the product. Communication and teamwork improved because students had to discuss, divide roles, communicate ideas, and complete the project collectively. Responsibility developed because each student had tasks that needed to be completed within the group.

The comparison of mean gain scores for each dimension is visualized in Figure 3. Based on Figure 3, the experimental group showed higher gain scores than the control group across all dimensions of soft skills. The largest gain difference was found in teamwork, at 2.81, followed by problem solving at 2.46, communication at 2.27, responsibility at 2.18, and adaptability at 1.73. In the experimental group, the highest gain was found in adaptability, while in the control group the highest gain was also found in adaptability, although with a lower value. This visualization reinforces the finding that the scientific creativity-based Teaching

Factory model had a broader impact on the development of soft skills across all measured dimensions.

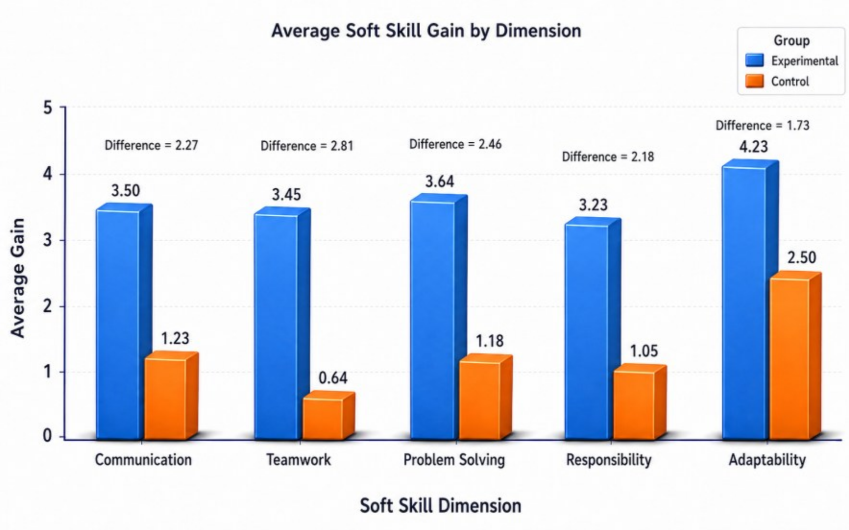

Figure 3. Mean soft skills gain by dimension

Test of Initial Score Differences

Before testing the effectiveness of the model, a test of differences in pretest scores between the experimental and control groups was conducted. This test was important because differences in initial scores could affect the interpretation of posttest score differences. The results of the pretest score difference test are presented in Table 7.

Table 7. Results of pretest soft skills score differences between the experimental and control groups

Comparison	Exp. pretest M ± SD	Control pretest M ± SD	t	df	p	Cohen's d	Decision
Exp. vs Control	67.45 ± 3.40	60.77 ± 6.35	4.35	42	< 0.001	1.31	Significantly different

As shown in Table 7, there was a significant difference in pretest soft skills scores between the experimental and control groups, $t(42) = 4.35$, $p < 0.001$. The mean pretest score of the experimental group was higher than that of the control group. Although both groups were in the moderate category, this initial score difference indicates that the two groups were not fully equivalent before the treatment. Therefore, the analysis of model effectiveness was not based only on posttest, gain, or N-gain comparisons, but was continued using ANCOVA to control for pretest scores as a covariate.

Assumption Testing for ANCOVA

Before conducting ANCOVA, several main assumptions were examined, namely residual normality, homogeneity of residual variance, and homogeneity of regression slopes. The results of the ANCOVA assumption tests for total soft skills scores are presented in Table 8.

Table 8. Results of ANCOVA assumption tests for total soft skills scores

Assumption	Statistic	p	Decision
Residual normality	Shapiro-Wilk W = 0.969	0.278	Met
Homogeneity of residual variance	Levene F = 1.073	0.306	Met
Homogeneity of regression slopes	F = 0.077	0.783	Met

As shown in Table 8, the model residuals were normally distributed, residual variance was homogeneous across groups, and there was no significant interaction between pretest score and group. Thus, the main assumptions of ANCOVA were met, and the analysis could be used to test differences in posttest soft skills scores after controlling for initial scores.

Test of Soft Skills Improvement Within Each Group

A paired-samples t-test was conducted to determine whether there was an improvement in soft skills scores from pretest to posttest within each group. The results of the paired-samples t-test are presented in Table 9.

Table 9. Results of paired-samples t-test for total soft skills scores

Group	Pretest M ± SD	Category	Posttest M ± SD	Category	t	df	p	Effect size dz
Experimental	67.45 ± 3.40	Moderate	85.50 ± 4.26	High	15.62	21	< 0.001	3.33
Control	60.77 ± 6.35	Moderate	67.36 ± 3.63	Moderate	4.57	21	< 0.001	0.98

As shown in Table 9, both the experimental and control groups experienced significant improvement in soft skills scores. In the experimental group, the improvement occurred from the moderate to the high category, whereas in the control group the improvement remained within the moderate category. Thus, although both groups improved statistically, a more substantively meaningful improvement occurred in the experimental group.

Test of Gain and N-gain Differences Between Groups

An independent-samples t-test was conducted on gain and N-gain scores to determine differences in soft skills improvement between the experimental and control groups. The results of the gain and N-gain difference tests are presented in Table 10.

Table 10. Results of gain and N-gain differences between groups

Variable	Experimental M ± SD	Control M ± SD	t	df	p	Cohen's d
Gain	18.05 ± 5.42	6.59 ± 6.76	6.20	42	< 0.001	1.87
N-gain	0.55 ± 0.13	0.15 ± 0.14	9.56	42	< 0.001	2.88

As shown in Table 10, there were significant differences between the experimental and control groups in both gain and N-gain scores. Cohen's d values indicate that the differences in improvement between the groups had large effect sizes. This means that the improvement in soft skills in the experimental group was much stronger than that in the control group. However, because the pretest scores of the two groups differed significantly, the gain and N-gain results should still be interpreted together with the ANCOVA results.

Testing Model Effectiveness Using ANCOVA

ANCOVA was used to examine differences in posttest soft skills scores between the experimental and control groups after controlling for pretest scores. The ANCOVA results for posttest soft skills scores are presented in Table 11.

Table 11. ANCOVA results for posttest soft skills scores

Source of variance	F	df	p	Partial eta squared
Pretest	0.43	1, 41	0.513	0.010
Group	147.92	1, 41	< 0.001	0.783

As shown in Table 11, after controlling for pretest scores, there was a significant difference in posttest soft skills scores between the experimental and control groups, $F(1, 41) = 147.92$, $p < 0.001$. The partial eta squared value of 0.783 indicates that the effect of group on posttest soft skills scores was very large. The adjusted posttest mean of the experimental group was 85.23, while that of the control group was 67.63.

Thus, after initial score differences were statistically controlled, the experimental group still showed higher soft skills achievement than the control group. This result supports the finding that the scientific creativity-based Teaching Factory model was more effective than expository instruction in improving vocational high school students' soft skills in the Renewable Energy Engineering Program.

Testing Effectiveness by Soft Skills Dimension

Further analysis was conducted to determine the effectiveness of the model in each dimension of soft skills. The ANCOVA results by soft skills dimension are presented in Table 12.

Table 12. ANCOVA results by soft skills dimension

Dimension	Adj. M of exp.	Adj. M of control	F	p	η_p^2
Communication	16.97	13.58	85.22	< 0.001	0.675
Teamwork	17.71	13.74	92.14	< 0.001	0.692
Problem solving	16.77	12.05	44.66	< 0.001	0.521
Responsibility	17.31	15.01	38.72	< 0.001	0.486
Adaptability	16.73	13.00	43.52	< 0.001	0.515

As shown in Table 12, the experimental group had higher adjusted posttest scores than the control group across all dimensions of soft skills. Significant differences were found in communication, teamwork, problem solving, responsibility, and adaptability. The largest effect sizes were found in teamwork and communication. This indicates that the scientific creativity-based Teaching Factory model most strongly promoted students' social-interactive dimensions, particularly through role distribution, discussion, idea communication, and group work.

The dimensions of problem solving, responsibility, and adaptability also showed significant differences with strong effect sizes. These findings indicate that the renewable energy project not only trained students to work collaboratively but also involved them in diagnosing problems, correcting errors, adjusting actions, and taking responsibility for the quality of their work.

Qualitative Findings

Student Interviews

Student interviews showed that the improvement in soft skills was related to learning experiences based on real projects, collaboration, communication of ideas, technical problem solving, and product revision. Students identified lighting needs in the school environment, proposed solar panel lamps as a solution, divided tasks, tested the system, resolved technical problems, and improved the product based on evaluation. A summary of the qualitative findings from student interviews is presented in Table 13.

Table 13. Summary of qualitative findings from student interviews

Theme	Main findings	Related soft skills	Interpretation
Real project-based problem identification	Students observed lighting needs in the school yard and proposed solar panel lamps 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.	Teamwork, responsibility	The project encouraged students to perform roles and help one another complete practical tasks.
Communication of creative ideas	Students communicated ideas about installation location and panel tilt to	Communication, adaptability	Students practised communicating technical

Theme	Main findings	Related soft skills	Interpretation
	obtain optimal sunlight exposure.		ideas and adjusting designs based on group discussion.
Technical problem solving	Students encountered problems when the lamp did not turn on and then checked cable connections, polarity, battery, and controller.	Problem solving, adaptability	Students learned to diagnose the causes of problems and try solutions based on circuit inspection.
Product revision based on evaluation	Students repaired circuits, tidied connections, and adjusted component positions after receiving feedback.	Adaptability, responsibility	Students showed readiness to accept feedback and improve product quality.
Integrated soft skills development	Students felt more confident in speaking, collaborating, expressing opinions, solving practical problems, and taking responsibility.	All dimensions	The model was perceived as supporting integrated soft skills development through project activities.

Based on Table 13, the improvement in soft skills in the experimental group can be explained through students' involvement in projects that required social, technical, and reflective activities. Students did not merely receive material or follow demonstrations, but were involved in the process of solving real problems. This process required them to discuss, divide tasks, communicate ideas, test circuits, correct errors, and complete the project responsibly. These findings are consistent with the quantitative results, which showed improvement across all soft skills dimensions.

Teacher Interview

The teacher interview provided information about implementation readiness, students' responses, changes in soft skills, challenges, and supporting factors of the model. The teacher stated that the implementation of the scientific creativity-based Teaching Factory required more thorough preparation than ordinary instruction, especially in preparing real problem scenarios, student worksheets, student role distribution, practical tools and materials, and soft skills assessment rubrics. A summary of the qualitative findings from the teacher interview is presented in Table 14.

Table 14. Summary of qualitative findings from the teacher interview

Focus of findings	Main results	Implications for the model
Implementation readiness	The teacher needed to prepare real problem scenarios, student worksheets, role distribution, tools and materials, and soft skills assessment rubrics.	The model requires systematic planning so that project implementation is effective and measurable.
Students' responses to the project	Students were more interested because the solar panel project was directly related to real conditions and the TESHA expertise field.	Project relevance to real life and expertise competencies can increase student participation.
Changes in communication	Students began to ask questions, engage in discussion, express opinions, and present their work more confidently.	The model provides broader interaction opportunities than expository instruction.

Focus of findings	Main results	Implications for the model
Changes in teamwork	Students learned to divide roles, help each other, and solve problems collectively.	The model supports collaboration, but still requires supervision to ensure that all students are actively involved.
Changes in problem solving	Students learned to check circuits, measure voltage, discuss the causes of problems, and try solutions.	The project trained students to think analytically and systematically in solving practical problems.
Implementation challenges	Challenges included limited practice time, tools and materials, variation in students' initial 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 model is easier to implement when the project is aligned with expertise competencies and learning materials are available.

Based on Table 14, the teacher observed improvements in students' communication, teamwork, and problem solving during the project activities. The teacher also emphasized that the success of the model did not occur automatically. The scientific creativity-based Teaching Factory needed to be supported by learning materials, project scenarios, practical facilities, supervision, and assessment rubrics. The teacher noted that some students still needed guidance so that they would not remain passive or depend too heavily on peers who had stronger practical skills. Thus, the model was effective, but it still required strong teacher facilitation.

Integration of Quantitative and Qualitative Findings

The integration of quantitative and qualitative findings was conducted to explain the relationship between improved soft skills scores and students' learning experiences during the implementation of the scientific creativity-based Teaching Factory model. The integration of findings is presented in Table 15.

Table 15. Integration of quantitative and qualitative findings

Quantitative findings	Supporting qualitative findings	Meaning of the results
The experimental group improved from the moderate to the high category.	Students were involved in a real project involving the identification of lighting needs and the development of a solar panel lamp solution.	Contextual projects provided space for students to develop soft skills through real problems.
The control group remained in the moderate category.	The control learning did not include explicit scientific creativity-based TEFA project experiences.	Expository instruction could improve scores, but it was not strong enough to move students' achievement into the high category.
The N-gain of the experimental group was in the moderate category, while that of the control group was low.	Students divided tasks, discussed, tested the system, corrected errors, and revised the product.	Project activities provided active learning experiences that supported soft skills improvement.
Communication and teamwork showed strong effects.	Students communicated ideas, asked questions, discussed,	Social interaction in the project became an important

Quantitative findings	Supporting qualitative findings	Meaning of the results
	worked in groups, and presented results.	mechanism for strengthening communication and teamwork.
Problem solving and adaptability improved significantly.	Students encountered technical problems, such as the lamp failing to turn on, incorrect cable connections, and panel positions that needed adjustment.	Technical challenges became learning opportunities for diagnosing problems and adjusting actions.
Responsibility improved in the experimental group.	Each student had a task within the group and shared responsibility for the quality of the project outcome.	Role distribution encouraged individual and collective responsibility.
Model effectiveness remained evident after pretest scores were controlled through ANCOVA.	The teacher emphasized the importance of student worksheets, rubrics, real problem scenarios, facilities, and guidance.	The improvement in soft skills was related to structured learning design, not merely to ordinary practical activities.

Based on Table 15, the quantitative and qualitative findings supported each other. Quantitatively, the scientific creativity-based Teaching Factory model showed stronger effectiveness than expository instruction in improving students' soft skills. This was evident from the shift in the experimental group's score category from moderate to high, the moderate N-gain score, the better distribution of individual improvement, the significant gain and N-gain test results, and the ANCOVA results, which continued to show significant differences after controlling for pretest scores. Qualitatively, this improvement can be explained by students' involvement in real projects, group work, communication of ideas, technical problem solving, product revision, and teacher guidance through structured learning materials.

DISCUSSION

The results of this study show that the scientific creativity-based Teaching Factory model was more effective than expository instruction in improving vocational high school students' soft skills in the Renewable Energy Engineering Program. This finding is reflected in the increase in the total soft skills score of the experimental group from the moderate to the high category, while the control group remained in the moderate category. The mean N-gain score of the experimental group was in the moderate category, whereas that of the control group was in the low category. The ANCOVA results also showed that, after controlling for pretest scores, there was a significant difference in posttest scores between the experimental and control groups. Thus, the improvement in soft skills in the experimental group was not only evident in the mean score differences but also remained strong after initial ability differences were statistically controlled. This finding is important because the pretest scores of the two groups were significantly different, making ANCOVA a more cautious analytical basis than merely comparing posttest or gain scores.

Substantively, these results indicate that scientific creativity-based Teaching Factory learning was able to provide richer learning experiences than expository instruction. In expository instruction, students may still experience improvement because they receive explanations, demonstrations, and exercises. However, this improvement tends to be limited because students are not intensively placed in work situations that require communication, role distribution, decision-making, and real problem solving. By contrast, in the experimental group, students were involved in a more contextual renewable energy project, namely identifying lighting needs in the school environment and developing a solar panel lamp solution. This activity enabled learning to move beyond the mastery of technical procedures and become a space for social, technical, and reflective practice at the same time. This is consistent with the view that vocational education needs to provide learning experiences aligned with the world of work in order to contribute to students’ career readiness and employability (Qin, 2024; Kusuma et al., 2023; Kamaliah et al., 2018; Yousfani et al., 2021).

The improvement in soft skills in the experimental group can be explained through the main characteristics of the scientific creativity-based Teaching Factory model. Teaching Factory essentially places students in learning situations that resemble industrial work processes. However, in this study, the model was not positioned merely as a production simulation. The element of scientific creativity enabled students not only to follow instructions or work procedures, but also to identify problems, develop alternative solutions, test designs, and make improvements based on evaluation results. In this sense, scientific creativity served as a pedagogical reinforcement so that TEFA activities did not become routine and mechanical practice. This view is in line with findings that TEFA can develop both technical and non-technical competencies when students are involved in real production activities that require communication, teamwork, and problem solving (Indramayanti et al., 2024; Tanjung et al., 2025). Nevertheless, the effectiveness of TEFA depends on the quality of instructional design, not merely on the use of the Teaching Factory label.

The findings by dimension show that the scientific creativity-based Teaching Factory model had an impact on all measured soft skills dimensions, namely communication, teamwork, problem solving, responsibility, and adaptability. The ANCOVA results for each dimension showed significant differences between the experimental and control groups. The strongest effects were found in teamwork and communication. This finding is reasonable because project activities placed students in group work situations that required role distribution, discussion, idea expression, questioning, and presentation of work results. In the context of vocational learning, communication and teamwork cannot develop optimally through lectures or demonstrations alone, because both require authentic social practice. In line with this, Robles (2012) and Okoye and Nkanu (2020) emphasized that graduates’ success in the workplace is determined not only by technical competence but also by soft skills such as communication, teamwork, problem solving, creativity, and adaptability.

The improvement in students’ communication was reflected in their increased confidence in expressing opinions, asking questions to the teacher, discussing with peers, and presenting group work. The teacher also observed that some students who were initially passive became more active in communicating after being involved in the project. This indicates that communication developed because students had a real need to exchange information during the project process. They did not speak merely because the teacher asked them to, but because the project required them to explain ideas, agree on designs, clarify errors, and report results. Thus, communication in this model was functional and contextual, rather than simply an oral activity separated from practical work. This finding supports literature stating that Teaching Factory can strengthen communication and collaboration when students are directly involved in production activities and realistic work situations (Irfan et al., 2024; Indramayanti et al., 2024).

The teamwork dimension also improved strongly because students had to share roles in completing the project. Interview data showed that students divided tasks such as recording the required tools and materials, preparing equipment, installing components, recording measurement results, and testing the lamp. These activities encouraged positive interdependence among students. Each group member had a contribution that was needed for the product to function properly. However, the teacher’s findings also showed that teamwork did not always emerge automatically. Some students still needed guidance so that they would not remain passive or depend too heavily on peers with stronger practical skills. This means that although the scientific creativity-based TEFA model was effective in fostering teamwork, its success still required teacher supervision, clear role distribution, and assessment rubrics that encouraged the involvement of every student. This is consistent with Prastiantomo et al. (2023), who argued that without explicit assessment and feedback on soft skills, project activities may shift into merely shared technical work rather than becoming a reflective socio-cognitive learning space.

In the problem-solving dimension, the improvement in the experimental group was closely related to students' experiences in dealing with technical problems during the project. Students encountered situations in which the lamp did not turn on, requiring them to recheck cable connections, polarity, battery, and controller until the system functioned properly. Such situations are important in vocational education because practical problems cannot always be solved through memorized procedures. Students need to diagnose the causes of problems, test possible solutions, and make decisions based on technical evidence. This is where scientific creativity plays a role, because students were not only asked to complete tasks according to examples, but also to adjust their actions based on the actual conditions they faced. This finding is in line with the view that TEFA can serve as a medium for developing scientific creativity when integrated with project-based learning and authentic problem solving, in which students analyse needs, design solutions, test products, and revise them based on data and feedback (Roemintoyo et al., 2021; Dhani & Kristiani, 2021).

The adaptability dimension showed the highest gain in the experimental group. This can be understood because the solar panel lamp project required students to adjust their designs and actions based on field conditions, testing results, and teacher feedback. Adaptability developed when students faced discrepancies between their initial plans and actual conditions, such as panel positions that needed adjustment, connections that had to be repaired, or components that needed to be arranged more safely and functionally. In other words, adaptability did not emerge simply because students were taught about flexibility, but because they directly experienced situations that required them to adjust their work strategies. In the context of renewable energy, the ability to adapt designs to local conditions is important because solar, wind, or hydro energy projects are often influenced by the physical environment, resource availability, and user needs (Mueller et al., 2020; Halada et al., 2016; Fang et al., 2021).

The responsibility dimension also improved in the experimental group. This improvement was related to task distribution and the demand to produce a functioning product. Each student had a part of the work to complete, making the success of the project dependent on both individual and collective contributions. In expository instruction, students' responsibility is generally related to following instructions, taking notes, or completing exercises. In the scientific creativity-based TEFA model, responsibility became more concrete because students had to ensure that the tools, materials, circuits, and final project outcomes could be accounted for. Real project-based activities can also foster a sense of responsibility because students see the relationship between the work they do and its benefits for the surrounding environment (Salzman et al., 2016; Hidayah et al., 2025). However, the responsibility dimension showed a slightly lower effect than communication and teamwork, which may indicate that responsibility requires longer habituation, especially if students are not yet accustomed to role-based work systems and product-oriented targets.

The qualitative findings strengthen the quantitative results by showing the factors that supported the improvement of soft skills. The first factor was the real and relevant project context. The solar panel lamp project was directly related to the TESHA expertise field and the school environment, making it easier for students to see the benefits of learning. This relevance encouraged student engagement because they were not completing abstract tasks, but solving observable problems. The second factor was the structure of group work. Role distribution gave students clearer responsibilities and encouraged interaction among group members. The third factor was the presence of technical problems. Problems such as the lamp failing to turn on or incorrect cable connections triggered problem solving and adaptability. The fourth factor was reflection and product revision. Students learned to accept feedback, repair circuits, and improve the quality of their work. The fifth factor was the support of learning materials, such as student worksheets, rubrics, and real problem scenarios, which helped teachers guide the learning process so that it did not become merely ordinary practical activity. These findings are consistent with literature emphasizing that TEFA needs to be accompanied by reflection, discussion, structured feedback, and assessment tools in order to develop soft skills meaningfully (Vitriani et al., 2023; Wahjusaputri & Bunyamin, 2022; Prastiantomo et al., 2023).

The teacher’s findings provide important boundaries for interpreting the effectiveness of the model. The teacher emphasized that the implementation of scientific creativity-based TEFA required more thorough preparation than ordinary instruction. The teacher needed to prepare problem scenarios, tools and materials, role distribution, student worksheets, and soft skills assessment rubrics. In addition, challenges such as limited practice time, limited availability of facilities, variations in students’ initial abilities, and the need for intensive supervision emerged during implementation. This means that the effectiveness of the model should not be understood as a consequence of the Teaching Factory label alone. The model was effective when implemented with clear design, relevant projects, adequate teacher guidance, and support from practical facilities. The literature also warns that limited facilities, learning resources, and teachers’ capacity to design and assess soft skills remain important issues in vocational education (Diwangkoro & Soenarto, 2020; Kafi & Harjanto, 2024). Without these supporting conditions, TEFA risks becoming routine production activity that is not substantially different from ordinary practice.

The initial score difference between the experimental and control groups also needs to be discussed critically. The experimental group had a higher mean pretest score than the control group. This condition indicates that the two groups were not fully equivalent before the treatment. Therefore, the conclusion about effectiveness cannot rely only on posttest score differences. The use of ANCOVA was important because it controlled for pretest scores as a covariate. The ANCOVA results still showed a significant difference after controlling for initial scores, thereby strengthening the claim of model effectiveness. However, this initial difference still needs to be acknowledged as a methodological factor that limits absolute causal interpretation. This study provides strong evidence that the model was associated with greater improvement in soft skills, but caution is still required in stating that all differences in outcomes were caused solely by the treatment.

Theoretically, the findings of this study support the view that soft skills development in vocational education requires explicit, structured, and contextual learning experiences. Soft skills should not be treated merely as by-products of technical practice. If communication, teamwork, problem solving, responsibility, and adaptability are to be developed, learning must be deliberately designed to elicit these activities. This aligns with criticism in the literature that soft skills training in vocational high schools is still often implicit and has not been developed systematically, even though the world of work regards soft skills as important factors in recruitment, work performance, and career readiness (Wulaningrum & Hadi, 2019; Febriyana et al., 2023; Nurrohmawati et al., 2023). The scientific creativity-based Teaching Factory model responds to this need by combining work contexts, real projects, scientific exploration, and reflection.

In the Renewable Energy Engineering Program, this model is relevant because the renewable energy workforce requires graduates who are not only able to install or maintain technical systems, but also able to work in teams, communicate with various parties, adapt solutions to field conditions, and solve problems creatively. The literature on renewable energy education also emphasizes that this expertise program is multidisciplinary, connecting physics, engineering, environment, and sustainable design. Therefore, its learning process needs to be designed through contextual projects that enable students to understand the relationship between technology, user needs, and socio-environmental impacts (Mueller et al., 2020; Halada et al., 2016; Fang et al., 2021). Thus, scientific creativity-based Teaching Factory is appropriate for the TESHA context because it provides space for students to connect technical competence with real problem solving.

Practically, the findings of this study indicate that vocational learning in renewable energy needs to move beyond expository instruction and procedural practice. Real-needs-based projects, such as solar panel lighting systems, can serve as a medium for integrating technical competence and soft skills. Productive-subject teachers need to be given the space and support to design projects that involve open-ended problems, allow students to express ideas, require teamwork, and provide time for product evaluation and revision. Schools also need to ensure the availability of tools, materials, safety procedures, and assessment rubrics so that project-based learning is not only engaging, but also safe, measurable, and aligned with learning objectives. This view is consistent with literature emphasizing the importance of pedagogical transformation, teacher capacity building, clear learning materials, and partnerships with industry so that vocational learning can genuinely respond to workplace needs (Jaya, 2025; Tanjung et al., 2025; Shuman et al., 2005).

Therefore, the findings of this study confirm that the scientific creativity-based Teaching Factory model is effective in improving students' soft skills because it shifts vocational learning from receiving instructions to experiencing real problem solving. The improvement in soft skills occurred through students' involvement in problem identification, communication of ideas, task distribution, product testing, technical problem solving, revision of work results, and collective reflection. However, the effectiveness of the model depends on teacher readiness, the clarity of learning materials, project relevance, facility availability, and supervision during practice. Therefore, this model can be used as an alternative vocational learning approach in the Renewable Energy Engineering Program, provided that its implementation is carefully designed and not merely understood as production activity within the school environment.

CONCLUSION

Based on the findings of this study, the scientific creativity-based Teaching Factory model was found to be more effective than expository instruction in improving vocational high school students' soft skills in the Renewable Energy Engineering Program. This effectiveness was indicated by the increase in the total soft skills score of the experimental group from the moderate to the high category, while the control group remained in the moderate category. The N-gain score of the experimental group was in the moderate category, whereas that of the control group was in the low category. The statistical test results also strengthened this finding, as the difference in posttest scores between the experimental and control groups remained significant after controlling for pretest scores through ANCOVA. Thus, the scientific creativity-based TEFA model can be considered effective in improving students' soft skills, particularly because it provides learning experiences that are more active, contextual, collaborative, and based on real problem solving.

The improvement in students' soft skills was not only reflected in the total score but also across all measured dimensions, namely communication, teamwork, problem solving, responsibility, and adaptability. Teamwork and communication showed strong effects because the project activities required students to divide roles, engage in discussion, express ideas, ask questions, and present their work. Problem solving and adaptability improved because students encountered technical challenges during the project, such as checking circuits, cable connections, polarity, batteries, controllers, and adjusting component positions. Responsibility developed because each student had tasks that contributed to the success of the group product. Therefore, the scientific creativity-based TEFA model contributed to the comprehensive strengthening of soft skills, rather than improving only one particular aspect.

The factors supporting the improvement of students' soft skills included the relevance of the project to the TESHA expertise field, the use of real problems in the school environment, role distribution within groups, students' involvement in communicating creative ideas, the presence of technical challenges that required problem solving, product evaluation and revision activities, and teacher guidance through student worksheets, rubrics, and structured learning scenarios. The solar panel lamp project provided space for students to connect technical competence in renewable energy with social skills and work attitudes. Therefore, the improvement in soft skills in this study was not merely caused by practical activities, but by a TEFA learning design that deliberately integrated scientific creativity, group work, problem solving, reflection, and product improvement.

LIMITATIONS

This study has several limitations that need to be considered when interpreting the findings. First, the study was conducted in only one school, namely SMK Negeri 1 Pringgabaya, and was limited to the Renewable Energy Engineering Program with a TESHA concentration. Therefore, the findings cannot yet be widely generalized to all vocational high schools or other expertise programs without further testing in more diverse contexts. Second, the number of participants was relatively limited, consisting of 44 students divided into 22 students in the experimental group and 22 students in the control group. This number was sufficient to provide an initial picture of the effectiveness of the model, but it remains limited for producing strong generalizations. Studies with larger sample sizes are needed so that the findings can be tested with a higher level of confidence. Third, the pretest scores of the experimental and control groups differed significantly. The experimental group had higher initial soft skills scores than the control group. This difference was statistically controlled through ANCOVA, allowing the effectiveness analysis to be conducted more cautiously. However, the initial difference remains a limitation because it indicates that the two groups were not fully equivalent before the treatment. Fourth, the duration of model implementation was limited to a particular learning period. Soft skills such as responsibility, teamwork, communication, and adaptability are competencies that develop through long-term habituation. Therefore, the findings of this study are more appropriately understood as initial evidence of the model’s effectiveness rather than as a representation of long-term soft skills development. Fifth, the measurement of soft skills was based on a soft skills scale and interviews. Both techniques were relevant for capturing score changes and students’ learning experiences, but they still have limitations. The soft skills scale may be influenced by students’ self-perceptions, while interviews depend on informants’ ability to explain their experiences. Therefore, future studies should include direct observation, performance rubrics, teacher assessment, peer assessment, or project portfolios to produce stronger and more triangulated measurements of soft skills. Sixth, the implementation of the model depended strongly on teacher readiness, the availability of tools and materials, the allocation of practical learning time, and supervision during electrical installation activities. This condition indicates that the effectiveness of the model was determined not only by the scientific creativity-based TEFA design but also by facility support, learning materials, and the capacity of school implementers.

RECOMMENDATIONS

For productive-subject teachers in the Renewable Energy Engineering Program, the scientific creativity-based Teaching Factory model can be used as an alternative learning approach to integrate technical competence and soft skills. Teachers are advised to design projects based on real problems, such as lighting needs, simple solar panel systems, micro-hydro energy utilization, or small-scale wind energy system simulations. Projects should be supported by clear role distribution, student worksheets that guide the process from problem identification to product revision, and rubrics that explicitly assess communication, teamwork, problem solving, responsibility, and adaptability.

For schools, the implementation of this model requires adequate institutional support. Schools need to provide sufficient practical learning time, relevant tools and materials, occupational safety procedures, and collaborative spaces involving productive-subject teachers, heads of expertise programs, and industry partners. Teaching Factory should not be understood merely as production activity in schools, but as a learning system that connects industrial work processes with pedagogical objectives. Therefore, schools need to ensure that TEFA activities do not only produce products, but also generate learning experiences that foster students' scientific creativity and soft skills.

For curriculum developers and expertise program managers, the findings of this study indicate the need to integrate soft skills explicitly into vocational learning. Soft skills should not only be written as general learning outcomes, but should also be translated into clear activities, indicators, rubrics, and feedback mechanisms. In the Renewable Energy Engineering Program, TEFA projects can be directed toward energy-related issues that are close to students' lives and the school environment, so that learning becomes more contextual and meaningful.

For future researchers, it is recommended that the scientific creativity-based Teaching Factory model be tested with larger sample sizes, in different schools, and across other expertise programs. Further studies may also use longitudinal designs to examine the durability of soft skills improvement over a longer period. In addition, soft skills measurement should be strengthened through classroom observation, performance rubrics, peer assessment, project portfolios, and documentation of students' work processes. In this way, evidence of model effectiveness will not rely only on scale scores and interviews, but also on students' actual behaviour during learning.

For the development of the TEFA model in the field of renewable energy, scientific creativity needs to be positioned as a core element. This means that students should not merely be trained to follow standard operating procedures or imitate work procedures, but should also be given space to identify problems, propose alternative solutions, test designs, analyse errors, and revise products. Through this approach, Teaching Factory can function not only as a miniature industry within the school, but also as a learning laboratory that develops technical competence, scientific creativity, and soft skills in an integrated manner.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Pathan	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Saiful Prayogi		✓		✓	✓	✓			✓			✓		
Lovy Herayanti		✓		✓			✓	✓		✓		✓	✓	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

The researchers meticulously followed ethical protocols throughout the research process, adhering to the principles outlined in the Declaration of Helsinki.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy considerations of research participants.

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