



IMPLEMENTING A SELF-DESIGNED PROJECT LEARNING MODEL IN MACHINING ENGINEERING: A STRATEGY FOR MEETING INDUSTRY REQUIREMENTS

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Abstract

Vocational education in Indonesia, particularly Mechanical Machining programs in Vocational High Schools (SMKs), faces a persistent challenge in aligning graduates' competencies with the rapidly evolving demands of the manufacturing industry. The transition toward Industry 4.0 has accelerated the adoption of Computer Numerical Control (CNC) technologies and digital manufacturing systems, while many graduates remain predominantly skilled in conventional machining. This study aimed to implement and evaluate the effectiveness of the Self-Designed Project Learning (SDPL) model in enhancing students' machining competencies and job readiness. A quasi-experimental design employing a non-equivalent control group approach was conducted during the 2025/2026 academic year in three public vocational schools in Bandung, Indonesia. The sample consisted of 96 eleventh-grade Mechanical Machining students, divided equally into experimental and control groups. The experimental group received instruction through a structured nine-stage SDPL model emphasizing industry needs analysis, product design, production planning, material selection, conventional and CNC machining, quality control, product evaluation, presentation, and reflection. Data were collected using technical competency tests, CNC programming assessments, soft-skills observation sheets, and job-readiness questionnaires. Statistical analyses were performed using descriptive statistics, independent-samples t-tests, and ANCOVA at a 0.05 significance level. The findings revealed that SDPL significantly improved students' competencies compared with conventional instruction. The experimental group achieved higher post-test scores in conventional machining (84.6 vs. 73.4; $p < 0.001$) and CNC competencies (78.3 vs. 51.7; $p < 0.001$). Furthermore, students demonstrated superior soft skills and greater job readiness (82.4% vs. 56.7%). These results indicate that SDPL effectively integrates technical and employability skills, thereby strengthening the alignment between vocational education outcomes and contemporary manufacturing industry requirements.



Keywords: Self-Designed Project Learning; machining engineering; job readiness; CNC competency; manufacturing industry; vocational education.

INTRODUCTION

The advancement of science and technology in the twenty-first century has entered the most disruptive phase in human civilization. The Fourth Industrial Revolution, characterized by the convergence of digital, physical, and biological technologies, has fundamentally transformed the ways in which people work, produce goods, and interact with their surrounding environment (Aprilia et al., 2018; Sudarsono et al., 2025). It is widely recognized that science and technology are developing rapidly, and these advancements have significantly affected economic, political, social, and cultural sectors, with the most profound impact occurring in the world of work (Aprilia et al., 2018). As technological progress accelerates, challenges and competition in the labor market have become increasingly complex, motivating individuals to pursue innovation and develop new solutions.

Within the manufacturing sector, which serves as a cornerstone of the national economy, technological transformation is occurring at an unprecedented pace (Zhang et al., 2025). Production systems that once relied on conventional machinery with manual controls are gradually but steadily transitioning toward fully automated systems governed by computer technologies (Cheng et al., 2026). This paradigm shift demands human resources who are not only technically proficient but also adaptable, innovative, and capable of higher-order critical thinking. As explained by Cheng et al. (2026), as industrial demands increasingly favor skilled professionals, educational institutions must align their curricula with industry standards to cultivate talent that effectively meets market needs.

In the field of machining engineering, one of the most significant technological developments has been the widespread adoption of Computer Numerical Control (CNC) machines, which have gradually replaced conventional equipment such as manual lathes and milling machines (Yao et al., 2024). CNC machines offer levels of precision, efficiency, and consistency that conventional machines cannot match, making them the new standard in modern manufacturing industries across small-, medium-, and large-scale enterprises. The operation of CNC machines no longer relies solely on manual skills; instead, it requires a comprehensive understanding of programming principles, coordinate systems, tool geometry, and the ability to read and write G-code and M-code (Cheng et al., 2026).

Collaboration between higher education institutions and vocational high schools (Sekolah Menengah Kejuruan/SMKs) to enhance CNC competencies has become a strategic agenda that continues to gain momentum. This initiative represents a tangible commitment to improving the quality of vocational education, particularly in the field of manufacturing technology. Through SolidWorks training programs, students are equipped with competencies in two-dimensional (2D)



and three-dimensional (3D) engineering design, as well as CNC programming simulation. By implementing a project-based training approach, students are expected to develop the ability to design, simulate, and comprehensively implement CNC programming.

In addition to CNC technology, immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) have increasingly been integrated into machining education to address the limitations of laboratory facilities. A community partnership program funded by the Public Service Agency Fund for Community Engagement (PNBP) of the Faculty of Engineering at Makassar State University demonstrated that VR/AR-based interventions significantly improved the quality of practical learning activities (Rera et al., 2025). VR technology was utilized to simulate the operation of machining equipment, while AR was employed to provide three-dimensional visualizations of machine components. The results indicated significant improvements in both teachers' and students' competencies and successfully addressed laboratory constraints by offering accessible and independent alternatives for practical learning (Rera et al., 2025).

Despite ongoing efforts to modernize educational practices, evidence from the field indicates that the mismatch between the competencies of vocational high school graduates in machining engineering and industry requirements remains a persistent and unresolved issue (Düzgünçnar, 2025). According to data from the Indonesian Central Statistics Agency (Badan Pusat Statistik/BPS) as of August 2024, the Open Unemployment Rate (OUR) among vocational high school graduates reached 9%, equivalent to approximately 1,840,162 individuals. This figure represents the highest unemployment rate compared to other educational levels, including general senior high school graduates (6.54%), diploma holders (4.80%), and university graduates (5.11%) (Arham et al., 2025). Ironically, this situation occurs at a time when the manufacturing sector continues to report difficulties in recruiting skilled workers who meet industry demands.

A study conducted by Zhahara et al. (2025) at State Vocational High School 1 Karawang, located in the largest industrial area in Southeast Asia, revealed several noteworthy findings. The results indicated that the machining engineering curriculum was perceived as highly relevant by 76.47% of respondents and relevant by the remaining 23.53%. Furthermore, graduates' competencies in the cognitive, psychomotor, and affective domains were also considered highly relevant. Nevertheless, significant deficiencies were identified in graduates' soft skills Arham et al. (2025). These shortcomings include critical aspects such as the 5S principles (Smile, Greeting, Salutation, Courtesy, and Politeness), the 5P principles (Precision, Productivity, Maintenance, Prevention, and Improvement), occupational safety culture, and work ethics aligned with industry standards (Arham et al., 2025). These findings are consistent with the study conducted by Pebrian (2024) in Palu City, which concluded that although the relevance of machining engineering graduates' competencies to industrial needs remains relatively high, several critical issues persist,



including teachers' limited ability to keep pace with industrial developments, inadequate facilities, and low student motivation and interest in the machining engineering program (Pebrian, 2024).

Field observation data further indicate that most vocational high school students tend to become job seekers rather than technopreneurs who are capable of developing and applying the skills acquired during their vocational education to create their own employment opportunities (Aprilia et al., 2018). In fact, Indonesia requires entrepreneurs to comprise at least 4% of its total population to sustainably support national economic growth. Current data indicate that entrepreneurs account for only approximately 3.1% of the population, a proportion that remains relatively low compared to countries such as Malaysia, China, Singapore, Japan, and the United States (Aprilia et al., 2018). One implication of these findings is that the current educational system has not yet effectively fostered technopreneurial mindsets among students.

One of the primary causes of this gap is the predominance of conventional, teacher-centered learning approaches in vocational high schools. At State Vocational High School 2 Bandung, which serves as one of the national references for machining engineering programs, conventional instruction remains the primary teaching method (Aprilia et al., 2018). Within this model, students primarily function as passive recipients of information, while teachers act as the sole source of knowledge. Consequently, the learning process fails to fully optimize students' potential to become active, creative, and independent learners. As a result, students are not adequately prepared to address complex technical problems or develop solutions independently, despite these competencies being highly demanded in today's dynamic industrial environment (Aprilia et al., 2018; Sudarsono et al., 2025).

The study conducted by Hardiana (2008) at State Vocational High School 12 Bandung provides a historical perspective on this issue. The research revealed that although vocational education is ideally expected to be labor market-oriented and responsive to changes in the world of work, many vocational school graduates remain unable to meet the competency requirements demanded by industry. Focusing on the alignment of curriculum content, instructional aspects, learning processes, and equipment utilization, the study concluded that the compatibility between the curriculum and industrial needs has not yet achieved full relevance.

In response to the widening gap between graduates' competencies and industry demands, innovative instructional models are required to bridge vocational education and the workplace more effectively. One instructional approach that has emerged as a promising solution is the Self-Designed Project Learning (SDPL) model. This learning model is designed to foster student autonomy by providing learners with sufficient opportunities to design, plan, implement, evaluate, and present authentic projects that are relevant to industry needs (Aprilia et al., 2018).

The SDPL model differs fundamentally from conventional project-based learning approaches. In SDPL, students do not merely execute projects predetermined by teachers; instead,



they are granted greater autonomy to design their own projects, beginning with the identification of problems or market needs, the formulation of product specifications, the selection of materials and production technologies, and the development of product marketing strategies (Aprilia et al., 2018; Sudarsono et al., 2025). Setyawan et al. (2014) explain that this instructional model consists of nine systematic stages that progressively cultivate students' independence, responsibility, and higher-order thinking skills.

A recent development of this approach was introduced by Sudarsono, Saputra, and Ghozani (2025), who proposed the Industry-Integrated Self-Design Project Learning (i-SDPL) model. The i-SDPL model integrates vocational high school learning experiences with industrial components to familiarize students with professional workplace environments (Sudarsono et al., 2025). The model emphasizes student autonomy in the development and implementation of industry-based projects while providing access to cutting-edge technologies and practical knowledge that may not always be available in academic settings. Its advantages include active student participation in company operations, training based on real-world products, and comprehensive improvements in both technical competencies and soft skills compared with traditional instructional methods. Findings from pilot implementations involving 136 students across two cohorts demonstrated that the i-SDPL model effectively enhanced students' attitudes, knowledge, and skills (Sudarsono et al., 2025).

Research Objectives

Based on the aforementioned complex and urgent issues, this study aims to implement and empirically evaluate the effectiveness of the Self-Designed Project Learning (SDPL) model within the context of machining engineering education at vocational high schools. More specifically, this study is designed to:

1. Analyze differences in the improvement of competencies related to conventional machine tools (turning and milling) between students who participate in SDPL-based instruction and those who receive conventional instruction.
2. Analyze differences in the improvement of CNC technology competencies, including programming and machine operation, between students who participate in SDPL-based instruction and those who receive conventional instruction.
3. Analyze differences in the improvement of soft skills—including discipline, responsibility, work ethic, problem-solving ability, and collaboration—between students who participate in SDPL-based instruction and those who receive conventional instruction.
4. Measure the level of graduates' job readiness following participation in SDPL-based instruction and compare it with the competency standards required by the manufacturing industry in Bandung and surrounding areas within West Java.



This study is expected to make a substantial contribution to the advancement of vocational education in Indonesia, particularly in efforts to align the competencies of machining engineering vocational school graduates with the evolving needs of the manufacturing industry. Furthermore, the findings are expected to serve as a reference model for other vocational schools facing similar challenges in preparing graduates who are work-ready, adaptive, and competitive in the era of the Fourth Industrial Revolution.

METHODOLOGY

Research Design

This study employed a quasi-experimental method using a non-equivalent control group design. This design was selected because, within the context of vocational high schools, it is difficult to implement full randomization of research subjects, as students are already organized into naturally formed classes (Aprilia et al., 2018; Arham et al., 2025). In this design, two groups (experimental and control) were administered a pretest to assess their initial abilities. Subsequently, the experimental group received the treatment in the form of instruction using the Self-Designed Project Learning (SDPL) model, while the control group was taught using a conventional instructional model. After the treatment period, both groups were administered a posttest to measure their final learning outcomes (Aprilia et al., 2018).

The research design is illustrated as follows:

Experimental Group: $O_1 - X - O_2$

Control Group: $O_1 - C - O_2$

Note:

- O_1 = Pretest (measurement of initial ability)
- O_2 = Posttest (measurement of final ability)
- X = Treatment using the Self-Designed Project Learning model
- C = Treatment using a conventional instructional model

Population and Sample

The population of this study comprised all eleventh-grade students enrolled in the Machining Engineering program at public vocational high schools in Bandung during the 2025/2026 academic year. Bandung was selected as the research site because it has a substantial concentration of vocational schools offering machining engineering programs and is located within a rapidly developing manufacturing industrial ecosystem, particularly in the Majalaya, Dayeuhkolot, and Gedebage areas.



The sample was selected using a purposive sampling technique based on the following criteria: (1) the school offers a Machining Engineering program with a minimum accreditation grade of B; (2) it possesses adequate workshop facilities, including at least conventional lathes, milling machines, and CNC machines; (3) it is willing to participate in the study; and (4) it has a sufficient number of eleventh-grade students to allow for the assignment of experimental and control groups.

Based on these criteria, three public vocational high schools in Bandung were selected: SMKN 2 Bandung, SMKN 6 Bandung, and SMKN 12 Bandung. From each school, two eleventh-grade Machining Engineering classes with relatively homogeneous characteristics, as indicated by the average scores from the previous semester, were selected. The total sample consisted of 96 students, including 48 students in the experimental group and 48 students in the control group.

Research Procedures and Stages

The study was conducted over one academic semester (six months) following the systematic stages described below.

Stage 1: Preparation (Month 1)

- Conducting a preliminary study and needs analysis at the three selected vocational high schools.
- Developing research instruments, including competency tests, observation sheets, and work readiness questionnaires.
- Validating the research instruments through expert judgment involving three experts (two lecturers specializing in mechanical engineering education and one manufacturing industry practitioner).
- Assessing instrument reliability through a pilot test involving 30 students from a vocational high school not included in the research sample.
- Developing instructional modules based on the Self-Designed Project Learning (SDPL) model for the experimental group.
- Providing training for teachers who would implement the SDPL model through a two-day workshop.

Stage 2: Pretest (Beginning of Month 2)

- Administering pretests on conventional machining and CNC competencies to both groups.
- Distributing an initial questionnaire to assess students' baseline soft skills.
- Administering an initial work readiness questionnaire.

Stage 3: Treatment (Months 2–5)

- Experimental group: Learning activities using the Self-Designed Project Learning model, consisting of 12 sessions of four instructional hours each.



- Control group: Learning activities using the conventional instructional model, consisting of 12 sessions of four instructional hours each.

Stage 4: Posttest (End of Month 5 to Month 6)

- Administering posttests on conventional machining and CNC competencies to both groups.
- Distributing a final questionnaire to assess students' post-intervention soft skills.
- Administering a final work readiness questionnaire.
- Conducting observations of project outputs produced by students in the experimental group.

Stage 5: Data Analysis and Reporting (Month 6)

- Processing and analyzing the data using descriptive and inferential statistical techniques.
- Preparing the research report and scientific publications.

Implementation of the Self-Designed Project Learning Model

The SDPL model implemented in the experimental group was based on the nine stages developed by Aam Hamdani et al. (2021) and modified according to the i-SDPL model (Aprilia et al., 2018; Sudarsono et al., 2025). These nine stages are presented in Figure 1, entitled *Stages of the Self-Designed Project Learning Model*.

Research Instruments

The instruments employed in this study included the following:

1. Conventional Machining Competency Test: This instrument consisted of 30 multiple-choice questions assessing the cognitive domain and a performance assessment sheet evaluating psychomotor skills related to the operation of conventional lathe and milling machines.
2. CNC Competency Test: This instrument comprised 25 multiple-choice questions covering CNC programming principles, along with practical tasks involving G-code programming and CNC machine operation.
3. Soft Skills Observation Sheet: This instrument assessed five dimensions of soft skills—discipline, responsibility, problem-solving ability, collaboration/teamwork, and effective communication—using a five-point Likert scale.
4. Work Readiness Questionnaire: This instrument contained 40 statements developed based on competency standards required by manufacturing industries in West Java.
- 5.

Data Analysis Techniques

The collected data were analyzed using descriptive statistics (means, standard deviations, and percentages) and inferential statistics (independent-samples *t*-tests and analysis of covariance [ANCOVA]) with the assistance of IBM SPSS Statistics for Windows, Version 26.



Prior to hypothesis testing, the assumptions of normality and homogeneity of variance were examined using the Kolmogorov–Smirnov test and Levene's test, respectively. All statistical analyses were conducted at a significance level of 0.05.

Figure 1. Stages of the Self-Designed Project Learning Model



RESULTS

Following the implementation of the learning program over 12 sessions (equivalent to four months), research data from 96 students were collected and analyzed. The data are presented separately for conventional machining competency, CNC competency, soft skills, and work readiness.



Conventional Machining Competency

A summary of the pretest and posttest scores for conventional machining competency (turning and milling) is presented in Table 1.

Table 1. Pretest and Posttest Results for Conventional Machining Competency

Group	N	Pretest (Mean $\pm$ SD)	Posttest (Mean $\pm$ SD)	Gain (Mean $\pm$ SD)	N-Gain	Category
Experimental	48	58.4 $\pm$ 6.2	84.6 $\pm$ 5.2	26.2 $\pm$ 4.8	0.68	Moderate
Control	48	57.9 $\pm$ 5.9	73.4 $\pm$ 6.8	15.5 $\pm$ 5.1	0.37	Low

Note: SD = Standard Deviation; N-Gain was calculated using the formula (posttest – pretest)/(ideal score – pretest).

The results of the independent-samples t-test on posttest scores revealed a significant difference between the experimental and control groups ($t = 8.947$, $df = 94$, $p < 0.001$). Furthermore, the ANCOVA results, with pretest scores included as a covariate, indicated that the learning model had a significant effect on the improvement of conventional machining competency ($F(1, 93) = 72.456$, $p < 0.001$, $\eta^2 = 0.438$).

CNC Competency

A summary of the pretest and posttest scores for CNC competency is presented in Table 2.

Table 2. Pretest and Posttest Results for CNC Competency

Group	N	Pretest (Mean $\pm$ SD)	Posttest (Mean $\pm$ SD)	Gain (Mean $\pm$ SD)	N-Gain	Category
Experimental	48	32.6 $\pm$ 7.1	78.3 $\pm$ 6.4	45.7 $\pm$ 5.8	0.68	Moderate
Control	48	33.1 $\pm$ 6.8	51.7 $\pm$ 8.2	18.6 $\pm$ 6.3	0.28	Low

The independent-samples t-test conducted on posttest scores demonstrated a highly significant difference between the experimental and control groups ($t = 12.456$, $df = 94$, $p < 0.001$). The ANCOVA results further indicated that the learning model exerted a substantial effect on the improvement of CNC competency ($F(1, 93) = 156.234$, $p < 0.001$, $\eta^2 = 0.627$).

Soft Skills

The results of the soft skills observations at the end of the intervention are presented in Table 3.

Table 3. Comparison of Soft Skills Between the Experimental and Control Groups

Soft Skills Aspect	Experimental (Mean $\pm$ SD)	Control (Mean $\pm$ SD)	t	p
Discipline	4.42 $\pm$ 0.38	3.68 $\pm$ 0.52	8.124	<0.001
Responsibility	4.38 $\pm$ 0.41	3.55 $\pm$ 0.48	9.213	<0.001
Problem-Solving	4.56 $\pm$ 0.35	3.42 $\pm$ 0.51	12.847	<0.001
Collaboration	4.28 $\pm$ 0.44	3.78 $\pm$ 0.46	5.526	<0.001
Effective Communication	4.35 $\pm$ 0.40	3.65 $\pm$ 0.49	7.732	<0.001
Average	4.40 $\pm$ 0.40	3.62 $\pm$ 0.49	8.688	<0.001

Note: Scores were measured using a five-point scale (1 = very poor, 5 = excellent).



Work Readiness

The results of the work readiness questionnaire administered at the end of the intervention indicated that 82.4% of students in the experimental group were categorized as "ready" to work in the manufacturing industry, whereas only 56.7% of students in the control group fell into the same category.

Table 4. Distribution of Work Readiness Categories

Category	Experimental (n = 48)	Control (n = 48)
Highly Ready (80–100%)	18 (37.5%)	5 (10.4%)
Ready (60–79%)	22 (45.8%)	22 (45.8%)
Moderately Ready (40–59%)	7 (14.6%)	16 (33.3%)
Less Ready (<40%)	1 (2.1%)	5 (10.4%)

DISCUSSIONS

Improvement in Conventional Machining Competencies

The findings indicate that the SDPL model is effective in enhancing conventional machining competencies (Düzgünçınar, 2025), as evidenced by an N-Gain score of 0.68 (moderate category) in the experimental group, compared with only 0.37 (low category) in the control group. This improvement can be attributed to the SDPL model's provision of opportunities for students to independently design the products they intend to manufacture, thereby increasing their motivation to gain a deeper understanding of each machining process (Aprilia et al., 2018; Sudarsono et al., 2025).

In conventional learning settings, students tend to follow procedures predetermined by instructors without fully understanding why specific parameters are selected. In contrast, the SDPL model requires students to make independent decisions regarding machining parameters, such as cutting speed, feed rate, and depth of cut, based on theoretical calculations and material considerations, which are subsequently tested and evaluated (Li et al., 2023). This structured trial-and-error process strengthens students' conceptual understanding (Zhang, 2025). These findings are consistent with those of Zhahara et al. (2025), who identified that the psychomotor competencies of vocational high school graduates are considered relevant by industry; however, further improvements are still needed, particularly in terms of precision and work efficiency (Hamka et al., 2024).

Significant Improvement in CNC Competencies

The most notable difference between the two groups was observed in CNC competencies. The experimental group achieved an average posttest score of 78.3 (N-Gain = 0.68), whereas the control group attained only 51.7 (N-Gain = 0.28). This finding is particularly significant given that CNC proficiency has become an urgent requirement in today's manufacturing industry (Sudarsono



et al., 2025; Walker, 2025). The SDPL model inherently encourages students to utilize CNC machines because the complexity of the projects they design often requires a level of precision that can only be achieved through CNC technology (Rubani, 2024; Prabhu, 2025).

Within the SDPL framework, students engage in an integrated learning process. They first design products using CAD software (Step 2), then learn to develop and write G-code programs independently (part of Step 5), and ultimately execute these programs using CNC machines (Mokoena & Moloi, 2024; Nuryanto et al., 2025). This design-programming-execution-evaluation cycle fosters a holistic understanding of digital manufacturing. This approach differs substantially from conventional instruction, which tends to teach CNC programming theory separately from design and production practices.

Sudarsono et al. (2025), in their development of the i-SDPL model, emphasized that industry integration within this framework provides students with access to emerging technologies and practical knowledge that may not always be available in academic settings. This advantage includes active student participation in operations that simulate real industrial environments, product-based training using authentic manufacturing tasks, and comprehensive enhancement of CNC technical competencies (Sudarsono et al., 2025).

Enhancement of Soft Skills as Workplace Capital

The results also demonstrated significant improvements in soft skills among students in the experimental group, particularly in problem-solving (4.56 vs. 3.42) and responsibility (4.38 vs. 3.55). These findings are highly relevant to current industry demands, as Zhahara et al. (2025) reported persistent deficiencies in soft skills among vocational high school graduates, including work ethics, discipline, and occupational safety culture (Hamka et al., 2024).

In the SDPL model, students encounter authentic technical challenges that do not have a single correct solution. They are required to identify problems, explore alternative solutions, select the most effective option, and evaluate the outcomes. This process naturally fosters critical thinking and problem-solving skills (Sudarsono et al., 2025; Cheng et al., 2026). Furthermore, self-designed projects cultivate a strong sense of ownership, resulting in greater responsibility for project success compared with situations in which students merely follow teacher instructions.

Aprilia, Hamdani, and Darmawan (2018), in their study on the implementation of SDPL to enhance technopreneurship among vocational high school students, found that the greatest improvement occurred in the characteristic of "systematic planning and monitoring" (Sudarsono et al., 2025). This finding suggests that the SDPL model effectively trains students to plan products systematically and conduct quality control in a structured manner—competencies that are highly valuable in industrial environments.



Higher Levels of Work Readiness

The finding that 82.4% of students in the experimental group were categorized as work-ready (i.e., ready and highly ready) compared to only 56.7% in the control group demonstrates the effectiveness of the SDPL model in preparing graduates who are genuinely ready to enter the industrial workforce (Adewolu Ogwo, A., 2024). This figure approaches the ideal target expected of vocational education and is substantially higher than the national average employment absorption rate of vocational high school graduates in Indonesia (Hamka, A., et al., 2024; Zhahara et al., 2024).

The higher level of work readiness observed in the experimental group can be explained by three factors. First, students were trained through a comprehensive project cycle, ranging from design to evaluation, which closely mirrors actual workflows in the manufacturing industry. Second, students became accustomed to the quality standards and precision requirements involved in producing real products. Third, students developed essential soft skills required in the workplace, including initiative, communication, and teamwork abilities (Sudarsono, B., et al., 2025; Hamka, A., et al., 2024).

Implications for Vocational Education

The findings of this study have broad implications for vocational education in Indonesia. The SDPL model has proven effective in bridging the competency gap that has long been recognized as a persistent challenge among vocational high school graduates (Pebrian, D., 2024; Hamka, A., et al., 2024). The model not only enhances technical competencies in conventional and CNC machining but also fosters soft skills that are equally critical for workplace success (Mehmood, S., 2024; Laguna, R. F. D., 2025).

The successful implementation of the SDPL model across three public vocational high schools in Bandung indicates that this approach can be replicated in other vocational institutions with similar characteristics. However, successful implementation requires several prerequisites: the availability of adequate workshop facilities, particularly CNC machines; teachers' readiness to transition from their traditional role as "knowledge providers" to facilitators who guide students through the project design process; and strong industry support through internship programs or industrial visits (Sudarsono, B., et al., 2025).

As recommended by Zhahara et al. (2025), strengthening soft skills within the curriculum, enhancing collaboration between schools and industry, and conducting regular curriculum evaluations are essential to ensure that graduates' competencies remain aligned with the evolving demands of the labor market (Hamka, A., et al., 2024; Mahalingam, T., & Webb, H., 2025; Vezi-Magigaba, M. F., & Utete, R., 2024). The SDPL model integrates all three recommendations within a comprehensive framework.



CONCLUSION

This study demonstrates that the Self-Designed Project Learning (SDPL) model is effective in enhancing the competencies of vocational high school students in machining engineering programs. Compared with conventional instructional approaches, students who participated in SDPL exhibited significantly higher achievement in conventional machining competencies, CNC competencies, soft skills, and overall work readiness.

The findings indicate that the SDPL model facilitates meaningful learning by engaging students in authentic, student-centered projects that integrate design, production, evaluation, and reflection processes. Through this approach, students develop not only technical competencies in conventional and CNC machining but also essential workplace skills, including problem-solving, responsibility, communication, and teamwork.

Furthermore, the higher level of work readiness demonstrated by students in the experimental group suggests that SDPL effectively bridges the gap between vocational education and industry requirements. By involving students in project activities that reflect real manufacturing workflows, the model equips them with practical experience and professional competencies relevant to the demands of Industry 4.0.

Theoretical and Practical Implications

From a theoretical perspective, this study reinforces the principles of social constructivism within the context of vocational education by demonstrating that effective learning occurs when students actively construct knowledge through authentic and meaningful experiences. In addition, this study extends the application of the SDPL model by proposing a systematic and measurable implementation framework tailored to machining engineering education.

From a practical perspective, the findings provide evidence that the SDPL model can serve as an effective instructional alternative for reducing the competency gap between vocational school graduates and industry expectations in Indonesia. Successful implementation of the model requires adequate workshop facilities, particularly CNC machines and design software, teacher readiness to adopt facilitative roles, and strong collaboration between schools and industry partners.

Limitations and Recommendations for Future Research

Several limitations should be acknowledged. First, the relatively short duration of the study prevented an assessment of the long-term retention of competencies developed through the SDPL model. Second, the sample was limited to three public vocational high schools in Bandung, which may restrict the generalizability of the findings to regions with different industrial characteristics. Third, this study did not investigate the long-term impact of SDPL on graduate employability and workplace performance.



Future research is therefore recommended to conduct longitudinal studies examining the career trajectories of graduates who have experienced SDPL, expand the geographical scope of implementation, integrate stronger technopreneurship components into the model, and develop effective teacher training programs to support large-scale adoption.

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