

Research Article

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Preparation for the Development of Project Based Learning Model Using Instructional Design Dick & Carey in Vocational School

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Abstract

Background/purpose. Vocational schools require relevant learning methods and models. Project based learning (PjBL) as a product-based learning model and provides real experience. This research describes the learning objectives to be developed, entry skills of vocational school students, characteristics, and learning environment, as well as specific objectives to be achieved in the development of the PjBL model.

Materials/methods. Dick and Carey's Research and Development (R&D) outlines the following steps: identifying instructional goals, conducting instructional analysis, analysing learners and contexts, and writing performance objectives. Purposeful sampling and analysis were conducted at Negeri 6 and Negeri 3 vocational schools in Palu, Central Sulawesi, Indonesia. Open-ended interviews, questionnaires and observation techniques were used as the research instrument. Four vocational teachers and sixteen students were interviewed. Qualitative descriptive data analysis was used.

Results. The learning objective is the application of the Gas Metal Arc Welding (GMAW) process in positions 1F, 2F, and 3F plate to plate. Entry skills of vocational students include an understanding of metal materials. Characteristics of students from moderate and low economic backgrounds, all male, and the expectation of direct employment in the industry. Learning environment with workshops and teacher support certified in competency. Specific objectives are setting, operating machines, and visual inspection according to parameters.

Conclusion. Competency gaps and industry demands require the integration of academic skills such as English report preparation. The heterogeneity of student backgrounds and disparity in facilities between regions demand an inclusive and adaptive learning approach. Performance-based authentic assessment and curriculum alignment with industry standards are key to the success of vocational graduates.

1. Introduction

Learning is an active process of individuals constructing knowledge through interaction with the environment, experience, and critical reflection. According to the constructivist perspective, learning is not simply a transfer of information from teacher to student, but rather an effort to build understanding through dialogue, experimentation, and problem solving (Donovan & Bransford, 2006). Students are the subjects responsible for their learning process, while the teacher acts as a facilitator who provides scaffolding. Social learning theory (Bandura, 1976) asserts that observation, imitation, and modeling are crucial factors in shaping students' behavior and cognitive skills.

Optimal learning occurs within the "zone of proximal development" (ZPD), where teachers design activities that are slightly more advanced than students' current abilities, but still achievable with expert assistance (Vygotsky, 1978). Research by van de Pol et al. (2010) has shown that adaptive scaffolding improves student engagement and learning outcomes. In addition, the integration of technology in learning (blended learning) is proven to expand access and personalize the learning process (Means et al., 2013).

Evaluation in learning was not Tanya's focus on the end result, but also on the process and student development. Formative approaches, such as specific feedback and authentic assessment, help students reflect on their strengths and areas for improvement (Hattie & Timperley, 2007). A meta-analysis study by Kingston and Nash (2011) revealed that timely feedback increases students' self-efficacy. Holistic learning integrates cognitive, affective, and psychomotor aspects and accommodates 21st-century needs such as creativity and collaboration (Pellegrino & Hilton, 2013).

Vocational schools integrate industry-driven curriculum, internships, and project-based learning to ensure the relevance of graduates to industry demands (Ah Gang et al., 2020). This concept was in line with human capital theory, which stated that investment in technical skills increased labor productivity and competitiveness (Becker, 1993). A study by Köpsén (2022) showed that the vocational system in Germany (Dual System) successfully reduced unemployment through intensive collaboration between schools, companies, and the government. Vocational schools emphasized a link and match with the business world to answer the challenges of the Industrial Revolution 4.0 in Indonesia (Permendikbud, 2018).

Vocational schools often face the challenges of social stigma towards non-academic education and facility gaps between urban and rural areas. Research by Rauner et al. (2013) revealed that a lack of industry participation in curriculum development and vocational teacher training can reduce the quality of learning. Vocational schools in Switzerland and Singapore address facility and teacher capacity gaps through strong government funding and international standards-based competency certification (Tütlys & Spöttl, 2017). To improve global competitiveness, modern vocational schools are starting to adopt technologies such as digital simulation, artificial intelligence, and hybrid learning (Pittich & Tenberg, 2020).

Thus, the transformation of vocational schools requires not only curriculum adaptation but also the synergy of various parties to create an educational ecosystem that is responsive to labor market dynamics. Schools and teachers must consider the characteristics, initial understanding, and learning objectives when designing learning processes to ensure the fulfillment of work-ready and entrepreneurial student competencies. Student background, facilities, and learning methods and approaches are prerequisites for effective learning models.

1.1. Theoretical Framework

Project-Based Learning (PBL) is a pedagogical approach that emphasizes learning through the completion of real and complex projects, where students actively explore contextual problems, develop creative solutions, and reflect on the process. Rooted in constructivist theory (Dewey, 1997),

which emphasizes experiential learning, PjBL aims to increase student engagement, conceptual understanding, and 21st-century skills, such as collaboration, critical thinking, and digital literacy (Thomas, J. W., Mergendoller, J. R., & Michaelson, 1999). A meta-analysis research by Hattie & Timperley (2007) showed that PjBL enhances learning effects as students internalize knowledge through practical application. An example of effective implementation is seen in the study by Calabrese and Capraro (2022), where students who used PjBL in science learning showed significant improvement in problem-solving ability and concept retention compared to traditional methods.

Despite its great potential, the implementation of PjBL faces challenges such as teachers' unpreparedness to design authentic projects and a lack of time allocation for the iterative process. A statement (Kokotsaki et al., 2016) identified three main barriers: (1) difficulty balancing curriculum demands with the flexibility of PjBL, (2) lack of teacher training in multidisciplinary project management, and (3) limited access to technological resources in remote areas. In Indonesia, a study by Erlina (2021) found that 76% of science teachers had difficulty integrating PjBL into the content-intensive national curriculum. However, research in Finland by Niemi et al. (2018) has shown that institutional support, in the form of coaching-based training and collaboration between teachers, can increase the effectiveness of PjBL.

The development of technology and the needs of industry 4.0 encourage the transformation of PjBL to be more integrated with digital tools such as virtual simulations, artificial intelligence, and online collaboration platforms. According to Bell (2010), technology-based scaffolding helps students manage project complexity through real-time feedback and data visualization. An innovative example is provided by Larmer et al. (2015), who demonstrate how the use of augmented reality (AR) in a history project increased students' motivation and spatial understanding. On the other hand, a study by Hasni et al. (2016) emphasized the importance of authentic assessments in PjBL, such as portfolios and public presentations, to measure students' holistic development.

Constructivist theory emphasizes that knowledge is actively constructed by learners through interaction with the environment, experience, and critical reflection. The learning process involves assimilation (the integration of new information into mental schema) and accommodation (the adjustment of schema), which are cognitive and individualized (Piaget, J., & Inhelder, 1969). Optimal learning occurs when students receive expert or peer assistance (L. S. Vygotsky, 1986). The theory of scaffolding and discovery learning states that knowledge structures are formed through direct experience and dialogue (Bruner, 1983). Theory, Perspectives, and Practice are integrated to create student-centered learning, with teachers as facilitators (Fosnot & Perry, 2005).

The concept of learning in the context of vocational schools emphasizes the development of practical competencies that are aligned with industry needs, where Project-Based Learning (PBL) becomes the pedagogical backbone. This approach aligns with constructivist theory, which emphasizes experiential learning, where students not only understand the theory but also apply it in real-world situations. Holistic identification is needed to determine the right model/method to achieve learning objectives in vocational schools. This research focuses on the following questions;

- What are the learning objectives to be developed?
- What are the entry skills of vocational school students?
- What are the characteristics of students and the learning environment?
- What are the specific objectives to be achieved in the development of the PjBL model?

The PjBL model is used in consideration of product-based learning and group assignments. PjBL sometimes cannot achieve learning objectives optimally. What is neglected is that teachers do not conduct preliminary studies before applying the PjBL learning model. This research will describe the initial understanding, characteristics, and learning objectives as a prerequisite for the PjBL model.

The hope is that the PjBL model effectively achieves its learning objectives, thereby impacting the maximum fulfillment of student competencies.

2. Literature Review

Learning design is a systematic framework for planning, implementing, and evaluating effective learning experiences. According to David Merrill (2007), effective instructional design principles should include activating prior knowledge, demonstrating concepts, providing practical application, and integrating them into real-world contexts. Learning models such as Project-Based Learning (PjBL) and Problem-Based Learning (PBL) are supported by constructivist theory, which emphasizes students' active role in building knowledge through authentic experiences (Ertmer & Newby, 2013). A study by Anazifa & Djukri (2017) demonstrated that PjBL enhances students' critical thinking skills compared to lecture-based methods, especially when projects are designed with structured scaffolding. This approach aligns with Cognitive Load Theory (Paas et al., 2010), which states that instructional design should minimize extrinsic cognitive load through gradual instruction.

Although innovative learning models are theoretically proven to be effective, their implementation is often hindered by infrastructure gaps and teachers' pedagogical readiness. Research in Indonesia by Erlina (2021) revealed that 76% of science teachers experienced difficulties adapting the content-heavy national curriculum to the PjBL model. A systematic study by Baran et al. (2019) highlighted the importance of teacher training in Technological Pedagogical Content Knowledge (TPACK) to integrate digital tools, such as virtual simulations. Contemporary solutions include blended learning designs that combine face-to-face instruction and digital platforms (Means et al., 2013), as well as the Flipped Classroom model, which enhances student interaction through video-based self-directed learning (Lo & Hew, 2017). In developing countries, collaboration with industry to provide virtual laboratory tools (e.g., Labster) has been shown to reduce facility gaps (Radu, 2021).

Technological developments are driving the transformation of learning models towards more personalized and adaptive approaches. The integration of Augmented Reality (AR) in science education design, as tested by Wiliyanti et al. (2024), demonstrated that understanding abstract concepts through interactive 3D visualization is possible. Artificial intelligence (AI) is also being utilized in adaptive systems such as Intelligent Tutoring Systems (ITS), which provide instant feedback tailored to students' skill levels (du Boulay, 2022). On the other hand, the Design Thinking model was beginning to be adopted to design learner-centered learning, with stages of empathy, prototyping, and iteration (Razzouk & Shute, 2012). However, a study by Hattie and Yates (2014) reminds us that technology is only effective when balanced with evidence-based pedagogical strategies. Therefore, modern learning design must balance digital innovation, theoretical frameworks, and cultural contextualization.

Project-Based Learning (PjBL) is a student-centered pedagogical approach where learning occurs through the completion of contextual and interdisciplinary projects. Rooted in constructivist theory (Dewey, 1997) and (Vygotsky, 1978), PjBL emphasized experience-based learning and social collaboration to build deep understanding. A study by Anazifa & Djukri (2017) showed that students using PjBL experience improved critical thinking and problem-solving skills compared to traditional methods. This effectiveness is supported by (Hattie & Timperley, 2007), who found that PjBL has an average effect size of 0.46 on learning outcomes, as students internalize concepts through practical application. The implementation of PjBL in STEM (Science, Technology, Engineering, and Mathematics) education has been proven to enhance motivation and concept retention (Sithole et al., 2017).

Despite its effectiveness, PjBL implementation often faces challenges such as teachers' lack of readiness in designing authentic projects, curriculum time constraints, and facility gaps. According to

Kokotsaki et al. (2016), three main challenges were identified: (1) difficulty aligning projects with curriculum standards, (2) lack of teacher training in project management, and (3) limited access to technology in remote areas. A case study in Indonesia by Erlina (2021) revealed that 76% of science teachers struggled to integrate PjBL into an education system focused on national exams. Proposed solutions include TPACK (Technological Pedagogical Content Knowledge)-based training for teachers (Koehler & Mishra, 2009) and the use of digital platforms such as Labster for virtual laboratory simulations (Radu, 2021). A hybrid PjBL model, combining face-to-face and online learning, has also proven to enhance flexibility (Means et al., 2013).

Technological advancements have opened opportunities to enrich PjBL with digital tools such as augmented reality (AR), artificial intelligence (AI), and global collaboration platforms. Research by Wiliyanti et al. (2024) indicated that integrating AR into science projects enhanced learning motivation through interactive visualization of abstract concepts. AI-based Intelligent Tutoring Systems (ITS) are used to provide personalized feedback during the project process (du Boulay, 2022). On the other hand, the Design Thinking approach in PjBL encouraged students to design innovative solutions through stages of empathy, prototyping, and iteration (Razzouk & Shute, 2012). However, a study by Hattie & Timperley (2007) found that technology is only effective when supported by clear pedagogical strategies. Therefore, future PjBL design must balance digital innovation, industry collaboration, and authentic portfolio-based assessment.

Vocational education was designed to equip learners with technical skills aligned with labor market needs (Becker, 1993). Vocational models like the German Dual System combine school-based learning and on-the-job training in companies, resulting in the lowest youth unemployment rate in Europe (Köpsén, 2022). Studies by Baumann et al. (2014) indicated that best practice project management principles are necessary to successfully design, implement, and operate industry-driven competency-based education systems that align stakeholder expectations. In Indonesia, the Ministry of Education and Culture Regulation No. 34/2018 on Vocational High Schools emphasizes the link and match between educational institutions and industry, although its implementation still faces challenges such as facility gaps between urban and rural areas (Meng & Sunarya, 2025).

The main challenges facing global Vocational Education & Training (VET) include social stigma against non-academic education, lack of industry participation, and inequality in access to quality training. Research (A. Rauner et al., 2013) showed that only 30% of companies in developing countries actively collaborate with vocational schools, resulting in irrelevant curricula. In South Africa, a study by McGrath et al. (2020) found that a lack of certified trainers and modern practical tools hinders the competence of graduates. Proposed solutions include: (1) tax incentives for companies participating in training (Hartini & Dicriyani, 2021), (2) adoption of digital twin technology for practical simulations (Boettcher et al., 2023), and (3) competency certification based on international standards. A successful example can be seen in Switzerland, where its VET system is recognized as the best in the world due to strong government funding and tripartite collaboration (industry-school-government).

The Fourth Industrial Revolution is driving transformation through the integration of technologies such as artificial intelligence (AI), the Internet of Things (IoT), and big data. A study by Hernandez-de-Menendez et al. (2020) suggests the development of smart workshops using virtual simulations for CNC machine and robotics training. China, Germany, Japan, the United Kingdom, and Australia, under the Society 5.0 program, have a collective commitment to enhancing digital skills and aligning vocational education with industry requirements, although specific priorities vary by country (Diao et al., 2025). However, research in Indonesia by Nur Utomo et al. (2023) indicates that vocational high school students are highly satisfied when they have access to IoT devices, underscoring the need for affirmative policies to promote technology equity. Additionally, the micro-credentials approach (specific skill certifications) is being adopted to enhance training flexibility,

enable human resources professionals to enhance candidates' resumes, and align with career goals, offering personalized skill development opportunities (Alasmari, 2024). The future success of VET depends on technological adaptation, global collaboration, and a focus on green skills to support a sustainable economy.

Vocational learning models are designed to bridge the gap between graduate competencies and industry needs. The Teaching Factory (TEFA) approach adopted in Indonesia combines school-based learning with simulations of real-world work environments, enhancing students' job readiness through mastery of both hard and soft skills (Rohaeni et al., 2021). Köpsén's study (2022) comparing the German (Dual System) and Swiss vocational systems concluded that intensive collaboration between schools and industry is key to success. The Theory of Situated Learning (Jean Lave, 1991) posits that learning occurs through participation in communities of practitioners. Recent innovations include the integration of technologies such as virtual reality (VR) for practical simulations, with the use of VR media significantly influencing the knowledge of welding students (Refdinal et al., 2023). The book *Vocational Education and Training in the Digital Age* (Billett, 2020) emphasized the importance of adapting vocational curricula to the Fourth Industrial Revolution.

The implementation of vocational models in developing countries is often hindered by social stigma, lack of practical facilities, and disparities in teacher quality. Research by M. S. Rauner et al. (2018) found that 60% of vocational teachers in Indonesia were not certified in industrial competencies, resulting in a misalignment between the curriculum and market needs. A comparative study by McGrath et al. (2020) in South Africa and Brazil revealed that the disparity in technology access between urban and rural schools exacerbates training inequality. Proposed solutions include: (1) teacher training based on the Industry 4.0 Competency Framework (González-pérez & Ramírez-montoya, 2022), (2) the Internet of Things as an additional technology to be included in the information technology curriculum (Gumina et al., 2024), and (3) international certification to enhance the global competitiveness of graduates. Hodges et al. (2022) recommend a blended learning approach that combines online learning with structured field practice.

The Fourth Industrial Revolution is driving the transformation of vocational education models through the integration of artificial intelligence (AI), big data, and green skills. A study by Dinesh Deckker and Subhashini Sumanasekara (2025) on the application of AI skills among teachers enables educational institutions to establish high-quality instructional practices aligned with industry requirements. Students must be prepared for success in a technologically advanced society by ensuring they possess critical thinking and collaboration skills while using technology ethically (Shahidi Hamedani et al., 2024). Meanwhile, certified vocational training had a better effect on income compared to regular vocational school graduates (Dharmawan & Adi Wijoyo, 2023). Collaboration between natural scientists and technicians, on the one hand, and social scientists, on the other, is necessary to address the challenges of societal progress (Söderholm, 2020).

3. Methodology

This study employs Dick and Carey's Research and Development (R&D) Instructional Design. Development research is a research method that combines elements of research and development to produce a specific product, then tests the effectiveness of that product (Sugiyono, 2022). Research and development in the context of instructional design is a systematic process for developing learning products (such as modules, curricula, or learning media) through the stages of needs analysis, design, development, formative and summative evaluation, and continuous revision (Walter Dick & Lou Carey, 2015).

Dick & Carey's Instructional Design consists of 10 steps for the product development process. This study outlines the first 4 steps of Dick & Carey's model: Identify Instructional Goal(s), Conduct Instructional Analysis, Analyze Learners and Contexts, and Write Performance Objectives.

The research instruments used semi-structured interviews, questionnaires, and observations. Interviews were conducted with four teachers and 16 students. The teachers were from two schools, with two teachers and eight students from each school. The questionnaire consisted of 12 questions/statements with a rating scale of very inappropriate, inappropriate, appropriate, and very appropriate (4-point scale). The observation consisted of 15 questions or statements about learning objectives, student characteristics, and environmental context.

The subjects were selected using a purposive sampling technique, namely vocational school students from State Vocational School (SMK) 6 Palu and SMK 3 Palu in Central Sulawesi, Indonesia. The research focused on the Welding and Metal Fabrication program and welding skills competencies. The study was conducted in two classes, one at SMK Negeri 6 Palu and one at SMK Negeri 3 Palu. A total of 61 students participated, with 28 from SMK Negeri 6 Palu and 23 from SMK Negeri 3 Palu.

The development design involved two experts with doctoral degrees, three students in the one-to-one phase, and five students in the small group phase. The first expert was a lecturer in educational technology at Surabaya State University with expertise in design and content. The second expert was a lecturer in mechanical engineering at Tadulako University with expertise in welding technology content. Five students who had successfully completed the learning materials related to the design and content of the development objectives participated. The data were analyzed using content and narrative analysis.

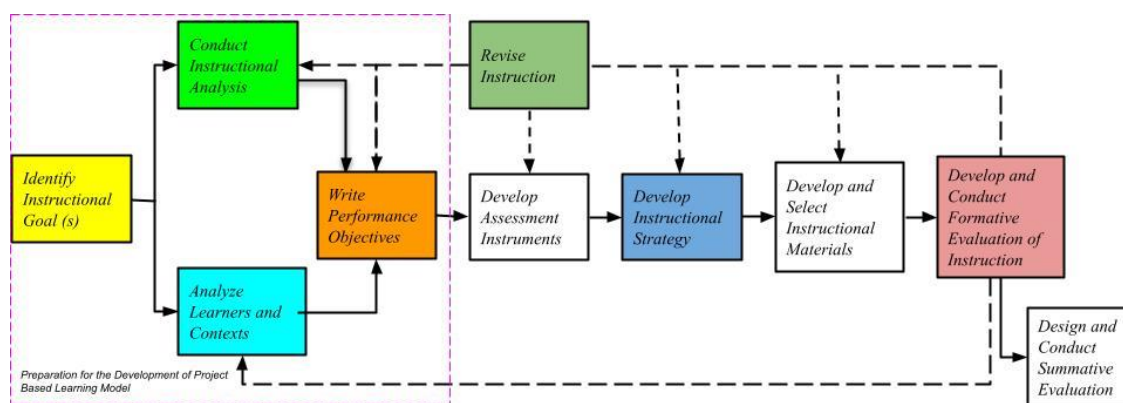


Figure 1. Preparation Limited Stage R&D Model Dick & Carey

The purple dotted line represents the preparatory research steps for developing a project-based learning model. These steps begin with identifying instructional goals and end with writing performance objectives. The first four steps of Dick & Carey serve as preparatory and/or research steps, while the next six steps constitute the development phase. This is intended to outline the research aspects, without yet addressing the development aspects. As such, Dick & Carey's research and development process consists of research steps and development steps.

4. Results

4.1. Identify instructional goal (s)

The main learning objective is to master Gas Metal Arc Welding (GMAW) techniques in positions 1F, 2F, and 3F for plate-to-plate joints. This achievement is measured through minimum average scores and practical skills. Performance analysis results show that most students are skilled in positions 1F and 2F. However, the 3F (vertical) position remains a significant challenge for some students. This indicates the need for a specialized pedagogical approach. Additionally, the ability to prepare laboratory reports in English in a timely manner has not yet reached the expected standards, although most students are able to complete tasks on time.

Table 1. Identify learning objectives

Sources of information	Description	Achievements/follow-up
Learning objectives	Applying the Gas Metal Arc Welding (GMAW) process to plates in positions 1F, 2F, and 3F.	Average score meets minimum criteria
Performance analysis	Practical training	On average, students were skilled at applying positions 1F and 2F, but some students were less skilled at applying position 3F.
	Preparing reports	On average, students struggle to write lab reports and assignments in English in a timely manner.
	Doing homework	On average, students are able to complete assignments on time; however, only a small proportion meets the quality standards, while a small proportion is unable to complete assignments on time.
Needs-based assessment	Students can apply Gas Metal Arc Welding (GMAW) on plates in positions 1F, 2F, and 3F according to the procedure.	Gas Metal Arc Welding (GMAW) process on plate-to-plate positions 1F, 2F, and 3F on mobile whiteboard products according to the shape of the plate (elbow).
Practical experience according to students' learning difficulties	Students lack skills in the 3F welding process on plate-to-plate	On average, students can apply the plate-to-plate welding process to products in accordance with minimum requirements.
Job-based analysis	Students are able to complete at least 3 processes (1F, 2F, 3F) in accordance with the minimum requirements.	On average, students can apply the welding process to products with a minimum of 3 processes (1F, 2F, 3F).
Additional learning objectives	Applying English and mathematics lesson content to skills competencies in accordance with students' skill programs.	Students can understand the application of subjects to professional competencies.

The additional learning objectives highlight the integration of English and mathematics content with technical competencies. Students are expected to understand the application of these subjects in technical contexts, such as the preparation of bilingual reports or the calculation of welding parameters (current, gas volume). This aligns with industry needs for graduates who are not only skilled in practice but also capable of documenting work professionally and applying mathematical

concepts in technical operations. Thus, the document emphasizes a holistic learning approach that bridges theory and practical application.

4.2. Conduct instructional analysis

4.2.1. Entry skill of vocational school students

Student characteristics include familiarity with types of welding machines (SMAW, GMAW), their components (cables, torches, gas regulators), and understanding of materials such as carbon steel and stainless steel. They are able to distinguish between electrodes (E6013, ER70S-6) and relate material properties to welding parameters (current, voltage). This knowledge is acquired through an integrated curriculum and hands-on practice, as demonstrated in the SMAW 3G welding tutorial video. However, applying this knowledge to complex projects (e.g., overhead 4G positions) still requires further development through simulation or intensive coaching.

Students have mastered basic SMAW techniques in flat positions (1G/1F), including arc initiation, slag removal, and weld inspection. Students are skilled in using measuring tools (vernier calipers, rulers) and operating supporting equipment such as grinders. Training videos like “3 Welding Techniques You Must Master” emphasize the importance of torch movement stability and measurement precision to avoid weld defects. This experience forms the foundation for developing advanced competencies such as vertical up welding (3F) or ceramic backing joint welding.

Basic mathematical skills (unit conversion, gas volume calculations) and technical drawing interpretation (welding symbols, joint geometry) serve as supporting pillars for practical performance. Students are trained to read simple working drawings and translate them into welding procedures, as illustrated in the welding symbol video. However, applying academic concepts in real-world contexts (e.g., calculating optimal welding speed) is often hindered by limited experience. Integrating project-based modules—such as fabricating a mobile whiteboard—can strengthen the relevance of these skills.

Soft skills such as discipline in following instructions, teamwork in group projects, and effective communication in the workplace distinguish high-quality vocational graduates. Students are accustomed to adapting in collaborative environments, such as sharing tools or workshop space, as reflected in the vocational school students' practice video. The challenge is developing leadership and conflict management skills, especially when facing time pressure or limited resources. Industry-based scenario training (e.g., repairing welding defects on a ship) can sharpen these abilities.

Student profiles include physical endurance to stand/kneel for extended periods in hot, noisy, and smoky workshop conditions. This adaptability is trained through intensive practice, such as 3F welding sessions lasting 4–6 hours, as shown in the certification video. However, the physical strain risks causing chronic fatigue if not balanced with ergonomic training and adequate rest. A scaffolding approach using VR simulations for posture training before physical practice can mitigate this risk while enhancing learning efficiency.

4.2.2. Student characteristics and learning environment

Table 2. Student characteristics and learning environment

Information categories	Characteristics	Data source
Prior knowledge of the topic area	a. Understanding of the principles of Shielded Metal Arc Welding (SMAW), including electrode selection and arc initiation.	Basic knowledge
	b. Familiarity with common welding terms (e.g., arc, slag, penetration).	

Information categories		Characteristics	Data source
(General preferences)	learning	c. Knowledge of base metals (mild steel, stainless steel) and their properties.	Practical knowledge
		d. Knowledge of material preparation (surface cleaning, rust/oil removal).	
		e. Basic awareness of electrical circuits in welding machines (e.g., grounding, types of current).	
		f. Experience with SMAW in flat positions (1G/1F) for simple joints (butt, lap, fillet).	
		g. Ability to strike and maintain an arc.	
		h. Safe operation of hand grinders, welding hammers, and wire brushes for post-welding cleaning.	
		i. Basic measurement skills using rulers and calipers.	Safety protocol
		j. Cutting and grinding materials to prepare joints (e.g., creating chamfers for groove welds).	
		k. Proper use of welding helmets, gloves, aprons, and safety goggles.	
		l. Awareness of fire hazards, ventilation requirements, and electrical shock risks.	Technical drawings and symbols
		m. Basic first aid for burns or minor injuries.	
		n. Safe disposal of welding waste (e.g., used electrodes, slag).	Soft skills
		o. Basic interpretation of welding symbols (e.g., fillet weld symbols, arrow side notation).	
		p. Understanding of simple technical drawings for welding projects.	
		q. Experience collaborating on group projects (e.g., assembling small welded structures).	
		r. Compliance with instructions, time management, and attention to detail.	
	learning	a. Students tend to be more interested in learning that involves hands-on practice, such as using welding machines, metal joint simulations, and real-world projects.	Practical learning
		b. Students are more motivated when they can see the immediate results of their work (e.g., creating strong and neat welds).	
		c. Activities in the welding workshop are a priority, as they allow students to master basic to advanced techniques (e.g., SMAW, GMAW) through repetition and direct feedback from the instructor.	
		d. Students prefer a learning system that emphasizes the achievement of specific competencies (e.g., mastering welding positions 1G, 2G, 3G, or welding certification according to BNSP/AWS standards). Students want to feel ready to work after graduation.	Competency-based learning
		e. Students prefer assessment through practical tests rather than written exams, as this reflects the real skills needed in the industry.	

Information categories	Characteristics	Data source
	f. Although welding is often an individual activity, students enjoy group projects involving the design of metal structures or collaborative technical problem-solving. This collaboration helps students develop soft skills such as communication and teamwork.	Integration of modern technology and tools
	g. The presence of experienced instructors or industry professionals is a valuable addition, as students can learn from real-world case studies and practical tips.	
	h. At schools with adequate facilities, students are interested in using technology such as VR (Virtual Reality)-based welding simulations or software to analyze weld quality. These tools help reduce the risk of errors during physical practice.	Industrial and contextual relevance
	i. There is a preference for using modern welding machines (e.g., MIG/MAG, TIG) and supporting tools like plasma cutters, especially in urban schools connected to the industry.	Flexibility and autonomy in learning
	j. Students value internship opportunities at welding shops, factories, or construction projects. These experiences reinforce understanding of industry standards and job requirements.	
	k. Learning linked to actual industry challenges (e.g., repairing welding defects in automotive components) enhances motivation and the relevance of the material.	Safety and work ethics
	l. Students enjoy the opportunity to experiment with different welding techniques under instructor supervision. This flexibility allows them to explore specific interests (e.g., metal art or precision welding).	Limited resources and facilities
	m. Preference for open access to tools, materials, and practical guidance during free time at school.	
	n. Students value intensive safety training, such as the use of PPE (Personal Protective Equipment), fire handling, and emergency procedures. This material is considered crucial for job readiness.	Combination of theory and practice
	o. Learning about professional responsibilities (e.g., punctuality, honesty in welding inspections) is an implicit preference, especially in schools partnered with industry.	
	p. Students tend to rely more on traditional methods (e.g., manual arc welding practice) and learning from instructors who creatively utilize local materials in schools with limited facilities.	
	q. Collaboration with local welding shops or community projects serves as an alternative to address equipment limitations.	
	r. Students value theory presented in a contextual manner, such as explanations of metal properties	

Information categories	Characteristics	Data source
<i>Attitudes toward training organization</i>	or heat transfer principles during welding, especially when linked to visual/video examples.	
	a. Students generally appreciate the school's focus on hands-on learning in the welding workshop, as it provides the real-world experience needed in the workplace.	Positive attitude
	b. Facilities such as SMAW/GMAW welding machines, personal protective equipment (PPE), and practice materials are considered important investments for skill development.	
	c. Schools that partner with industry (e.g., internship projects, factory visits) are highly appreciated. Students feel that training is more relevant when it is directly connected to the needs of the job market.	
	d. Instructors with industry backgrounds and the ability to clearly transfer knowledge are respected by students. Students feel more confident when taught by practitioners who understand the real challenges in the field.	Neutral stance
	e. Students tend to be less satisfied and feel that training is suboptimal in schools with limited or outdated equipment (e.g., conventional welding machines that are broken, incomplete PPE).	
	f. Some students feel that the curriculum has not fully adopted the latest technologies (e.g., welding robotics, digital simulation), leaving them ill-prepared to meet the demands of Industry 4.0.	Negative attitude
	g. Not all students have the opportunity to intern at renowned companies, especially in areas with limited industrial networks. This creates a sense of unfairness among some students.	
	h. A dense or inflexible training schedule (e.g., welding practice only at certain times) can cause students to feel exhausted, especially if they have to take turns using equipment.	Factors influencing attitudes
	i. Schools that do not provide intensive occupational safety and health (OSH) training (e.g., fire handling, emergency procedures) are seen as neglecting a crucial aspect. Students feel unprepared to handle risks in real-world work environments.	
	j. Unclear or subjective assessment criteria (e.g., practical grades based solely on the instructor's decision) lead to dissatisfaction and a lack of trust in the organizational system.	
	k. Schools with modern equipment (CNC plasma cutters, MIG/MAG welding machines) and complete PPE tend to receive positive feedback. For example, students at the Center of Excellence Vocational School (SMK PK) are more satisfied because the facilities are adequate.	

Information categories	Characteristics	Data source
	l. Schools that invite industry practitioners as guest lecturers or align their curriculum with BNSP/AWS standards are considered more professional and trustworthy.	
	m. Open feedback mechanisms (e.g., student satisfaction surveys) enhance students' sense of ownership over the training process.	

4.3. Analyze learner and contexts

come from diverse academic backgrounds with varying abilities in mathematics, physics, English, and technical drawing interpretation. Some have basic practical experience (e.g., helping out in the family workshop), while others are complete beginners. This diversity requires a differentiated learning approach. The majority of students (95%+) are male, with a handful of highly motivated females challenging gender stereotypes. Economic factors vary—30% work part-time (workshops, construction) to finance their schooling, creating a unique dynamic in terms of managing study time.

There is a gap in tool proficiency: some are proficient with basic SMAW, while others are just getting acquainted with GMAW/MIG. Previous experience such as 1F position welding provides a foundation, but unpreparedness for complex techniques (3F/4G) remains a challenge. Class capacity (32 students) is often not commensurate with machine availability. The ideal ratio of 4-5 students per machine is difficult to achieve; in remote areas, a 10:1 ratio reduces individual practice time by 70%, hindering mastery of vertical positions (3F). Students demonstrate high enthusiasm during workshop practice sessions, especially when tackling technical challenges (welding defects, 3F positions). Collaboration in group projects and healthy competition serve as intrinsic motivators.

Experienced students often serve as informal mentors for peers facing difficulties. This collaborative pattern enhances learning efficiency, especially in schools with an unfavorable instructor-to-student ratio (1:30). The lack of modern machines and complete PPE (auto-darkening helmets, leather gloves) remains a major obstacle. 25% of students disregard safety protocols when supervision is lax, increasing the risk of accidents. SMAW skills are relevant for construction and shipbuilding, while GMAW is required in automotive and manufacturing. Mastery of complex positions (3F/4G) and specialized materials (stainless steel) is a valuable asset in strategic projects like the National Capital City (IKN).

The ability to read welding symbols (ISO/AWS), operate a plasma cutter, and use precision measuring tools (vernier caliper) are critical competencies required by 85% of certified welder job openings. BNSP/AWS certification (e.g., SMAW Level I) is a prerequisite for employment. Industrial safety training—such as handling gas leaks—must be integrated into the curriculum to meet the safety standards of oil refineries or offshore operations. Vocational schools in coastal areas (e.g., Batam) focus on heavy equipment repair and offshore structures, while schools near automotive industrial zones emphasize GMAW/TIG for vehicle components.

Workshops are designed to resemble industrial fabrication facilities, with workstations for 1F-3F practice. Contextual projects such as constructing school gates or repairing household appliances reinforce the relevance of learning. A 30% theory (via Google Classroom) and 70% practice (workshop) model was adopted post-pandemic. Demonstration videos of welding techniques and defect analysis on industrial components are used to reinforce cognitive understanding. Instructors act as “masters” guiding students (“apprentices”) individually, for example, correcting body posture during 3F welding. Collaboration with industry practitioners (e.g., underwater welding experts) provides a realistic perspective.

Only 40% of teachers have BNSP/AWS certification; most rely solely on practical experience. The instructor-to-student ratio (1:20-30) is not ideal, and the lack of dedicated OSH experts hinders in-depth safety training. There is an imbalance in the allocation of practical time between schools with adequate facilities and those with limited facilities. Ideally, schools should provide 6-8 hours/week for workshop practice with structured stages: 4-6 weeks focusing on basic techniques (1F/K3), followed by difficult welding positions (3F/4G) and a final project (8-12 weeks). However, in areas with a machine-to-student ratio of 10:1, practical training time is reduced by 50% due to queues.

4.4. Write performance objectives

4.4.1. Specific objectives to be achieved in the development of the PjBL model

Table 3. Psychomotor Aspects and Performance Goals

Steps	Performance Objectives
3.1. Position the plate in position 1F, 2F, or 3F.	3.1.1. Students are able to position the plate on a flat surface and secure it using a clamp so that the weld joint is in the upper (flat) position with the plate stable, horizontally aligned (deviation $\leq 2^\circ$), and ready for welding within ≤ 5 minutes. 3.1.2. Students are able to set the plate angle at 45° relative to the horizontal plane and secure it using a vise, with the plate angle must be consistent ($\pm 3^\circ$), not shift during the tack welding process, and meet safety standards (full PPE). 3.1.3. Students are able to position the plate vertically and perform tack welding at the joint ends to prevent shifting with strength (no cracking when tested), ensure even weld penetration, and complete the work within ≤ 7 minutes.
3.2. Perform tack welding on the joint.	3.2.1. Students are able to perform tack welding on 3-4 connection points according to the specified markings while holding the plate parallel (deviation ≤ 1.5 mm). 3.2.2. Students are able to perform tack welding by adjusting the current and speed of the torch movement to minimize thermal distortion without causing the plate to bend (distortion ≤ 1 mm).
4.1. Weld position 1F with a torch angle of 10-15° and a straight motion.	4.1.1. Students are able to weld a 1F position joint by maintaining a torch angle of 10-15° to the plate surface and moving straight along the joint, resulting in a consistent weld bead (6-8 mm wide). 4.1.2. Students are able to weld a 1F position joint with a torch angle of 10-15° and a straight movement to achieve full penetration (full penetration) with weld penetration reaching 80-100% of the plate thickness (visible from the back side of the joint).
	4.2.1. Students are able to weld a 2F position joint by maintaining a torch angle of 45° to the horizontal plane and controlling the torch movement speed steadily without deviating more than $\pm 2^\circ$ from 45° during welding.

Steps	Performance Objectives
4.2. Weld position 2F with a torch angle of 45° and speed control.	4.2.2. Students are able to weld in the 2F position at a 45° angle and with an appropriate movement speed to achieve full penetration and prevent defects by reaching a minimum of 75% of the plate thickness (as seen from the back side of the joint). 4.3.1. Students are able to weld vertical joints (3F) using a zig-zag motion from bottom to top while maintaining a torch angle of 10–15° relative to the vertical plane, resulting in a uniform weld pattern with a bead width of 8–10 mm. 4.3.2. Students are able to weld in the 3F position using a vertical zig-zag motion to achieve full penetration and prevent porosity defects or cracks, with no porosity, cracks, or excessive spatter in the welded joint.
4.3. Weld position 3F with a vertical zig-zag motion from bottom to top.	

5. Discussion

Some students are not proficient in mastering the 3F welding position and writing reports in English yet. This phenomenon is consistent with the findings (M. S. Rauner et al., 2018), which highlighted the importance of a gradual scaffolding approach to technical difficulties that often arise due to a lack of contextual practice and specific feedback. Research by Chaijum and Hiranyachattada (2020) emphasized the need to integrate technical report writing skills with field practice through real-world, product-based projects (such as mobile whiteboards), enabling students to understand the relevance of English and mathematics in an industrial context. Recommended solutions include the use of virtual welding simulators for 3F position simulation before physical practice, as tested by Mulders et al. (2024) in simulator use, as well as the application of structured bilingual report templates to train technical literacy.

The finding that only a small proportion of students completed tasks to quality standards indicates the need for performance-based assessment (authentic assessment) with multidimensional rubrics. The study by McGrath et al. (2020) suggested criteria such as timeliness, welding precision, and weld quality, which align with industry needs. The implementation of blended learning (Means et al., 2013) can mitigate task completion delays by dividing modules into online (welding theory) and offline (practice) components, while collaborating with industry through structured internship programs. Tütlys and Spöttl's research (2017) emphasized the need for competency certification based on international standards (e.g., ISO 9606 for welding) to ensure graduates' readiness to enter the global job market.

Student characteristics reveal the complexity of competencies required for welding mastery, encompassing technical skills (utilization of SMAW/GMAW machines, interpretation of welding symbols) and safety awareness (application of personal protective equipment, adherence to occupational safety and health procedures). These findings align with a study by Berk (2020) that emphasizes the importance of integrating procedural knowledge (e.g., welding parameters, unit conversion) with contextual practice in a simulated workshop environment for effective vocational learning. Refdinal et al. (2023) suggest using a virtual welding simulator to train torch movement stability and joint geometry understanding before physical practice, thereby reducing the risk of accidents and improving skill retention. The main challenge lies in the gap in students' experience,

where some have mastered the basics of SMAW in grade 10, while others still struggle to adapt to the noisy and hot workshop environment. Recommended solutions include differentiated learning modules based on scaffolding, such as step-by-step training for 1F-3F welding positions with visual feedback using augmented reality (AR).

Students' needs in collaboration, communication, and physical adaptation skills are often overlooked in traditional vocational curricula. The study by Rahman & Johari (2022) emphasized the importance of integrating soft skills (such as teamwork and discipline) with technical competencies through collaborative projects based on real-world problems. For example, compiling a bilingual (Indonesian-English) report on K3 procedures can train both technical literacy and cross-cultural communication. On the other hand, applied mathematics skills (such as unit conversion and gas volume calculations) are crucial in bridging theory and practice, as demonstrated by Kai et al. (2021) in the context of machine operation training. Implementing blended learning with digital platforms (e.g., AI-based welding parameter simulations) can facilitate personalized learning, particularly for students with physical limitations. However, the success of this curriculum depends on teacher training in innovative pedagogical methods and collaboration with industry to develop authentic competency-based assessment standards.

The characteristics of the learning environment indicate a strong preference among students for hands-on learning with welding machines (SMAW/GMAW) and VR-based simulations, in line with Jean Lave's (1991) concept of the effectiveness of situated learning. A study by Refdinal et al. (2023) confirms that the use of virtual welding simulators improves welding technique accuracy and reduces the risk of early workplace accidents, especially for complex positions (3G/3F). However, the disparity in facilities between urban schools (SMK PK with CNC plasma cutters) and rural schools (relying on local materials) is consistent with research conducted by McGrath et al. (2020) on the inequality of access to vocational technology in developing countries.

Students feel that the curriculum has not adopted the latest technologies (welding robotics, IoT), reflecting global challenges in aligning vocational education with the Fourth Industrial Revolution yet. Research by Firman Nauli Hutajulu et al. (2025) in Indonesia found significant positive effects of use, value, and risk barriers on resistance to digital twin adoption. Image barriers show a weaker and insignificant influence. Meanwhile, Alasmari's (2024) study recommends integrating micro-credentials based on AWS/ISO 9606 standards. Students' positive attitudes toward industry internships align with the Swiss Dual System model, which reduces competency mismatches through tripartite funding (government-school-industry). To address subjective assessment criteria, Hattie, Yates, and Gregory (2014) suggest using competency rubrics with objective parameters.

Document analysis reveals heterogeneity among vocational welding students in academic ability, practical experience, and motivation. Most engineering students are male, with diverse economic backgrounds, and 30% work part-time in workshops or construction to fund their education. The main challenge lies in the unfavorable student-to-machine ratio (10:1 in remote areas), hindering mastery of complex techniques such as vertical welding positions (3F). A study (Kokotsaki et al., 2016) confirmed that such facility disparities can reduce learning effectiveness by up to 40%. Recommended solutions include providing backup welding machines during additional practice hours and having experienced students (such as those who have worked in workshops) serve as instructor assistants.

The vocational school's welding curriculum is designed to meet industry needs, including Level I certification and GMAW/TIG skills relevant to the automotive and energy sectors. However, job openings for welders prioritizing certified vocational school graduates remain limited, highlighting the gap between educational standards and industry expectations. Research by Boettcher et al. (2023) recommends integrating digital twins for underwater welding simulation and AI-based weld

defect analysis (Gantala & Balasubramaniam, 2021). A successful implementation example is evident at SMK Morowali, where 70% of learning time is dedicated to real-world projects, such as the fabrication of heavy equipment components. Other strategies include intensive OSH training with VR modules for gas leak simulations and an ideal instructor-to-student ratio (1:10) supported by TPACK training for teachers. A study by Yusuf et al. (2024) notes that collaboration with industry practitioners enhances curriculum relevance, though human resource limitations remain a challenge in remote areas.

6. Conclusion

The main challenge in vocational welding education lies in the gap between student competencies and industry demands, particularly in mastering complex techniques (3F positions) and integrating academic skills such as writing reports in English. Studies by M. S. Rauner et al. (2018) and Chaijum & Hiranyachattada (2020) confirmed that a gradual scaffolding approach and project-based learning can enhance students' contextual understanding. Solutions such as virtual welding simulators (Mulders et al., 2024) and bilingual report templates have proven effective in training technical precision and academic literacy. However, their implementation requires adequate facilities and teacher training based on Technological Pedagogical Content Knowledge (TPACK) to ensure safety (K3) and learning quality.

Authentic performance-based assessment and curriculum alignment with industry standards are key to the success of vocational graduates. Research (McGrath et al., 2020) and (Tütlys & Spöttl, 2017) recommends multidimensional assessment criteria (timeliness, quality of welding results) and international competency certification (ISO 9606/AWS). Blended learning models (Means et al., 2013) and industry collaboration through structured internships can reduce competency mismatches. Integrating technologies such as digital twins (Boettcher et al., 2023) and VR simulations for OSH training also enhances curriculum relevance in the Industry 4.0 era, although infrastructure limitations in remote areas remain a challenge.

The heterogeneity of students' backgrounds and disparities in facilities between regions demand an inclusive and adaptive learning approach. Studies (Kokotsaki et al., 2016) indicated that an ideal student-to-machine ratio (4-5:1) and peer-mentoring programs can optimize practical training time. On the other hand, improving teacher quality through certification by the National Professional Standards Agency (BNSP)/AWS and innovative pedagogical training (e.g., augmented reality) is necessary to address the needs of students with diverse abilities. Tripartite collaboration (government-school-industry), such as the dual system model, along with equitable access to technology (CNC plasma cutters, IoT), constitutes a strategic solution for creating a responsive, sustainable, and globally competency-oriented vocational ecosystem.

7. Suggestion

To address the gap in mastery of complex welding techniques (e.g., 3F position) and academic literacy, it is recommended that virtual welding simulators and augmented reality (AR) be integrated as a scaffolding learning medium. These simulators can be used to train torch movement stability and joint geometry prior to physical practice, reducing the risk of accidents and improving skill retention. Bilingual learning (Indonesian-English) through structured report templates, such as K3 procedure reports or welding defect analyses, can improve technical literacy while meeting global industry demands. The blended learning model also needs to be optimized by dividing theory modules (online) and practice modules (offline), and using digital platforms for AI-based welding parameter simulations. Authentic assessment should include multidimensional rubrics (timeliness, precision, quality of results) aligned with ISO 9606/AWS standards.

Vocational curricula need to be aligned with industry needs through competency certification (BNSP/AWS) and structured internship programs, such as the successful example at SMK Morowali, which allocates 70% of learning time to real-world projects. Collaboration with industry to provide backup welding machines, VR-based occupational safety and health (K3) training, and tripartite funding can reduce facility gaps between regions. The government should enhance the Teaching Industry Learning Center (TILC) program by incorporating IoT technology and digital twins for underwater welding simulation. In remote areas, peer-mentoring schemes (where experienced students act as instructor assistants) and the use of local materials can address the unfavorable student-to-machine ratio (10:1). Teacher training based on TPACK and industry-certified instructor certification are also key to improving pedagogical quality and graduate readiness for the 4th Industrial Revolution.

Declarations

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