Effectiveness of Project-Based Learning in Metal Welding Technology Course with STEAM Approach in Vocational Education

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Abstract **– This study assesses the effectiveness of merging project-based learning (PjBL) with STEAM education in metal welding curricula for 64 vocational students at Universitas Negeri Padang over 11 sessions. A quasi-experimental design with pre- and post-tests compared the performance of a PjBL-STEAM experimental group to a traditionally taught control group. The PjBL-STEAM approach significantly outperformed traditional methods, evidenced by higher mean N-gain scores in cognitive (0.763), affective (0.772), and psychomotor (0.759) domains, indicating its high effectiveness. Consequently, it is deduced that educational projects that amalgamate the STEAM approach yield more profound advancements in student academic outcomes than those conducted through conventional means.**

The procedural intricacies of the PjBL-STEAM syntax are meticulously elucidated, serving as a vital resource for educators and students alike in implementing this methodology within lecture settings and equipping students with pertinent competencies for the 21st-century workforce in the welding sector.

Keywords **– Learning outcomes, metal welding technology, project-based learning, STEAM approach.**

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1. Introduction

Data from Indonesia's Central Bureau of Statistics in 2021 indicate that the unemployment rate among higher education graduates with vocational diplomas ranges between 6% and 8% [1]. Although the number of vocational education institutions in Indonesia is increasing yearly, graduates' quality is still far from expectations and needs [2], [3], [4]. This issue arises due to an industry-discrepant curriculum, inadequate facilities, infrastructure, and insufficient collaboration with the industrial sector [5], [6]. Observations of metal welding technology courses in the odd semester of 2023 reveal that lecturers commonly utilize traditional teaching tools like blackboards and PowerPoint. This practice influences the learning process, hindering students from engaging in in-depth discussions and subsequently impacting learning outcomes [7]. Consequently, there is a demand for a pedagogical model that facilitates the exploration of students' competencies and skills before entering the workforce.

The metal welding technology course follows a semester learning plan, emphasizing practical instruction in Shield Metal Arc Welding (SMAW). This technique involves connecting metals in a liquid state using heat energy to join multiple metal rods [8], [9]. The lecture and research occur in the Department of Mechanical Engineering Vocational Education at Universitas Negeri Padang within workshops and study groups. The goal is to meet learning objectives and cultivate students with professional competence and entrepreneurial skills in the industrial sector. Given these circumstances, the study aims to enhance project-based learning through the STEAM approach, focusing on the SMAW metal welding technology project aligned with industrial standards. This approach seeks to enable students to apply theoretical knowledge and skills, preparing them as competent graduates in SMAW metal welding.

1.1. Metal Welding Technology Course with the Project-Based Learning

Project-based learning is an educational method that prioritizes fostering student competence by completing integrated projects aligned with industry requirements. This aims to produce welders proficient in problem-solving and advancing their knowledge [10], [11]. Despite this, real-world projects in the metal welding technology course can be executed by crafting learning scenarios mirroring occupational demands [12]. This aids in cultivating proficient students with pertinent field experience in authentic settings.

According to Syahril *et al*. [13], project-based learning is a student-centered engagement that involves students actively addressing real-world problems and challenges through project work. This method fosters the development of critical, creative, innovative, and collaborative thinking, enhancing problem-solving skills in authentic learning contexts [14], [15]. They are learning and concentrating on cultivating students' abilities and skills in executing welding project-themed tasks. This encompasses tasks such as drafting proposals, designing metal welding models, and presenting final results through reports and seminars—delivered by students in a class setting—formulating tasks at an industrial level.

1.2. The STEAM Approach in Metal Welding Technology Course

The metal welding technology course employs the STEAM approach, integrating science, technology, engineering, arts, and mathematics [16], [17]. Interdisciplinary concepts in metal welding learning reveal relationships between disciplines and their real-world applications. Applying the STEAM approach fosters innovation in metal welding by involving art and engineering, generating creative ideas to enhance efficiency, safety, or reliability through precise welding patterns [18].

The field of metal welding technology undergoes continuous evolution [19]. Project-based learning, coupled with a STEAM approach, offers a creative solution, aiding students in adapting to technological changes and understanding renewable skills crucial for industry demands [20]. This method delivers a comprehensive learning experience encompassing various aspects [21], [22]. Consequently, students grasp the technical intricacies of metal welding and its connections to other disciplines and societal contexts. Hence, this study enriches student learning, provides exploration opportunities, and contributes to advancing technical and vocational education.

1.3. Research Objectives

This research seeks to improve cognitive, affective, and psychomotor competencies in metal welding technology by assessing the effectiveness of project-based learning integrated with a STEAM framework in promoting student creativity and innovation. It focuses on practical skill development in welding across industrial, construction, and manufacturing domains. The research will address specific questions throughout its course:

1. How can the impact of STEAM-orientated project-based learning in welding technology be assessed?
2. How can the effectiveness of a STEAM-based project learning framework be evaluated on cognitive, affective, and psychomotor abilities?

2. Methodology

The research method employed in this study involved a quasi-experimental design to assess the effectiveness of project-based learning (PjBL) with a STEAM approach in metal welding technology courses for vocational students.

2.1. Subject and Research Procedure

This study assesses the effectiveness of STEAM-based project learning in welding technology courses, employing a quasi-experimental design with an experimental group undergoing PjBL-STEAM treatment and a control group receiving traditional instruction. Pre-test and post-test assessments were used to elucidate the causal relationships among the variables [23], [24], [25].

A purposive sample of 64 Mechanical Engineering Vocational Education students from Universitas Negeri Padang, divided into experimental and control groups and instructed by the same lecturer, is detailed in Figure 1.

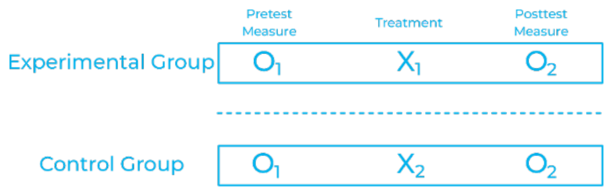

Figure 1. Research procedure of quasi-experiment design

Both experimental and control groups underwent a pre-test to evaluate initial competencies, revealing comparable baseline abilities in metal welding technology [26]. The study sequentially addressed 1) Student needs analysis, 2) Pre-test data collection, 3) PjBL-STEAM application to the experimental group, and 4) Post-test evaluation.

The PjBL-STEAM syntax was implemented weekly for one week per cycle, with a single activity each week. Figure 2 illustrates the research procedure, outlining activities conducted by lecturers and students involving STEAM-integrated project tasks in metal welding technology. SYNTAX outlines inclusive learning steps, encompassing initial activities to showcase student project outcomes.

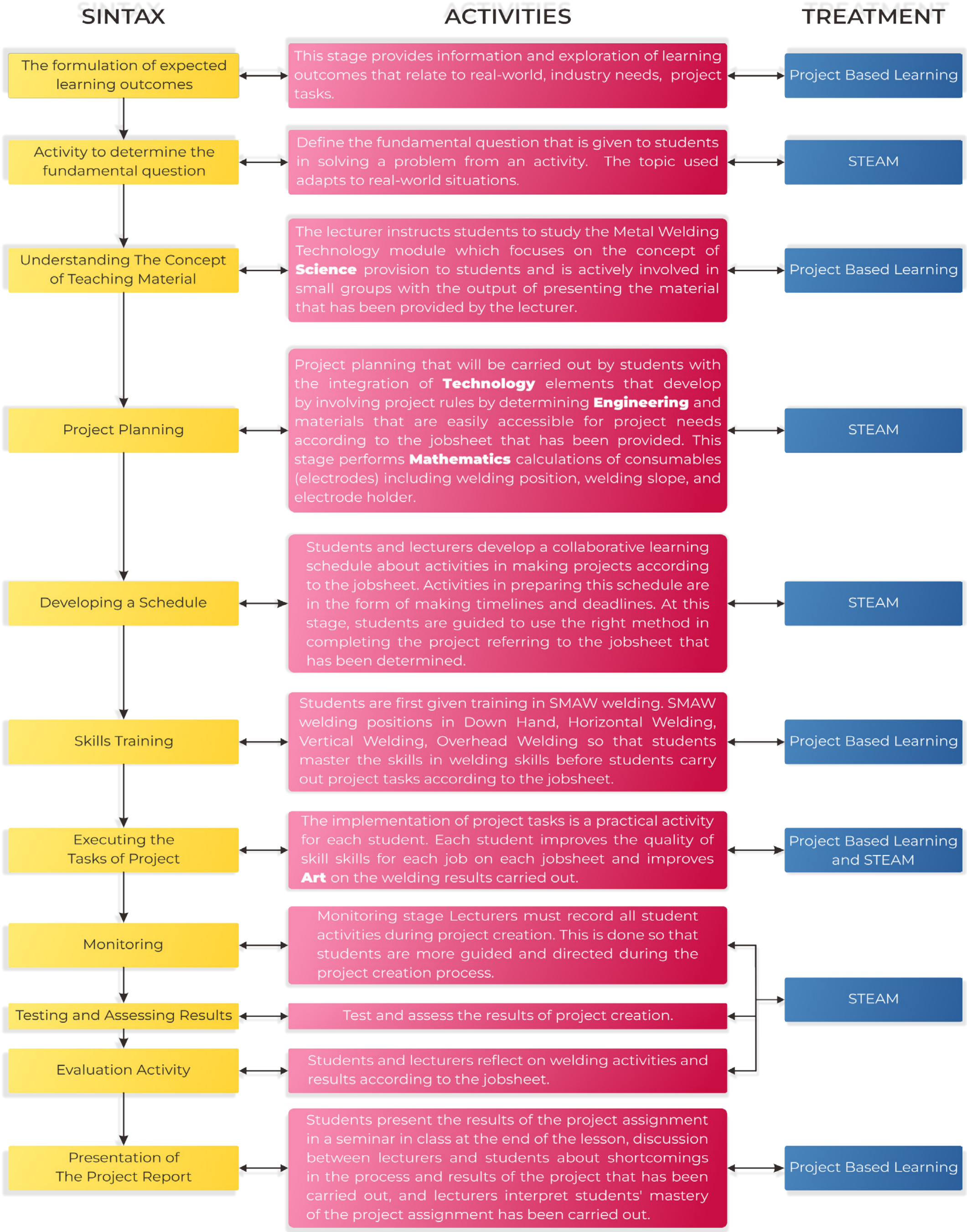

Figure 2. Project-based learning syntax using the STEAM approach

2.2. Data Collection

Data collection included an initial needs analysis, pre-treatment pre-test scores, and post-tests after implementing project-based learning with the STEAM approach. The instruments assessed cognitive, affective, and psychomotor abilities [27]. Research indicators, validated by experienced educators with 30-40 years in teaching and researching project-based learning in metal welding technology courses, comprised initial needs data, pre-test, treatment, and post-test [28]. Initial data analysis was obtained through coefficient analysis [29]. The data interpretation results show a value greater than 0.05, with the r-table value exceeding 0.349 (N = 32) [30]. Item queries underwent validation by experts and were assessed on a 5-point Likert scale from strongly agree to disagree. Statistical outcomes regarding instrument validity and reliability are outlined in Table 1.

Table 1. Instrument domain indicators of cognitive, affective, and psychomotor abilities

Domains	Indicators	Validity	Reliability
Cognitive ability	Knowledge of welding process and working environment conditions	0.691	0.949
	Ability to visually analyze metal welding joints	0.687	0.947
	Analyse metal welding work safety	0.730	0.942
	Basic knowledge of work equipment maintenance	0.673	0.949
	A synthesis of problem-solving and time-management skills	0.738	0.955
Affective ability	Motivation and confidence to perform metal welding tasks	0.702	0.954
	Enthusiasm and dedication to welding work	0.635	0.956
	Awareness of following safety procedures during the welding process	0.698	0.946
	Open-minded to innovative and renewable methods	0.696	0.945
	Competence in the collaborative execution of complex metal welding projects.	0.786	0.946
Psychomotor ability	Operating welding equipment with correct parameters	0.707	0.944
	Good welding joint preparation skills	0.753	0.930
	Skill in organizing ergonomic and safe working positions during the welding process	0.794	0.929
	Reading comprehension of metal welding symbols	0.770	0.933
	Evaluation and visual inspection of welding results	0.819	0.949

The evaluation of cognitive, affective, and psychomotor abilities involved utilizing 55 questions that underwent validation by three proficient experts in the field of metal welding technology courses, as outlined in Table 1. Reliability tests involved 64 students from both control and experimental groups throughout the semester. Cronbach's alpha analysis indicated strong reliability (>0.70) for cognitive (0.947-0.955), affective (0.946-0.956), and psychomotor (0.930-0.949) abilities. The independent sample t-test compared mean student ability assessments between experimental and control groups, using statistical visualization of data results.

2.3. Data Analysis Technique

Data collection assesses the effectiveness of PjBL-STEAM in determining student learning outcomes across cognitive, affective, and psychomotor abilities [31]. Data analysis will utilize SPSS software, employing descriptive statistical analysis for pre-test and post-test values, standard deviation, and data significance levels to inform subsequent decisions [32], [33].

Test results are scored using the Rights Only method [34], where a correct answer receives a value of one, and an incorrect answer is assigned zero. The assessment process of the research instrument includes validity, reliability, normality, homogeneity, independent sample T-tests, and normalized gains, with detailed data analysis in Table 2.

Table 2. Data analysis technique

Analyze	Purpose of Analyze
Descriptive Analyze (statistics)	Detail the features of mean value acquisition, standard deviation, and significance level of research data for decision-making in next stage.
Normality test (Shapiro-Wilk)	Assess data normality to determine suitability for subsequent analysis.
Homogeneity test (Levene-Test)	Evaluate whether the variability (heterogeneity) between groups has the same variability.
Independent Sample T-test (Parametric)	They have contrasted mean outcomes in a quasi-experiment between two treatment groups to gauge the effectiveness of an intervention in eliciting a substantial change in a response variable.
Normalized-gain	Assessing the improvement of learning outcomes after PjBL-STEAM treatment involves computing the score difference between pre-test and post-test results.

N-gain, a metric gauging the enhancement in student achievement after the intervention, serves to evaluate PjBL's effectiveness. It is determined by comparing pre-test and post-test values using the D. E. Meltzer model [35]. N-gain values' comparison assesses project-based learning effectiveness, aiding the enhancement of future learning designs beyond samples with pre-test and post-test. The formula for calculating student N-gain post-PjBL-STEAM treatment is as follows:

$$N\text{-gain} = \frac{\text{Skor post-test} - \text{Skor pre-test}}{\text{Maksimum skor possible} - \text{Skor pre-test}} \times 100$$

Effectiveness evaluation considers improvements in cognitive, affective, and psychomotor abilities, gauged through N-gain formulation for measuring student learning outcomes. The interpretation of N-gain and learning effectiveness is categorized as follows: high/very effective ($(g) \geq 0.70$), medium/effective ($0,31 \leq (g) \leq 0.69$), low/less effective ($(g) < 0.30$) [35].

The final stage of testing PjBL-STEAM effectiveness in the metal welding technology course involves measuring learning outcome improvements through pre-test and post-test scores. This process incorporates normality tests, homogeneity tests, independent sample t-tests, and assessment analysis using normalized gain.

3. Results

This study aims to determine the effectiveness of integrating project-based learning with the STEAM approach in improving students' competence in metal welding technology and preparing them to enter the world of work.

3.1. Project-Based Learning Using STEAM Approach

The study aims to enhance cognitive, affective, and psychomotor skills in Metal Welding Technology courses. It assesses the effectiveness of project-based learning treatment with the STEAM approach, focusing on active and enthusiastic student involvement in project assignment development. The measurement of student achievement emphasizes comprehensive learning outcomes, providing valuable insights with sustainable impact in the future.

Figure 3. Metal welding technology handbook project-based learning using STEAM approach

Figure 3 illustrates the guidebook's development for implementing PjBL syntax with the STEAM approach in metal welding technology. This integration offers a comprehensive learning experience, aligning skills with industrial project demands.

The book highlights student involvement throughout the PjBL Syntax cycle, emphasizing planning, implementation, and final project presentation.

Incorporating STEAM aspects encourages collaboration, such as considering environmental factors (Science), including design and aesthetics (Art), and applying mathematics for precision calculations.

Beyond welding technical skills, the guidebook addresses fundamental concepts like material properties, engineering principles, and structural strength. Moreover, it includes industrial case studies to improve the conceptual grasp of metal welding technology applications in vital projects.

Figure 4. Metal welding technology job-sheet on project-based learning the steam approach

Figure 4 displays the outcomes of crafting a job sheet to enhance students' 21st-century skills. This involves STEAM-based learning steps for developing innovative products with metal welding technology. The project steps encompass: 1) Science: Identifying a real problem related to metal welding, like sustainable energy efficiency. 2) Art and Engineering: Conceptualizing creative designs for welding models with varied tools and materials. 3) Technology: Applying metal welding techniques, considering safety, structural strength, and efficiency. 4) Mathematics: Calculating product measurements based on material requirements and dimensions. 5) Engineering and Science: Assessing products for strength, safety, and efficacy while identifying and rectifying potential shortcomings [36]. 6) Art and Mathematics: Showcase project assignment outcomes incorporating design concepts, metal welding technology implementation, product testing, and critical evaluation. This assignment aims to cultivate students' technical skills, creative thinking, innovation, collaboration, and a profound understanding of the integration between welding technology and STEAM approaches.

3.2. Cognitive Ability

Table 3 displays descriptive analysis results, featuring mean, standard deviation, pre-test, and post-test outcomes for both experimental and control groups. Regarding cognitive ability, the experimental group demonstrated a pre-test mean of 45.03 and a standard deviation of 4.13, rising to a post-test mean of 93.61, with a standard deviation of 3.56. This increased mean value suggests the positive impact of PjBL treatment with the STEAM approach. Compared to the pre-test, the minor post-test standard deviation indicates convergence in students' cognitive abilities after treatment. The control group's cognitive abilities analyzed with conventional learning media had a pre-test mean value of 43.40 and a standard deviation of 6.37. The post-test mean value rose to 79.51, with a decreased standard deviation of 4.82, indicating increased cognitive abilities toward the middle of the distribution for both groups.

Table 3 displays the Shapiro-Wilk normality test results for cognitive abilities in both experimental and control groups.

In the experimental group, both pre-test [S-W = 0.912; Sig. > 0.05 = 0.453] and post-test [S-W = 0.872; Sig. > 0.05 = 0.236] values confirm normal distribution. Similarly, in the control group, the pre-test [*S-W* = 0.963; *Sig.* > 0.05 = 0.845] and post-test [*S-W* = 0.823; *Sig.* > 0.05 = 0.094] values demonstrate normal distribution. Levene's statistics homogeneity test affirms homogeneity for both pre-tests [*Sig.* > 0.05 = 0.447; *L* = 0.627] and post-test [*Sig.* > 0.05 = 0.328; *L* = 1.059] values, supplying ample evidence to advance to the independent sample t-test.

Table 3. Descriptive analysis results of normality and homogeneity tests on cognitive abilities

Type of Test	Group	Mean	SD	Normality Test		Homogeneity Test	
				Shapiro-Wilk Statistics	Sig.	Levene's Statistic	Sig.
Pre-Test	Experiment	45.03	4.13	0.912	0.453	0.627	0.447
	Control	43.40	6.37	0.963	0.845		
Post-Test	Experiment	93.61	3.56	0.872	0.236	1.059	0.328
	Control	79.51	4.82	0.823	0.094		

Table 4 reveals results from the independent sample t-test conducted through SPSS software. It highlights a substantial difference in students' average abilities between the experimental and control groups [*t* = 7.960; *p-value. (2-tailed)* < 0.05 = 0.000]. This signifies the noteworthy enhancement in the experimental group's cognitive learning outcomes post PjBL-STEAM treatment, assessed through an N-gain test for effectiveness.

Table 4. Independent sample t-test on cognitive ability

Group	Mean	SD	Independent sample T-test			
			F	Sig.	*t*	Sig. (2-tailed)
Experiment	88.66	5.50	0.172	0.687	7.960	0.000
Control	64.05	5.20				

3.3. Affective Ability

Table 5 illustrates descriptive analysis for the experimental and control groups' mean, standard deviation, pre-test, and post-test. In the experimental group, affective abilities increased after PjBL-STEAM treatment, with a pre-test mean of 44.68 and a post-test mean of 93.62 (standard deviation 3.80). The consistent standard deviation near the mean indicates consistent results. Conversely, in the control group with conventional learning, students' affective abilities displayed significant variations, with a mean pre-test of 45.22 and a post-test of 81.25 (standard deviation 2.88 and 6.71), indicating substantial variations deviating from the anticipated mean value.

Table 5 displays the Shapiro-Wilk normality test outcomes for students' affective ability. In the experimental group, both pre-test [S-W = 0.933; Sig. > 0.05 = 0.605] and post-test [S-W = 0.934; Sig. > 0.05 = 0.607] values indicate normal distribution. For the control group, the pre-test [S-W = 0.953; Sig. > 0.05 = 0.754] and post-test [S-W = 0.942; Sig. > 0.05 = 0.672] values also suggest normal distribution. Conclusively, both groups exhibit normal distribution. Levene's statistics homogeneity test indicates homogeneity for both pre-tests [*Sig.* > 0.05 = 0.563; *L* = 0.359] and post-test [*Sig.* > 0.05 = 0.328; *L* = 1.136] values. This provides sufficient evidence to proceed with an independent sample t-test, which was conducted considering the outcomes of normality and homogeneity tests.

Table 5. Descriptive analysis results of normality and homogeneity tests on affective abilities

Type of Test	Group	Mean	SD	Normality Test		Homogeneity Test	
				Shapiro-Wilk Statistics	Sig.	Levene's Statistic	Sig.
Pre-Test	Experiment	44.68	3.80	0.933	0.605	0.359	0.563
	Control	45.22	2.88	0.953	0.764		
Post-Test	Experiment	93.62	3.80	0.934	0.607	1.136	0.312
	Control	81.25	6.71	0.942	0.672		

Table 6, assessing the independent sample t-test for affective ability, shows a significant difference in mean student capability between the control and experimental groups [*t* = 4.057; *p-value. (2-tailed)* < 0.05 = 0.002].

This signifies a substantial improvement in students' affective abilities after PjBL-STEAM treatment, where the experimental group outperformed the control group. The subsequent stage includes the N-gain test to evaluate effectiveness.

Table 6. Independent sample t-test on affective ability

Group	Mean	SD	Independent Sample T-test			
			F	**Sig.**	***t***	**Sig. (2-tailed)**
Experiment	88.82	6.43	1.144	0.310	4.057	0.002
Control	65.76	12.35				

3.4. Psychomotor Ability

Table 7 displays descriptive analysis results, including the experimental and control groups' means, standard deviations, and pre-test and post-test scores. In the experimental group, students' affective abilities improved, registering a mean pre-test of 45.43 and post-test of 92.34 (standard deviations of 4.24 and 3.06). The uniform variation around the mean value suggests consistent improvement after implementing the PjBL method with the STEAM approach. Conversely, in a control group with conventional learning, there were significant variations in affective ability, with a mean pre-test of 40.91 and a post-test of 79.12 (standard deviations of 5.06 and 6.38), indicating substantial variation deviating from the expected mean value.

Table 7 illustrates the results of the Shapiro-Wilk normality test for assessing the normal distribution of students' affective ability. The experimental group's pre-test yielded [*S-W* = 0.933; *Sig*. > 0.05 = 0.605], and the post-test showed [*S-W* = 0.934; *Sig*. > 0.05 = 0.607]. Meanwhile, the control group's pre-test value was [*S-W* = 0.953; *Sig*. > 0.05 = 0.754], and the post-test was [*S-W* = 0.942; *Sig*. > 0.05 = 0.672]. Hence, data from both groups demonstrate normal distribution. Levene's statistic for homogeneity indicated pre-test values between the experimental and control groups of [*Sig*. > 0.05 = 0.563; *L* = 0.359], while post-test values were [*Sig*. > 0.05 = 0.328; *L* = 1.136]. This evidence supports the claim that the variance between the scores of the two groups is homogeneous. Consequently, the normality and homogeneity test results allow the independent sample t-test to be used.

Table 7. Descriptive analysis results of normality and homogeneity test of psychomotor ability

Type of Test	Group	Mean	SD	Normality Test		Homogeneity Test	
				Shapiro-Wilk Statistics	**Sig.**	**Levene's Statistic**	**Sig.**
Pre-Test	Experiment	45.43	4.24	0.879	0.263	1.059	0.245
	Control	40.91	5.06	0.864	0.202		
Post-Test	Experiment	92.34	3.06	0.877	0.256	4.024	0.073
	Control	79.12	6.38	0.863	0.199		

The independent sample t-test analysis for psychomotor ability, shown in Table 8, indicates a significant difference in average ability levels between the experimental and control groups, with a t value of [*t* = 5.405; *p-value.(2-tailed)* < 0.05 = 0.000]. In summary, these findings indicate significant improvements in the psychomotor abilities of the experimental group students after implementing PjBL with the STEAM approach, compared to the control group using traditional methods. Finally, the N-gain test will be conducted to evaluate the effectiveness level.

Table 8. Independent sample t-test for psychomotor ability

Group	Mean	SD	Independent Sample T-test			
			F	**Sig.**	***t***	**Sig. (2-tailed)**
Experiment	85.94	5.63	0.454	0.516	5.405	0.000
Control	66.03	7.05				

3.5. Analysis of the N-Gain Score to Enhance Learning Outcomes with PjBL-STEAM Effectiveness.

Normalized gain, a metric assessing learning outcomes, gauges learners' abilities and the efficacy of improvement with PjBL-STEAM treatment in metal welding technology courses over a specific period [37]. Normalized gain, a standardized measure, evaluates the influence of PjBL-STEAM treatment on the learning outcomes of 36 students in the Department of Mechanical Engineering Vocational Education at Universitas Negeri Padang.

Table 9. Analyze the N-gain value of learning outcomes

Aspects	SD	N-gain Score	Criteria
Cognitive ability	0.138	0.763	Effective
Affective ability	0.152	0.772	Effective
Psychomotor ability	0.120	0.759	Effective

Table 9 displays the N-gain value of learning outcomes. Firstly, cognitive ability has a high/very effective N-gain of 0.763 with a standard deviation of 0.138. Secondly, affective ability exhibits a high/very effective N-gain of 0.772, accompanied by a standard deviation of 0.152. Finally, psychomotor ability records a high/very effective N-gain of 0.759, featuring a standard deviation of 0.120. In summary, PjBL-STEAM treatment in welding technology courses effectively enhances competent graduates' cognitive, affective, and psychomotor abilities in the industrial world.

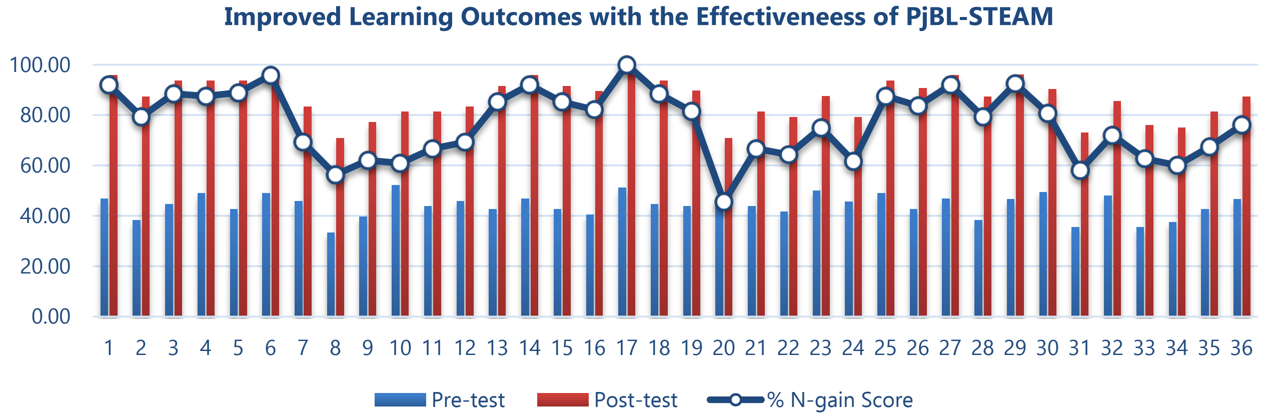

Figure 5. Enhanced learning outcomes using the effectiveness of PjBL-STEAM

Figure 5 depicts the effects of PjBL-STEAM on enhancing students' cognitive, affective, and psychomotor abilities. The collective N-gain value of 0.765 signifies a high/very effective outcome.

4. Discussion

This study evaluates the effectiveness of implementing project-based learning with the STEAM approach, incorporating guidebooks, tools, modules, and jobsheets integrated with industrial-standard materials in metal welding technology [38], [39], [40], [41]. In this study, the experimental group, involved in a metal welding technology project with integrated STEAM modules and job sheets, exhibited better learning outcomes than the control group. These findings are consistent with the research conducted by Chistyakov *et al.* [42]; PjBL positively influences teaching, learning motivation, and engagement in STEAM-integrated education, serving as a viable alternative across all educational levels [43]. Research conducted by Susanti *et al.* [44], discovered that cognitive, affective, and psychomotor abilities exhibited improved learning outcomes with PjBL treatment compared to conventional methods. Employing the PjBL-STEAM approach also cultivates 21st-century skills in vocational students [45], [46], [47]. Integrating metal welding principles and creative components facilitates students' acquisition of practical experiences aligned with industry demands [48]. Students work in small groups on a project task, such as designing a roller bending machine commonly used in metal fabrication. PjBL-STEAM integration employs science, mathematical calculations, art elements, welding techniques, and SolidWorks 3D technology for machine design. The following is an example presented in Figure 6 of the results of student project work that is integrated with industry needs.

(a) (b)

Figure 6. (a) Bending roller machine, (b) Design and Implementation Results

This research innovatively explores the effectiveness of project-based learning in metal welding technology courses by assessing cognitive, affective, and psychomotor dimensions, offering fresh insights into the impact of the STEAM approach. A novel aspect involves employing N-gain as an innovative evaluation method to gauge the success of PjBL with the STEAM approach, highlighting its advantages in enhancing learning motivation, fostering practical skills in project organization, and promoting creativity and innovation. This holistic student experience integrates art, science, and mathematics, providing relevant and in-depth solutions to the research questions.

5. Conclusion and Recommendations

This study emphasizes the effectiveness of PjBL-STEAM treatment in significantly enhancing students' cognitive, affective, and psychomotor abilities. Notable differences in mean values between the experimental and control groups were observed, contributing novelty by applying project-based learning in an industrial context through STEAM evaluation. The positive impact prepares students with 21st-century skills for diverse career opportunities in the industrial sector. N-gain test results confirm the high effectiveness of PjBL-STEAM in motivating student learning outcomes in metal welding projects. Conclusions suggest developing contextual learning strategies for optimal cognitive, affective, and psychomotor outcomes. Future research should evaluate PjBL-STEAM in collaboration with industries, focusing on real-time project integration and conducting case studies across diverse educational institutions. Generalizing advanced STEAM-based PjBL can benefit the education and industrial sectors by fostering creative solutions and skilled human resources for the fabrication and welding industry.

References:

[1]. Purwanti, S., Agung, I. N., Amalia, N., Indrawati, A., & Wishnu Wardana, L. (2023). Problematics Of Business And Management Education In Vocational Schools : Systematic Literature Review (SLR). *Brilliant International Journal Of Management And Tourism*, *3*(2), 121–133. Doi:10.55606/bijmt.v3i2.1403

[2]. Wulansari, R. E., Marta, R., Sakti, R. H., Dewi, S. M., Safitri, D., Kassymova, G. K., Folkourng, F., & Kumar, V. (2023). Computer Assisted Instruction (CAI) Integrated Case Method-Flipped Classroom: Innovative Instructional Model to Improve Problem-Solving Skill and Learning Outcome of TVET Students. *Journal of Technical Education and Training*, *15*(4), 100–113. Doi:10.30880/jtet.2023.15.04.009

[3]. Mubai, A., Ambiyar, Irfan, D., & Rasul, M. S. (2023). Flipped Direct Instruction (FDI): A New Practicum Learning Model in Vocational Education. *International Journal of Learning, Teaching and Educational Research*, *22*(7), 547–565. Doi:10.26803/ijlter.22.7.29

[4]. Prasetya, F., Fajri, B. R., Wulansari, R. E., Primawati, & Fortuna, A. (2023). Virtual Reality Adventures as an Effort to Improve the Quality of Welding Technology Learning During a Pandemic. *International Journal of Online and Biomedical Engineering (IJOE)*, *19*(2), 4–22. Doi:10.3991/ijoe.v19i02.35447

[5]. Le, S. K., Adi, N. H., & Kusuma, A. B. (2023). Development of Web-Based Computer Information System at SMKS Pertiwi Batam Laboratory Management. *Journal of Computer-Based Instructional Media*, *1*(2), 57–72. Doi:10.58712/jcim.v1i2.107

[6]. Varadila, J., Meilisa, R., Annisa, A., & Folkourng, F. (2023). Development of learning media based on macromedia flash 8 to see learning outcomes and achievements in vocational high school students. *Journal of Computer-Based Instructional Media*, *1*(1), 9–18. Doi:10.58712/jcim.v1i1.16

[7]. Handrayani, D., Rahmadani, K., Baqi, F. A., & Kassymova, G. K. (2023). Education Transformation in Era 4.0: The Effect of Learning Facilities on Student Learning Outcomes. *Journal of Computer-Based Instructional Media*, *1*(1), 34–43. Doi:10.58712/jcim.v1i1.106

[8]. Suparno, S., Syahril, S., Rahim, B., & K., A. (2019). Development of the Teaching Material at Sheet Metal Course in Program Vocational Mechanical Engineering. *International Conference on Technical and Vocational Education and Training*, *299*, 152–157. Doi:10.2991/ictvet-18.2019.33

[9]. Refdinal, R., Adri, J., Prasetya, F., Tasrif, E., & Anwar, M. (2023). Effectiveness of Using Virtual Reality Media for Students' Knowledge and Practice Skills in Practical Learning. *JOIV: International Journal on Informatics Visualization*, *7*(3), 688–694.

[10]. Ambiyar, A., & Afifah, N. (2019). The Effect of Project Based Learning Towards Student Achievement in Electrical Machines and Energy Conversion Subject. *Journal of Physics: Conference Series*, *1387*(1). Doi:10.1088/1742-6596/1387/1/012087

[11]. Syahril, Purwantono, Wulansari, R. E., Nabawi, R. A., Safitri, D., & Kiong, T. T. (2022). The Effectiveness of Project-Based Learning On 4Cs Skills of Vocational Students in Higher Education. *Journal of Technical Education and Training*, *14*(3), 29–37. Doi:10.30880/jtet.2022.14.03.003

[12]. Wang, B., Li, Y., & Freiheit, T. (2022). Towards intelligent welding systems from a HCPS perspective: A technology framework and implementation roadmap. *Journal of Manufacturing Systems*, *65*, 244–259. Doi:10.1016/j.jmsy.2022.09.012

[13]. Syahril, S., Nabawi, R. A., & Safitri, D. (2021). Students' Perceptions of the Project Based on the Potential of their Region: A Project-based Learning Implementation. *Journal of Technology and Science Education*, *11*(2), 295–314. Doi:10.3926/jotse.1153

[14]. Tang, T., Vezzani, V., & Eriksson, V. (2020). Developing critical thinking, collective creativity skills and problem solving through playful design jams. *Thinking Skills and Creativity*, *37*, 100696. Doi:10.1016/j.tsc.2020.100696

[15]. Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. Doi:10.15294/jpii.v9i1.21754

[16]. Rizki, I. A., Suprapto, N., & Hariyono, E. (2023). Designing Vertical Axis Wind Turbine Prototype as Future Renewable Energy Source in STEAM Learning. *TEM Journal*, *12*(1), 452–458. Doi:10.18421/TEM121-55

[17]. Holbrook, J., Rannikmäe, M., & Soobard, R. (2020). STEAM Education—A transdisciplinary teaching and learning approach. *Science education in theory and practice: An introductory guide to learning theory*, 465-477.

[18]. Getachew, M. T., Shiferaw, M. Z., & Ayele, B. S. (2023). The Current State of the Art and Advancements, Challenges, and Future of Additive Manufacturing in Aerospace Applications. *Advances in Materials Science and Engineering*, 1–13. Doi:10.1155/2023/8817006

[19]. Reisgen, U., Mann, S., Middeldorf, K., Sharma, R., Buchholz, G., & Willms, K. (2019). Connected, digitalized welding production-Industrie 4.0 in gas metal arc welding. *Welding in the World*, *63*(4), 1121–1131. Doi:10.1007/s40194-019-00723-2

[20]. Mikhaylovsky, M. N., Karavanova, L. Z., Medved, E. I., Deberdeeva, N. A., Buzinova, L. M., & Zaychenko, A. A. (2021). The Model of STEM Education as an Innovative Technology in the System of Higher Professional Education of the Russian Federation. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(9), 1–11. Doi:10.29333/ejmste/11173

[21]. Ambiyar, Nawi, M. N. M., Rizal, F., Sukardi, Edidas, Verawardina, U., Rahim, F. I., Yaacob, N. A., Baharum, F., & Shahron, S. A. (2024). The Experiences and Challenges of Online Learning Technology for Teaching during the COVID-19 Pandemic among University Undergraduate Students. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *35*(2), 47–56. Doi:10.37934/araset.35.2.4756

[22]. Yoo, S., Lee, S., Kim, S., Hwang, K. H., Park, J. H., & Kang, N. (2021). Integrating deep learning into CAD/CAE system: generative design and evaluation of 3D conceptual wheel. *Structural and multidisciplinary optimization*, *64*(4), 2725-2747.

[23]. Le, S. K., Hlaing, S. N., & Ya, K. Z. (2022). 21st-century competences and learning that Technical and vocational training. *Journal of Engineering Researcher and Lecturer*, *1*(1), 1–6. Doi:10.58712/jerel.v1i1.4

[24]. Jalinus, N., Haq, S., & Kassymova, G. K. (2023). Work-based learning for the engineering field in vocational education : Understanding concepts , principles and best practices. *Journal of Engineering Researcher and Lecturer*, *2*(1), 9–17. Doi:10.58712/jerel.v2i1.22

[25]. Jalinus, N., Wulansari, R. E., Heong, Y. M., & Kiong, T. T. (2023). Teaching activities for supporting students' 4cs skills development in vocational education. *Journal of Engineering Researcher and Lecturer*, *2*(2), 70–79. Doi:10.58712/jerel.v2i2.95

[26]. Rusli, F. N., Zulkifli, A. N., bin Saad, M. N., & Yussop, Y. M. (2019). A Study of Students' Motivation in Using the Mobile Arc Welding Learning App. *International Journal of Interactive Mobile Technologies (IJIM)*, *13*(10), 89–105. Doi:10.3991/ijim.v13i10.11305

[27]. Owan, V. J., Ekpenyong, J. A., Chuktu, O., Asuquo, M. E., Ogar, J. O., Owan, M. V., & Okon, S. (2022). Innate ability, health, motivation, and social capital as predictors of students' cognitive, affective and psychomotor learning outcomes in secondary schools. *Frontiers in Psychology*, *13*, 1–19. Doi:10.3389/fpsyg.2022.1024017

[28]. Prasetya, F., Fortuna, A., Samala, A. D., Fajri, B. R., Efendi, F., & Nyamapfene, A. (2023). Effectiveness of Distance Learning Computer Numerical Control Based on Virtual Laboratory Using a Metaverse Platform to Improve Students' Cognitive Ability and Practice Skills. *International Journal of Interactive Mobile Technologies (IJIM)*, *17*(24), 4–21. Doi:10.3991/ijim.v17i24.45019

[29]. Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, *45*(1), 131–142. Doi:10.1177/0013164485451012

[30]. Murniati, D. E., Purwanti, S., Handayani, T. H. W., Harsana, M., Razzaq, A. R., & Rohiat, M. A. (2022). The Influence of Final Project Product Development on Students' Entrepreneurial Motivation. *Journal of Technical Education and Training*, *14*(2), 119–132. Doi:10.30880/jtet.2022.14.02.011

[31]. Simonton, K. L., Layne, T. E., & Irwin, C. C. (2021). Project-based learning and its potential in physical education: an instructional model inquiry. *Curriculum Studies in Health and Physical Education*, *12*(1), 36–52. Doi:10.1080/25742981.2020.1862683

[32]. Sansi, A. S., Rini, F., Mary, T., & Kiong, T. T. (2023). The Development of Android-based Computer and Basic Network Learning Media. *Journal of Computer-Based Instructional Media*, *1*(2), 44–56. Doi:10.58712/jcim.v1i2.19

[33]. Mubai, A., Rukun, K., Giatman, M., & Edidas, E. (2020). Needs Analysis in Learning Media Development Based on Augmented Reality (AR) for Computer Network Installation Courses. *Jurnal Pendidikan Teknologi Kejuruan*, *3*(1), 31–35. Doi:10.24036/jptk.v3i1.3723

[34]. Taban, T., & Kiray, S. A. (2022). Determination of Science Teacher Candidates' Misconceptions on Liquid Pressure with Four-Tier Diagnostic Test. *International Journal of Science and Mathematics Education*, *20*(8), 1791–1811. Doi:10.1007/s10763-021-10224-8

[35]. Meltzer, D. E. (2002). The relationship between mathematics preparation and conceptual learning gains in physics: A possible "hidden variable" in diagnostic pre-test scores. *American Journal of Physics*, *70*(12), 1259–1268. Doi:10.1119/1.1514215

[36]. Kusuma, W., Adi, N. H., Afrina, A., & Jimenez, J. R. A. (2023). Development of Web-Based Goods Inventory Information System to Improve Efficiency and Effectiveness of Inventory Management at Batam Cable Vision Company. *Journal of Computer-Based Instructional Media*, *1*(2), 88–105. Doi:10.58712/jcim.v1i2.110

[37]. Garbin, C., Zhu, X., & Marques, O. (2020). Dropout vs. batch normalization: an empirical study of their impact to deep learning. *Multimedia Tools and Applications*, *79*, 12777–12815. Doi:10.1007/s11042-019-08453-9

[38]. Lesmana, I., Mulianti, M., Primawati, P., & Kassymova, G. K. (2023). Implementation of project-based learning (PjBL) model to increase students' creativity and critical thinking skill in vocational creative product subjects. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(3), 202–215. Doi:10.24036/jptk.v6i3.34023

[39]. Febrianti, R., A, Y., Putra, R. P., & Phongdala, P. (2023). Implementation of project-based learning for improve students' critical thinking skills in creative product and entrepreneurship subjects. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(4), 240–247. Doi:10.24036/jptk.v6i4.34523

[40]. Aziz, W. A., Wulansari, R. E., Putra, R. P., Tun, H. M., Tin, C. T., & Ya, K. Z. (2023). Project-based learning module on creativity and entrepreneurship products subject: Validity and empirical effect. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(3), 216–227. Doi:10.24036/jptk.v6i3.34323

[41]. Chung, C. C., Huang, S. L., Cheng, Y. M., & Lou, S. J. (2022). Using an iSTEAM project-based learning model for technology senior high school students: Design, development, and evaluation. In *International Journal of Technology and Design Education*, *32*(2). Springer Netherlands. Doi:10.1007/s10798-020-09643-5

[42]. Chistyakov, A. A., Zhdanov, S. P., Avdeeva, E. L., Dyadichenko, E. A., Kunitsyna, M. L., & Yagudina, R. I. (2023). Exploring the characteristics and effectiveness of project-based learning for science and STEAM education. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(5), 1–7. Doi:10.29333/ejmste/13128

[43]. Nuraini, N., Asri, I. H., & Fajri, N. (2023). Development of Project Based Learning with STEAM Approach Model Integrated Science Literacy in Improving Student Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1632–1640. Doi:10.29303/jppipa.v9i4.2987

[44]. Susanti, S., Susilowibowo, J., & Tantri Hardini, H. (2019). Effectiveness of Project-based Learning Models to Improve Learning Outcomes and Learning Activities of Students in Innovative Learning. *International Conference on Economics, Education, Business and Accounting (KnE Social Sciences)*, *3*(11), 82. Doi:10.18502/kss.v3i11.4000

[45]. Samala, A. D., Dewi, I. P., & Mursyida, L. (2023). "E-LabSheet Project" 4Cs-Based Supplementary Media for Flexible Learning: Is it Well Implemented? *International Journal of Online and Biomedical Engineering (IJOE)*, *19*(1), 4–20. Doi:10.3991/ijoe.v19i01.35523

[46]. Ahmad, S. T., Watrianthos, R., Samala, A. D., Muskhir, M., & Dogara, G. (2023). Project-based Learning in Vocational Education: A Bibliometric Approach. *International Journal of Modern Education and Computer Science*, *15*(4), 43–56. Doi:10.5815/ijmecs.2023.04.04

[47]. Rahmawati, Y., Hadinugrahaningsih, T., Ridwan, A., Palimbunga, U. S., & Mardiah, A. (2021). Developing the critical thinking skills of vocational school students in electrochemistry through STEM - Project-based learning (STEM-PjBL). *AIP Conference Proceedings*, 1–7. Doi:10.1063/5.0041915

[48]. Hearn, G., Williams, P., Rodrigues, J. H. P., & Laundon, M. (2023). Education and training for industry 4.0: a case study of a manufacturing ecosystem. *Education and Training*, *65*, 1070–1084. Doi:10.1108/ET-10-2022-0407