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Enhancing GTAW Proficiency through ADDIE-Integrated Joyful Learning Simulation: Empirical Insights from Vocational High School Implementation

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Abstract

Welding practice learning in vocational schools often faces challenges such as limited equipment, time constraints, and safety risks. This study aims to implement a Welding Simulator using a joyful learning approach to improve students' practical competencies in GTAW (Gas Tungsten Arc Welding) at vocational high school level. The research is part of an ADDIE-based development process, with a focus on the implementation phase. The participants were 34 purposively selected 11th-grade students. Data were collected through practical tests (pre-test and post-test) and student perception questionnaires, analyzed using paired t-tests and descriptive statistics. The results showed a significant improvement in post-test scores compared to pre-test (from 64.2 to 77.35; $p < 0.05$). Students' perceptions of the media were highly positive, with an average rating of 4.00 out of 5. The simulator effectively enhanced students' welding skills while creating an engaging and enjoyable learning environment. The study concludes that the joyful learning-based welding simulator is effective as a practical learning tool in vocational education.

Keywords: digital-based curriculum, GTAW welding, innovative learning model, joyful learning, learning motivation, practical competence, welding simulator

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1. Introduction

In the field of vocational education, particularly in vocational high schools (SMK), practical skills are of paramount importance. One of the core competencies in the Welding Engineering department is students' ability to master welding techniques with precision and safety. However, in practice, welding training at SMK still faces various challenges, such as limited practice equipment, high accident risks, costly materials, and restricted practice time and space (Febrianto, 2012). These constraints ultimately impact the overall quality of students' skills. To address these challenges, there is a need for innovative learning media that can facilitate safe, efficient, and engaging practical experiences.

Several studies have highlighted that the use of simulators, particularly welding simulators, can enhance students' welding competencies. For example, Chung et al. (2020) and Ipsita et al. (2022) reported that the implementation of virtual reality–based simulators not only reduces the risk of accidents but also improves conceptual understanding and students' confidence. Similarly, Pambudi et al. (2024) found that integrating 3D animation into welding modules positively influenced students' motor skills. Furthermore, Chan et al. (2022) and Huang et al. (2020) emphasized that simulators significantly accelerate the mastery of SMAW and GMAW techniques.

On the other hand, the joyful learning approach has also been proven effective in increasing students' motivation and engagement. Kiikeri et al. (2024) stated that enjoyable learning fosters a conducive classroom atmosphere and encourages creativity. Dahalan et al. (2024) developed a gamification-based simulator for occupational safety training, which made learning more attractive and interactive. Likewise, Pamungkas et al. (2021) revealed that vocational students respond positively to joyful learning, especially when combined with simulation technology.

Nevertheless, the integration of welding simulators with a joyful learning approach has not been widely explored in Indonesia, particularly in the context of Welding Engineering at SMK. In fact, combining technological tools with affective pedagogical strategies is expected to create a more holistic and meaningful learning experience for students (Prastikawati et al., 2025). Most previous studies primarily focused on simulators as technical learning tools without addressing the pedagogical aspects of joyful engagement. For instance, studies by Heibel et al. (2023) and Huang et al. (2020) examined the effectiveness of VR and AR in training but did not explore students' affective aspects and engagement in depth. This research gap forms the foundation of the present study.

The novelty of this research lies in the integration of welding simulator media with a joyful learning approach into a contextual, enjoyable, and applicable learning model for vocational schools. This study does not only assess students' cognitive and psychomotor skills but also considers affective aspects such as motivation, enthusiasm, and learning comfort (Chung et al., 2020; Maknun et al., 2018; Alfizahr et al., 2023). This approach is in line with the Merdeka Belajar (Freedom to Learn) policy and the strengthening of digital-based vocational curricula.

The development of a learning model that integrates simulator technology with joyful learning is expected to provide an innovative solution to the challenges of vocational practical training (Hardini et al., 2022). This model allows students to practice intensively without facing accident risks or material limitations (Azizah et al., 2023; Priyawati, 2020). Moreover, a joyful learning atmosphere encourages active student engagement during the learning process, which ultimately contributes to improved overall learning outcomes (Sutopo et al., 2022). Therefore, it is essential to design a model that not only emphasizes technical aspects but also considers vocational students' characteristics, learning styles, and authentic learning environments (Susanti et al., 2024).

The purpose of this study is to implement welding simulator media with a joyful learning approach and to examine its effectiveness in improving the practical competence of Welding Engineering vocational students. This study also aims to identify students' perceptions of their learning experiences with this innovative media and to evaluate changes in their learning behaviors during welding practice.

Practically, the study is expected to contribute to the development of innovative learning media in vocational high schools, particularly in the field of welding engineering. Theoretically, it enriches the discourse in vocational education by integrating technology and positive pedagogy. From a policy perspective, the findings of this study may serve as a reference for school leaders, teachers, and policymakers in designing learning strategies that are engaging and adaptive to the demands of the Industry 4.0 era.

2. Method

This study is part of a series of research and development (R&D) activities employing the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model is considered a systematic and flexible framework for developing effective and efficient learning media (Branch, 2009). In the context of this study, the primary focus is on the implementation stage, namely the process of integrating the developed media into classroom learning to examine its impact on students' competence achievement.

The implementation stage was carried out to investigate how the welding simulator media, which had previously undergone validation and revision, could be applied in real learning situations. The use of the simulator was integrated into Gas Tungsten Arc Welding (GTAW) practice at SMK Negeri 1 Mondokan. The features integrated into the media included simulation of welding torch movements or oscillations, swing consistency, swing alignment, and torch travel speed, all of which aligned with GTAW welding principles.

The research design employed was a quasi-experimental method with a one-group pretest–posttest design, in which learning outcomes were measured before and after the intervention within the same group, without a control group (Fraenkel, Wallen, & Hyun, 2012). This design was deemed suitable for limited and exploratory implementation, focusing on the effect of a treatment on the targeted subjects. The participants of this study were 34 eleventh-grade students from the Welding Engineering program, selected purposively based on their readiness to engage in advanced welding practice.

The data collection instruments consisted of two components. First, a practical competency test in the form of welding tasks was administered before and after the treatment. Second, a student perception questionnaire was used to explore their responses to the use of joyful learning–based media, with indicators such as visualization, ease of use, feedback, and joyful learning (Sugiyono, 2018).

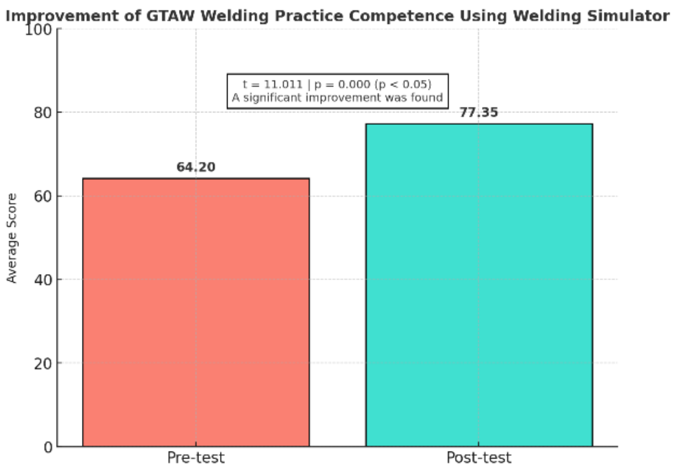

Figure 1. Comparison of Average Pre-test and Post-test Values of GTAW Welding Practice Competencies Using a Welding Simulator

The test data were analyzed quantitatively using a paired sample t-test to determine the significance of the difference in scores between the pre-test and post-test (Pallant, 2020). This analysis technique is suitable for use in a single-group design to determine the effect of the treatment on the dependent variable. Meanwhile, the questionnaire data were analyzed descriptively quantitatively by calculating the average score and percentage distribution of responses to illustrate students' perceptions of the learning media used.

From this implementation stage, it is hoped that empirical evidence will be obtained regarding the effectiveness of the welding simulator media with a joyful learning approach in improving the practical competencies of vocational high school students. Furthermore, the results of this study are expected to serve as a basis for improving media and learning strategies in technology-based vocational education.

3. Result and Discussion

A. Improvement of Students' Practical Competence

The measurement of students' practical competence in Gas Tungsten Arc Welding (GTAW) was conducted through pre-tests and post-tests using a performance-based rubric. This study involved 34 eleventh-grade students of the Welding Engineering program at a vocational high school who had participated in the learning process using Welding Simulator media with a joyful learning approach.

The data analysis revealed that the students' average pre-test score was 64.2, while the average post-test score increased to 77.35. A paired-sample t-test produced a result of $t = 11.011$ and $p = 0.000$ ($p < 0.05$). These findings indicate a statistically significant improvement in students' practical competence after the use of Welding Simulator media. This result supports the hypothesis that simulation-based learning media can meaningfully enhance students' GTAW welding practice skills. Testing showed a significant improvement in practical proficiency following the implementation of the Welding Simulator utilising an engaging learning methodology. Students' perceptions of the medium were favourable and corroborate the observed enhancement. The investigation reveals significant improvements resulting from the utilisation of the Welding Simulator with an engaging learning method, and students' perceptions of the medium are categorised positively, hence reinforcing the enhancement.

These findings are consistent with Knoke and Thoben (2017), who demonstrated that the integration of simulation-based training in vocational education significantly improves technical accuracy and reduces material consumption in real practice. Similarly, Chung et al. (2020), in their study of VR welding implementation, found that students practicing with interactive simulations achieved higher efficiency, particularly in torch oscillation patterns and control.

Whitney and Stephens (2014) also reported that welding simulators enhanced procedural understanding and improved the quality of weld joints produced by technical students. Furthermore, Yunus et al. (2025) highlighted the effectiveness of augmented reality–based 3D simulation modules in helping vocational students comprehend welding skills through a contextual and enjoyable approach. Additional support comes from Pambudi, Yunus, and Wibowo (2024), who concluded that the use of animated simulation modules in SMAW learning directly and significantly improved students' motor skills.

Supported by empirical data and reinforced by recent literature, it can be concluded that Welding Simulator media is not only an alternative when practical resources are limited but also a primary tool for effectively and efficiently improving practical competence in vocational education

This enhancement aligns with the research supporting the efficacy of simulation-based training in improving technical precision and operational efficiency. The integrated features—visualization of torch oscillation, consistency and linearity of oscillation, and movement velocity—offer a systematic and secure practice experience, hence promoting the acquisition of proficiency..

B. Students' Perceptions of the Welding Simulator Media

A total of 34 eleventh-grade Welding Engineering students provided responses through a perception questionnaire regarding the use of Welding Simulator media with a joyful learning approach. The instrument consisted of eight items rated on a five-point Likert scale. Descriptive analysis showed that the average scores per item ranged from 3.79 to 4.15, with an overall mean score of 4.00, indicating that students had positive perceptions toward the media.

Table 1. Average Score of Students' Perceptions of Welding Simulator Media

Aspect	Section Assessed	Item Statement	Score Average
Visualization	Appearance	The media displays welding simulations well	4,09
	Self-confident	I feel more confident when studying	3,91
Ease of use	Ease of use	I can use this media easily	4,06
	Skill enhancement	I feel my skills are improving	4,06
Feedback	Feedback	This media provides helpful feedback	3,79
	Motivation	This media makes me excited to learn	3,94
Joyful learning	Pleasant atmosphere	Learning feels fun with this media	3,97
	Involvement	I feel more active and involved	4,15

The questionnaire results revealed that the aspect of student engagement obtained the highest score (4.15). This indicates that the Welding Simulator successfully fostered active participation and student involvement during practice sessions. Students reported being more focused and engaged because the media offered interactive elements such as motion visualization, point systems, and hands-on experiences despite being in a simulated environment. Karstensen and Lier (2020) emphasized that simulator-based learning environments enhance engagement as students feel greater control over their own learning. Similar findings were reported by Gibbons et al. (2013), who stated that technical practice simulations are capable of simultaneously generating emotional and motor engagement. Moreover, Jossberger et al. (2018) argued that high engagement in digital simulations significantly improves technical skill retention among vocational students.

The visualization aspect of the media also received a high score (4.09), indicating that students perceived the visualization of welding torch movements, oscillations, and weld bead results as clear and easy to understand. Media that provide visual representations of technical procedures have a substantial impact on students' perceptions, particularly in internalizing the steps of welding techniques. Choi et al. (2015) noted that visual representation in simulations allows students to better understand the relationship between welding techniques and outcomes. This is reinforced by Manione et al. (2021), who found that the use of 3D visualization in technical training directly enhances students' cognitive comprehension of work procedures. In addition, Van Gog et al. (2010) demonstrated that visualization effects in procedural skill learning can reduce cognitive load and increase learning effectiveness.

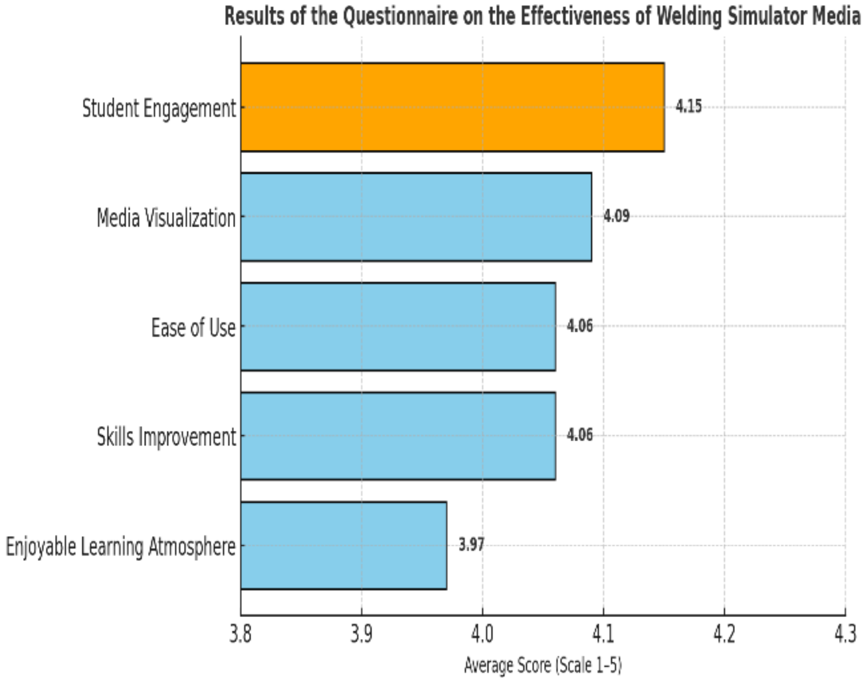

Figure 2. Graph of the Results of the Welding Simulator Media Effectiveness Questionnaire Based on Assessment Aspects

Two other aspects that received high scores were ease of use and skill enhancement (4.06 each). Students felt that the media was easy to operate independently and directly contributed to the improvement of their practical skills. Research by Chan et al. (2022) stated that a simple and user-friendly interface on a simulator can significantly increase learning effectiveness. Yunus et al. (2025) also emphasized that easy-to-use simulation media encourages students to learn exploratively and not rely entirely on teacher instructions. Research by Chan et al. (2022) supported this argument by stating that ease of navigation and control on the simulator increases learning time efficiency and enhances user satisfaction.

The aspect of joyful learning also scored high (3.97). This indicates that the learning experience using the simulator is perceived as enjoyable, not boring, and encourages positive emotional engagement. The implementation of joyful learning can create a humanistic and participatory learning space, thereby encouraging active involvement and strengthening comprehensive conceptual understanding (Prayitno et al., 2024). Eze et al. (2020) stated that learning with interactive media and gamification elements can create a positive affective environment, thereby strengthening vocational high school students' learning motivation. Furthermore, according to Ahmad, Z., & Rofiq, Z. (2020), a pleasant learning environment is important in a vocational context because it can reduce practical anxiety and increase students' courage in trying new techniques. This finding is also supported by Abdi, Nurhasanah, and Fitriana (2021), who emphasized that joyful learning can increase student attention and accelerate the internalization of competencies in vocational learning.

Figure 3. Students Practicing using a Welding Simulator

Conversely, the feedback aspect received the lowest score (3.79), although it is still in the good category. This indicates that the feedback feature in the simulator needs improvement, for example by displaying technical errors or post-practice improvement recommendations. Stav et al. (2010) stated that a real-time feedback system is highly effective in improving the quality of engineering skills learning because it allows for immediate correction. Similarly, research by Hamzah et al. (2019) stated that feedback features in simulation media can facilitate reflection and conceptual reinforcement. Furthermore, Billings (2010) explained that adaptive system-based feedback can accelerate the formation of correct engineering work habits and correct recurring errors in welding practice.

Overall, student perceptions of the Welding Simulator media showed very positive responses across almost all aspects. With an overall average score of 4.00, this media proved effective not only as a technical practice tool but also as a means of creating a conducive, enjoyable learning environment and encouraging independent learning among vocational high school students. By supporting cognitive, affective, and psychomotor dimensions, this media is in line with the needs of 21st-century vocational learning which demands the integration of technology and a humanistic pedagogical approach.

Humanistic learning based on conscious, meaningful, fun, active in-depth learning, with case examples, and producing projects will certainly be the best experience in the learning process and educate students effectively with welding simulator media. This will certainly encourage balanced mastery of hard skills and soft skills consisting of integrated mastery of cognitive, affective, and psychomotor aspects to realize 21st-century skills, namely creative, critical, communicative, and collaborative thinking. The use of this welding simulator media will greatly support the mastery of six basic literacies that must be mastered by the 21st-century generation, especially vocational students, namely literary literacy, diligent writing and reading, science, finance, digital, numerical, cultural and civic literacy. Thus, 21st-century vocational students will be produced who have superior, creative, innovative, productive, and inspiring graduate competencies in a sustainable manner as Indonesia's golden generation.

4. Conclusion

This study aimed to implement a Welding Simulator based on a joyful learning approach to improve vocational high school students' practical competency in the GTAW welding technique subject. Based on the implementation results with 34 11th-grade Welding Engineering students, empirical evidence was obtained that this media was effective in supporting practical learning.

The pre-test and post-test analysis results showed a significant increase in students' practical competency, with the average score increasing from 64.2 to 77.35. A paired t-test yielded a significance value of $p < 0.05$, confirming that the use of the simulator had a significant impact on improving students' welding skills. This was further supported by the finding that the media helped students understand movement techniques, swing speed, and weld straightness more systematically and safely.

Furthermore, the questionnaire results indicated that students' perceptions of the media's use were very positive, with an overall average score of 4.00. The aspects of engagement, visualization, ease of use, and a pleasant learning environment received high scores, indicating that the joyful learning approach was successfully implemented effectively in simulation-based vocational learning.

Theoretically, this research adds to the literature in vocational education by demonstrating that integrating simulation technology with a fun pedagogical approach can simultaneously enhance student motivation, skills, and engagement. Practically, this medium can be a viable alternative for schools with limited welding practice facilities and can be part of a digital-based learning strategy that adapts to the needs of Industry 4.0.

Suggestions for future development include enhancing the feedback feature in the simulator to be more adaptive and diagnostic, providing students with real-time corrective information. Furthermore, trials should be conducted in different school contexts and across different skill areas to test the scalability and generalizability of the medium's effectiveness. Further research could also incorporate augmented reality (AR) or artificial intelligence (AI) technology to enhance interactivity and personalization in welding engineering learning.

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