

Low-cost Portable SMAW Welding Simulator as Learning Media for Sensory-Impaired Vocational Trainees

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Article Info	ABSTRACT
Article history: Received Aug 07, 2026 Revised Sep 11, 2026 Accepted Sep 11, 2026 Published Oct 30, 2026	Vocational training for Shielded Metal Arc Welding (SMAW) conventionally relies on real-time verbal instruction, presenting a critical communication barrier for sensory-impaired trainees. The mandatory use of welding helmets obstructs essential visual cues, such as lip-reading and sign language, thereby preventing immediate corrective feedback on fundamental welding parameters. Consequently, technical errors are often only identified after the welding process is complete, which prolongs the learning curve and increases material waste. To address this pedagogical gap, this study aimed to develop a portable, low-cost SMAW simulator as an inclusive learning medium for trainees with sensory disabilities at Sentra Terpadu Inten Soewono and to evaluate its feasibility. The study employed the Research and Development (R&D) method using the 4D model consisting of the define, design, develop, and disseminate stages. The resulting product is a sensor-based welding simulator that provides real-time visual feedback through LED indicators and a Python-based evaluation dashboard. The learning media was evaluated through expert validation and user testing. The expert validation achieved a feasibility score of 89% and 99%, while the user evaluation obtained 91.32%, both categorized as very feasible. The findings indicate that the simulator is suitable as a learning medium to help trainees practice fundamental SMAW welding competencies before performing actual welding using standard equipment.
Keywords: Inclusive Vocational Education Low-cost Technology Sensory Disability SMAW Learning Simulator	
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INTRODUCTION

Mastering Shielded Metal Arc Welding (SMAW) presents unique pedagogical challenges when applied to sensory-impaired trainees. Foundational welding competencies require consistent control of work angle, travel angle, arc length, and travel speed, as these parameters directly influence the quality and integrity of the resulting weld (Jeffus, 2016). Trainees with auditory sensory disabilities rely predominantly on visual information, including visual cues, symbols, and direct physical demonstrations, rather than conventional verbal instruction (Marschark & Hauser, 2008). However, field

observations at Sentra Terpadu Inten Soewono revealed a critical limitation in instructional communication during practical welding sessions. The mandatory use of welding helmets obstructs visual communication, including lip-reading and sign language, making real-time instructor corrections difficult. Consequently, deviations in welding parameters may only be identified after a welding attempt has been completed, potentially prolonging skill acquisition and increasing the consumption of training materials.

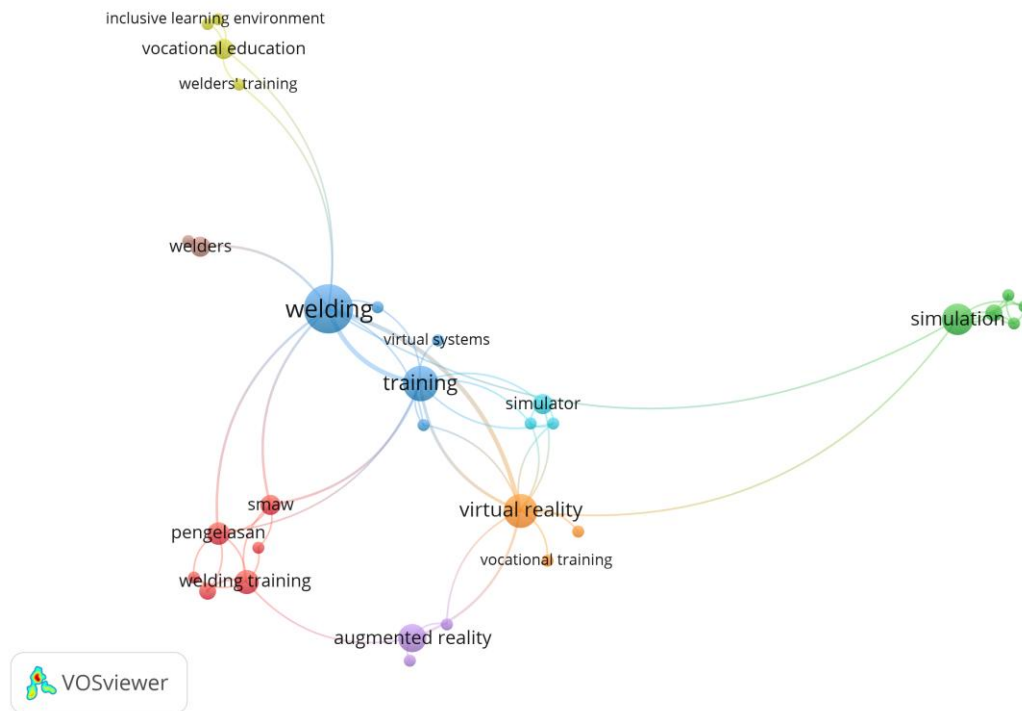


Figure 1. Bibliometric Network of Welding Simulation and Inclusive Learning Research

To examine the research landscape surrounding welding simulation as a learning medium, a bibliometric network analysis was conducted using VOSviewer. Figure 1 presents the relationships among keywords associated with welding, training, simulation, and learning technologies. The central network is characterized by terms such as “welding,” “training,” “simulator,” “simulation,” “virtual reality,” and “augmented reality,” indicating that simulation-based technologies have become closely associated with welding training. The network also contains terms related to vocational education and low-cost simulation, whereas “inclusive learning environment” appears at the periphery with limited connections to the central welding-simulation network. This distribution indicates that welding simulation and inclusive vocational education remain relatively weakly integrated research themes. In particular, the limited connection between simulation-related keywords and inclusive learning suggests that the application of welding simulation as an instructional medium in inclusive learning environments remains insufficiently explored.

Recent studies have predominantly developed immersive and digitally mediated approaches to welding simulation. Michalak et al. (2024), Mancisidor et al. (2025), and Shankhwar et al. (2022)

developed VR-based welding training systems incorporating immersive environments and haptic or visual feedback, while Pribadi and Shinoda (2022) employed hand-motion analysis using inertial measurement sensors to assess welder proficiency. These studies demonstrate substantial progress in simulation technology, motion measurement, and quantitative performance assessment. However, their primary emphasis is on immersive simulation, technological realism, or general welding performance rather than on physical learning media specifically adapted to trainees with sensory disabilities.

To address this gap, this study develops a portable, low-cost, sensor-integrated physical SMAW simulator specifically designed as a learning medium for sensory-impaired trainees. The technical novelty lies in integrating multiple sensing and feedback functions within a single physical device, including an MPU6050 sensor for work-angle measurement, a PMW3901 optical-flow sensor for travel-speed measurement, and a VL53L0X time-of-flight sensor for arc-length measurement. The system is controlled by an Arduino Nano and connected to a Python-based dashboard for graphical evaluation, while LED indicators provide immediate visual feedback during simulation. The simulator also incorporates a servo-driven electrode-shortening mechanism and rule-based evaluation of welding conditions. Rather than reproducing the complete welding process through virtual immersion, the proposed system focuses on fundamental psychomotor parameters that trainees must control before progressing to actual welding practice.

Accordingly, this study is positioned at the intersection of welding simulation, sensor-based performance monitoring, and inclusive vocational education. While previous studies have largely emphasized VR/AR immersion, haptic interaction, or general welder performance assessment, the present study prioritizes accessibility, portability, affordability, and visual feedback through a tangible physical learning medium. The proposed simulator therefore extends the application of welding simulation toward an inclusive vocational context by providing sensory-impaired trainees with an opportunity to repeatedly practice fundamental SMAW parameters and receive immediate performance information before using conventional welding equipment.

METHOD

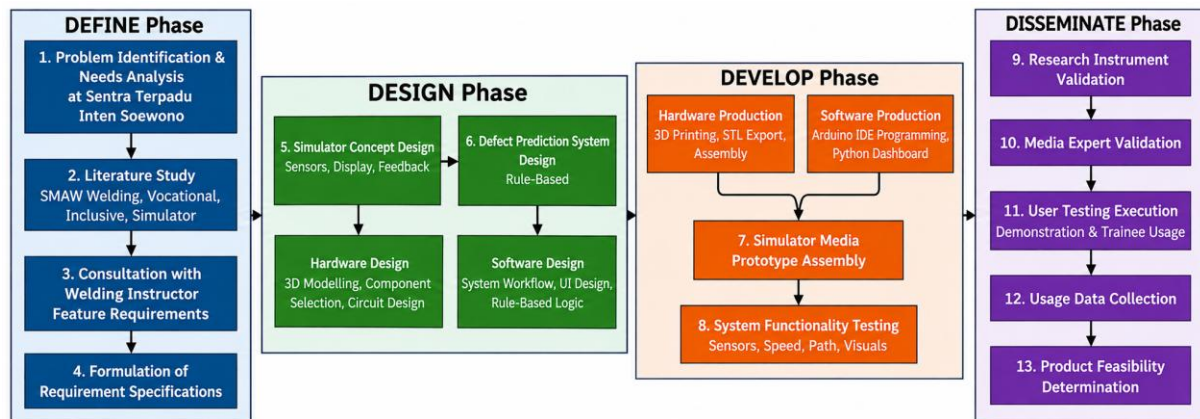


Figure 2. 4D Development Flowchart

This study employed the Research and Development (R&D) method using the Four-D (4D) development model as described by Sugiyono (2023), which consists of four sequential stages: define, design, develop, and disseminate. The define stage focuses on identifying learning problems and determining product requirements. The design stage involves planning the product architecture, selecting appropriate components, and preparing the overall system design. The develop stage is intended to produce and refine the prototype through fabrication, integration, and preliminary testing. Finally, the disseminate stage aims to evaluate and introduce the developed product through validation and user testing before broader implementation. The 4D model was selected because it provides a systematic and iterative framework for developing educational products, ensuring that each stage is completed before progressing to the next. This structured process enables product improvements to be incorporated continuously throughout development, resulting in learning media that are aligned with user needs and validated prior to implementation.

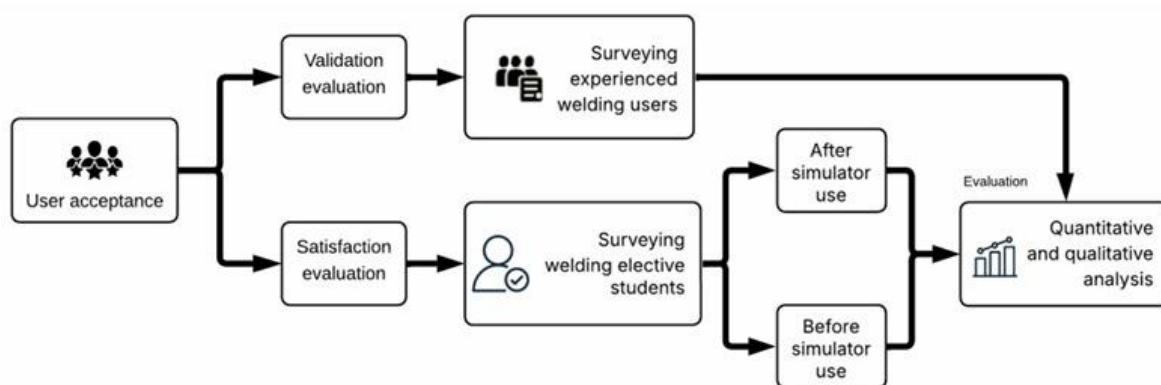


Figure 3. Procedure of Expert Evaluation and User Testing

Note. Adapted from Mancisidor et al. (2025).

The research was conducted at Sentra Terpadu Inten Soewono in Bogor, West Java, from September 2025 to June 2026. The research subjects consisted of one university lecturer acting as the

primary media expert, one welding practitioner serving as the secondary media expert, and eight trainees with sensory and mild physical disabilities enrolled in the SMAW training program. The detailed composition of the research subjects is presented in Table 1. To elucidate the empirical evaluation process, Figure 3 illustrates the user acceptance workflow adapted from Mancisidor et al.(2025). This procedure evaluates both validation and satisfaction. The validation evaluation is conducted by surveying experienced welding users (the media experts). Concurrently, the satisfaction evaluation surveys the welding trainees, capturing their assessments of simulator use. Ultimately, the insights gathered from the experienced users and the trainees are consolidated into a comprehensive quantitative and qualitative analysis.

Table 1. Research Subjects

Subject	Quantity	Role
Media expert	1	Media validation
Welding practitioner	1	Media validation
Trainees	8	User testing

The developed product is a low-cost, portable SMAW simulator functioning as an educational medium to assist trainees in mastering fundamental welding parameters, including work angle, travel angle, arc length, and travel speed. The device provides real-time visual feedback via LED indicators and evaluative feedback through a digital dashboard. This configuration enables participants to practice and reflect on their learning outcomes prior to operating actual welding machinery.

Research data were collected through observations, interviews, expert validations, and user tests employing a five-point Likert scale questionnaire. The data underwent descriptive analysis by calculating the feasibility percentage, which compared the obtained scores against the maximum possible scores. These percentages were subsequently interpreted into specific media feasibility categories.

Media expert validation evaluated the quality of the educational medium based on Five distinct aspects:

Table 2. Expert Validation Instrument for the Developed Learning Media

Aspect	Indicator
Realism	Parameter Accuracy
	Visual Representation
Accessibility & Inclusivity	Accessibility
	Visual Clarity
Technical Challenges	Responsiveness
	Control
Instructional Design	Feedback
	Evaluation
Usefulness	Psychomotor Support
	Implementation Potential

The expert validation instrument was adapted from Mancisidor et al. (2025) and refined to accommodate the objectives and characteristics of the developed portable low-cost SMAW welding simulator. As presented in Table 2, the instrument consists of five evaluation aspects and ten indicators covering realism, accessibility and inclusivity, technical challenges, instructional design, and usefulness. These aspects were used to assess parameter accuracy, visual representation, accessibility, visual clarity, system responsiveness, control, feedback, evaluation, psychomotor support, and implementation potential. User testing assessed the simulator's acceptance level by evaluating six specific aspects:

Table 3. User Testing Instrument for the Developed Learning Media

Aspect	Indicator
Trainee Experience	Perception and self-confidence before and after using the simulator
Ease of Use	Understanding of the simulator functions
	Clarity of the visual interface
Usefulness	Electrode angle practice
	Understanding of the welding path
Feedback	Clarity of LED indicators
	Clarity of parameter visualization
Comfort	Ease and comfort of operation
Satisfaction	Interest in using the learning media
	Willingness to reuse the simulator

The user testing instrument was adapted from the evaluation framework developed by Mancisidor et al. (2025) and modified to reflect the objectives of the developed learning media. As presented in Table 3 the instrument consists of six evaluation aspects and ten indicators that assess trainee experience, ease of use, usefulness, feedback, comfort, and overall satisfaction with the developed SMAW welding simulator.

Quantitative data obtained from the expert validation and user testing questionnaires were analyzed using descriptive statistics to determine the feasibility level of the developed learning media. Each questionnaire item employed a five-point Likert scale, where higher scores indicated greater agreement with the evaluation criteria. The total score obtained from each evaluation was converted into a percentage using Equation (1).

$$\text{Feasibility (\%)} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100 \quad (1)$$

The resulting percentage was interpreted according to the feasibility criteria presented in Table 4, which were adapted from Sugiyono (2023). The developed learning media was categorized as very feasible, feasible, fairly feasible, less feasible, or not feasible based on the obtained percentage.

Table 4. Feasibility Criteria of Learning Media

Percentage (%)	Category
81–100	Very Feasible
61–80	Feasible
41–60	Fairly Feasible
21–40	Less Feasible
0–20	Not Feasible

RESULTS AND DISCUSSION

This study successfully engineered and evaluated a portable, sensor-integrated Shielded Metal Arc Welding (SMAW) simulator specifically tailored for sensory-impaired trainees. The findings demonstrate a definitive shift from traditional, verbal-heavy instructional methods to an autonomous, visual-feedback-driven pedagogical framework. By translating complex kinematic data into immediate visual cues, the device is designed to reduce dependence on verbal communication by providing immediate visual feedback. Furthermore, The findings demonstrate that a targeted hardware-based learning medium can provide the required fundamental welding practice while maintaining greater accessibility and lower implementation costs.

Result

Define Phase

The define phase was conducted to identify instructional problems and determine the design requirements of the proposed simulator. Field observations and interviews conducted at Sentra Terpadu Inten Soewono revealed that welding instruction for trainees with sensory disabilities remains highly dependent on verbal communication. During practical welding sessions, instructors experienced difficulties providing immediate corrective feedback because trainees wearing welding helmets could not observe lip movements or sign language. Consequently, mistakes related to work angle, travel angle, travel speed, and arc length were generally recognized only after welding had been completed, reducing learning efficiency and increasing the consumption of electrodes and practice materials.

Needs analysis further showed that the learning process required an instructional medium capable of providing immediate visual feedback while maintaining welding safety and minimizing operational costs. In addition, the characteristics of trainees indicated that learning media should prioritize visual information rather than auditory instruction, consistent with the principles of inclusive vocational education. Based on these findings, the product specifications were established to include portability, low-cost construction, real-time visual feedback, delayed performance evaluation, and simulation of the four fundamental SMAW welding parameters before actual welding practice.

Table 5. Formulation of Product Based on Need Analysis

Design Rationale	Product Requirements	Implementation in Simulator
Instructor corrections are difficult to deliver during practical sessions.	Visual media providing continuous information throughout the training.	LED indicators for real-time feedback coupled with a visual-based evaluation dashboard.
High electrode consumption during initial training stages.	Low-cost preliminary training media.	Physical simulator utilizing a mock electrode without generating an electric arc.
Trainees rely on visual learning and require non-verbal feedback.	Learning media that is highly visual, straightforward, and easily comprehensible.	A simplified dashboard interface, LED indicators, and visual evaluation results functioning independently of verbal instructions.
Fundamental welding competencies encompassing work angle, travel angle, travel speed, and arc length	A system capable of measuring the four fundamental welding parameters	Integration of sensors for work angle, travel speed, and arc length measurement, with travel angle derived from the orientation measurement

Design phase

Based on the identified instructional requirements, the design process emphasized portability, affordability, and accessibility while ensuring that the simulator could monitor the four fundamental SMAW welding parameters, namely work angle, travel angle, travel speed, and arc length. To support independent learning, the system was also designed to provide immediate visual feedback during simulation and delayed performance evaluation after each training session. Therefore, the required components were selected based on the features specified in Table 5, with particular consideration given to low-cost creation and portability.

Table 6. Hardware Components and Implemented Features

Component	Implemented Feature
Arduino Nano	Controls the entire simulator system and integrates all electronic components.
MPU6050 Sensor	Measures the work angle in real time.
PMW3901 Optical Flow Sensor	Measures travel speed during the welding simulation.
VL53L0X Time-of-Flight Sensor	Measures the distance between the electrode and the workpiece (arc length).
SG90 Servo Motor	Simulates electrode shortening through a dual rubber-roller mechanism.
LED Module	Provides real-time visual feedback on welding parameter conditions.
Arduino Nano Expansion Board	Facilitates integration and connectivity among all electronic components.

After the hardware components had been selected, the mechanical casing of the simulator was designed to replicate the dimensions and handling characteristics of a conventional SMAW electrode holder. This design consideration was intended to provide trainees with a learning experience that closely resembles actual welding practice, thereby facilitating the transfer of psychomotor skills from simulation to real-world operation. Subsequently, the electronic components were integrated into the housing, and a hardware schematic was developed to define the interconnection and operation of each sensor within the system. The resulting hardware architecture demonstrates how the Arduino Nano coordinates data acquisition from the MPU6050, PMW3901, and VL53L0X sensors while controlling the servo motor and LED module to monitor welding parameters and provide real-time visual feedback during the simulation. The overall hardware and software designs are presented in Figures 4 and 5, respectively.

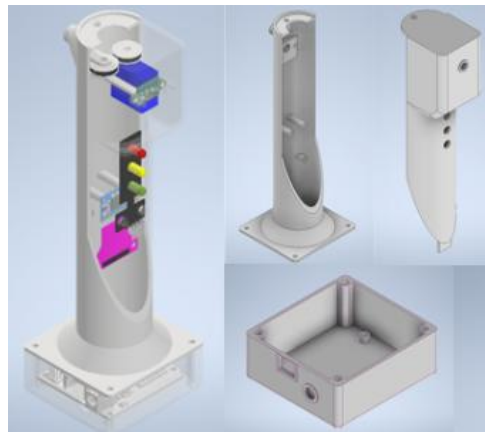


Figure 4. Hardware Design for the Media Simulator

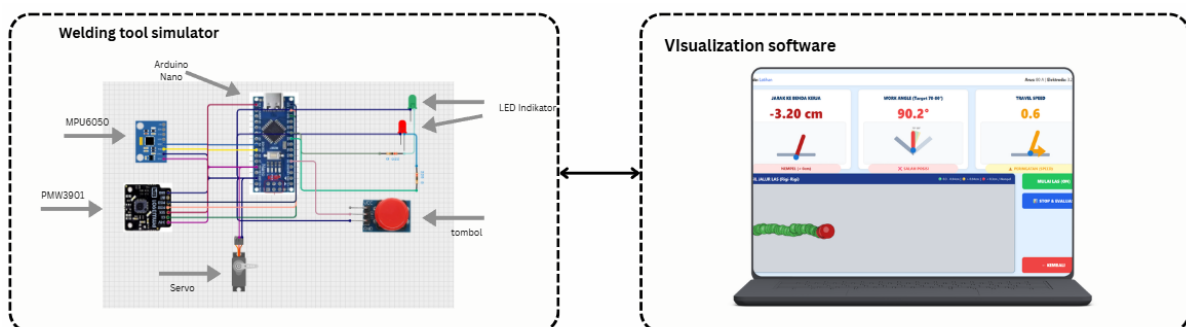


Figure 5. Software System Design

As illustrated in Figure 4, the hardware subsystem integrates an Arduino Nano microcontroller, MPU6050 inertial measurement unit, VL53L0X distance sensor, PMW3901 optical flow sensor, servo motor, and LED indicator modules within a compact enclosure that resembles a conventional SMAW electrode holder. This configuration enables the simulator to acquire welding parameter data while maintaining portability and ease of operation. Meanwhile, Figure 5 illustrates the software architecture, in which the embedded controller continuously processes sensor measurements and communicates with

a Python-based dashboard for data visualization and performance evaluation. The software combines real-time LED indicators with delayed graphical feedback, allowing trainees to receive immediate corrective information during practice and comprehensive performance analysis after completing the simulation. Through the integration of these hardware and software components, the simulator was designed to support independent learning while reducing dependence on continuous instructor intervention.

Develop Phase

During the develop phase, the proposed design was transformed into a functional prototype of the portable low-cost SMAW welding simulator. The development process consisted of mechanical fabrication, hardware integration, embedded system programming, and software implementation. Mechanical components were first modeled using Autodesk Inventor and manufactured through fused deposition modeling (FDM) 3D printing, which was selected because it enables rapid prototyping, low manufacturing cost, and flexible design modification, making it particularly suitable for developing educational prototypes and low-volume functional products (Gibson et al., 2021). The printed components were then assembled with the selected electronic hardware, including the Arduino Nano microcontroller, MPU6050 inertial measurement unit, VL53L0X distance sensor, PMW3901 optical flow sensor, servo motor, and LED indicator modules. This integration resulted in a compact simulator that replicates the dimensions and handling characteristics of a conventional SMAW electrode holder while maintaining portability and low manufacturing cost.

The embedded software was developed using the Arduino IDE to continuously process sensor data and evaluate the welding parameters against predefined thresholds. During operation, the system provides immediate visual feedback through LED indicators to assist trainees in correcting welding posture and movement in real time. In parallel, a Python-based desktop application was developed to receive sensor data, visualize welding parameters, and present post-training evaluations, including electrode trajectory, angle variation, movement speed, and rule-based welding defect predictions. The completed software interface and assembled simulator are presented in Figures 6 and 7, respectively.

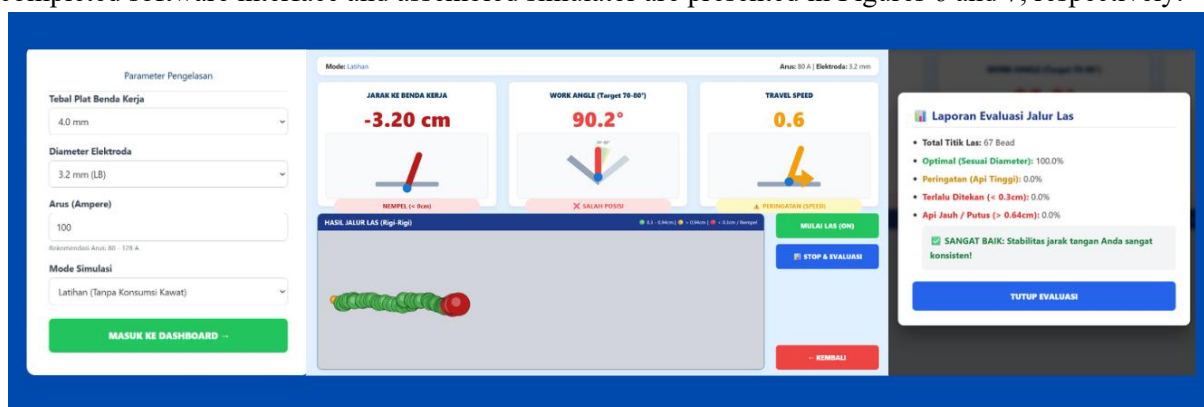


Figure 6. Dashboard of the Learning Media Welding Simulator



Figure 7. Learning Media Welding Simulator

As shown in Figure 6, the dashboard provides a comprehensive visualization of welding performance by displaying real-time parameter values, graphical electrode trajectories, and predicted welding defects to facilitate post-training evaluation. Meanwhile, Figure 7 presents the completed simulator prototype, demonstrating the successful integration of the mechanical enclosure, embedded electronics, and sensing components into a single portable learning device. Functional testing confirmed that the hardware and software subsystems operated as intended, enabling reliable acquisition, visualization, and evaluation of fundamental SMAW welding parameters prior to feasibility assessment.

Disseminate Phase

The dissemination phase was conducted to evaluate the feasibility of the developed SMAW welding simulator through expert validation and limited user testing at Sentra Terpadu Inten Soewono. The evaluation aimed to determine whether the developed learning media satisfied the technical, instructional, and usability requirements before being implemented in vocational welding training. The expert validation results and user testing outcomes are presented in Figures 8 and 10, respectively.

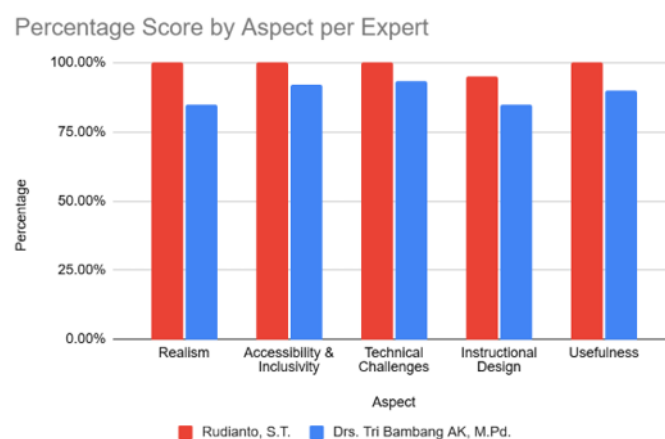


Figure 8. Media Expert Validation Result

The expert validation was carried two times to refine the quality of the developed simulator. The initial evaluation produced an overall feasibility score of 89.00%, indicating that the product was categorized as very feasible but still required several improvements related to its functionality and

instructional presentation. After implementing the recommendations provided by the experts, the revised prototype achieved a feasibility score of 99.00%, demonstrating a substantial improvement across all evaluation aspects. As illustrated in Figure 8, both experts consistently assigned high scores for realism, accessibility and inclusivity, technical challenges, instructional design, and usefulness, confirming that the developed simulator fulfilled the expected requirements for vocational learning media.



Figure 9. User Testing at the Sentra Terpadu Inten Soewono

The revised simulator was subsequently evaluated by trainees with sensory disabilities during a limited user trial. Figure 9 presents the user testing session conducted at Sentra Terpadu Inten Soewono, where trainees used the developed SMAW welding simulator in a practical learning environment. The activity served as a limited field trial to evaluate the simulator's usability, functionality, and user satisfaction while documenting its implementation during vocational welding training.

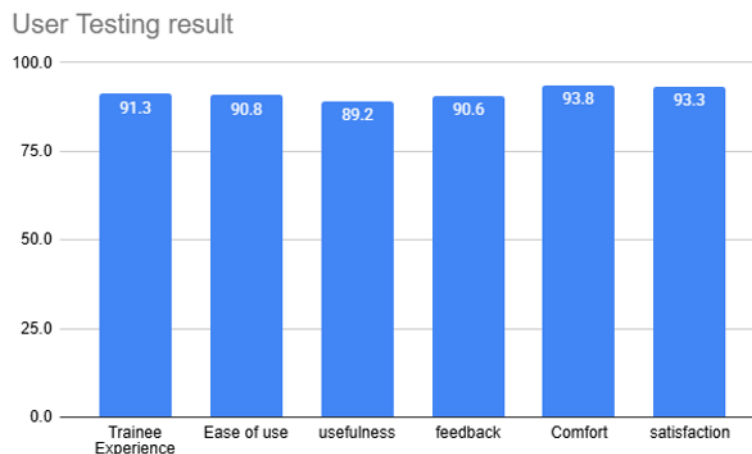


Figure 10. User Testing Result

The user evaluation obtained a feasibility score of 91.32%, which also falls within the very feasible category. These findings indicate that the developed simulator is technically functional, easy to operate, and appropriate for supporting introductory SMAW welding practice through visual feedback. Overall, the dissemination phase indicates that the developed product is suitable for use as an inclusive learning medium in vocational welding training.

Discussion

The findings of this study demonstrate that the developed SMAW welding simulator successfully fulfilled the design objectives established during the 4D development process. The product achieved high feasibility ratings from both expert validation and user testing, indicating that it is suitable for use as an instructional medium for introductory welding training. Beyond technical feasibility, the broader objective of this learning media is to align with the principles of inclusive vocational education, which emphasize equitable access to practical learning opportunities for all learners regardless of disability (UNESCO, 2020). The results highlight two important contributions of the developed simulator: the successful implementation of the portable low-cost concept and the integration of inclusive learning principles for trainees with sensory disabilities. These aspects are discussed in the following sections to explain how the developed simulator addresses the identified instructional needs and contributes to accessible vocational welding education.

One of the main characteristics of the developed simulator is the implementation of the portable low-cost concept, which became the primary consideration throughout the product development process. The compact design integrates all electronic components into a single housing, allowing the simulator to be easily transported and operated without permanent installation or complex configuration. These characteristics are consistent with the concept of portable educational technology proposed by Soloway et al. (2001) and Klopfer and Squire (2008), who emphasize portability, accessibility, and flexibility as essential attributes of learning technologies.

The low-cost concept was implemented through the selection of economical, reusable, and readily available components while maintaining the essential instructional functions of the simulator. The device uses a reusable mock electrode to eliminate repeated consumption of welding electrodes during basic training, open-source electronic components to reduce hardware costs, and 3D-printed mechanical parts to simplify manufacturing. These choices reduce both production and operational costs while allowing trainees to repeatedly practice fundamental SMAW parameters without consuming welding electrodes or steel plates or requiring the electrical power needed to generate an actual welding arc. This approach follows the frugal innovation framework of Weyrauch and Herstatt (2017), which identifies three essential criteria: substantial cost reduction, preservation of core functionalities, and an optimized performance level according to user requirements.

The three criteria were incorporated into the simulator according to the needs of introductory SMAW training. Substantial cost reduction was achieved through economical electronic components, simplified mechanical construction, and reusable training materials. The core functionalities were retained through the measurement and feedback of work angle, travel angle, arc length, and travel speed, which represent the fundamental parameters targeted by the training. Meanwhile, performance was optimized for pre-welding practice rather than for reproducing the complete functions of commercial welding simulators. This deliberate limitation allows the device to provide the functions required for

developing basic welding movements without incorporating technological features that are beyond the learning objectives of the target users.

The production cost of the developed simulator was approximately IDR 660,000, substantially lower than commercial VR- and AR-based welding simulators, which typically cost hundreds of millions of Indonesian Rupiah. Although commercial simulators provide immersive virtual environments and additional training features, the developed simulator intentionally focuses on fundamental SMAW welding parameters, including work angle, travel angle, arc length, and travel speed, as defined within the scope of this study. Consequently, the reduced production cost does not diminish the primary instructional purpose of the simulator but instead demonstrates that essential welding competencies can be practiced using an affordable and accessible learning medium. Recent studies have integrated augmented reality and three-dimensional simulations into welding instruction to improve learners' engagement and conceptual understanding. While these approaches provide immersive digital learning experiences, the developed simulator in this study emphasizes affordability, portability, and repeated hands-on practice through a physical sensor-based platform, making it more accessible for institutions with limited resources (Yunus et al., 2025), while maintaining the instructional objectives of introductory welding practice. These findings also support previous studies suggesting that welding simulation should function as a preparatory learning activity that enables learners to develop procedural competence before progressing to actual welding practice (Karstensen & Lier, 2020).

The developed simulator was specifically designed to accommodate the learning characteristics of trainees with sensory disabilities by emphasizing visual communication throughout the learning process. Unlike conventional welding instruction, which relies heavily on verbal explanation and immediate instructor intervention, the simulator provides information through visual indicators and graphical performance reports. This design is consistent with the principles of Universal Design for Learning (UDL), which recommend presenting information using multiple forms of representation to improve learning accessibility (CAST, 2018). Furthermore, Marschark and Hauser (2008) argue that learners with hearing impairments acquire technical information more effectively through visual rather than auditory communication.

The inclusive design is reflected not only in the feedback mechanism but also in the overall product configuration. The simulator housing replicates the dimensions and handling characteristics of a conventional SMAW electrode holder. This design approach is also consistent with the Cognitive Theory of Multimedia Learning, which states that well-organized visual representations reduce unnecessary cognitive processing and facilitate meaningful learning, particularly when learners must interpret procedural information (Mayer, 2021). The dashboard employs graphical visualization, icons, and simplified interfaces to minimize cognitive load during learning. In addition, the simulator combines real-time feedback through LED indicators with delayed feedback presented on the evaluation dashboard. This dual-feedback approach enables trainees to recognize movement errors during practice

while also reviewing their overall performance after completing the simulation. According to Schmidt and Lee (2019), integrating knowledge of performance with knowledge of results enhances motor skill acquisition because learners receive information regarding both movement execution and performance outcomes.

The positive feasibility ratings obtained during expert validation and user evaluation further support the effectiveness of this inclusive design. Participants reported that the visual feedback system was easy to understand and assisted them in identifying incorrect welding movements independently. These findings indicate that the developed simulator not only functions as a training medium for fundamental SMAW welding skills but also promotes accessibility by reducing dependence on verbal instruction and supporting independent learning, consistent with previous studies on inclusive vocational training, which emphasize that adaptive instructional media and appropriate learning support enable trainees with disabilities to participate more independently in vocational learning activities (Setiyarini & Abdullah, 2022; Monyarela et al., 2025).

CONCLUSION

Based on the research findings, this study successfully developed a Low-Cost Portable Shielded Metal Arc Welding (SMAW) Simulator as an inclusive learning medium for sensory-impaired trainees at Sentra Terpadu Inten Soewono. The developed simulator effectively implements visual feedback through LED indicators and an evaluation dashboard to assist trainees in practicing fundamental welding competencies prior to operating actual welding machinery. The evaluation produced high feasibility scores, with the expert validation achieving a feasibility score of 89.00% and 99.00% and the user testing obtaining a score of 91.32%. These results place the simulator in the "very feasible" category, indicating that the device has strong potential to support a more inclusive, user-friendly, and adaptive welding education process tailored to the specific requirements of sensory-impaired trainees.

SUGGESTION

Future research directions and recommendations based on the limitations and findings of this study include:

- Future research should expand the simulator's technical capabilities to support advanced welding positions beyond the foundational 1F orientation, alongside integrating a more diverse array of welding parameters.
- Subsequent iterations of the simulator could be engineered as a standalone hardware system featuring an integrated display, or alternatively, the evaluation dashboard could be transitioned into a fully accessible web-based application to maximize deployment flexibility across various devices and training environments.

- Future studies are highly recommended to employ experimental designs to quantitatively evaluate the simulator's direct effectiveness in enhancing concrete learning outcomes and practical psychomotor welding skills.

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