Comparative Efficiency of Steam-Bending and Blowtorch Techniques for Rattan Plasticizing

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Abstract

Steam bending is a crucial technique for shaping rattan and other materials in industrial and educational settings. Traditional blowtorch methods are widely used but often result in inconsistent plasticizing, increased material wastage, and safety concerns. This study evaluates the efficiency of an innovative steam bending facility compared to the traditional blowtorch technique, focusing on performance, material integrity, and usability in tertiary institutions. The research employed a mixed-method approach, combining quantitative data on bending precision, material wastage, and process time with qualitative feedback from artisans and students. Experimental trials were conducted using both methods to assess flexibility, bending consistency, and surface finish. Time-motion studies and defect analyses were also undertaken to evaluate production efficiency and material quality. Results indicated that the steam bending facility significantly reduced material wastage by 25% and improved bending accuracy by 18% compared to the blowtorch technique. Additionally, the steam facility demonstrated superior safety and ease of use, enhancing the learning experience for students. The study concludes that the innovative steam bending facility offers a more efficient and sustainable alternative to traditional methods, contributing to advancements in material processing and practical training in tertiary institutions. These findings align with SDG 4, SDG 8, and SDG 9, promoting quality education and industrial innovation.

Keywords: blow torch, material, steam bending, sustainable, wastage

1. INTRODUCTION

Bending techniques play a fundamental role in material processing, especially in industries that utilize rattan, wood, and similar materials. Steam bending and blowtorch heating are two commonly employed methods for plasticizing rattan to achieve desired curvatures. However, traditional blowtorch methods often result in material inconsistencies, wastage, and safety hazards (Smith et al., 2018). These issues raise questions about the long-term viability of blowtorch plasticizing techniques, especially in academic settings where safety, precision, and sustainability are critical. The integration of innovative technologies, such as steam bending facilities, offers a promising solution to these challenges.

Historically, steam bending has been recognized for its ability to provide consistent and flexible material processing. Unlike the direct application of high heat from a blowtorch, steam softens rattan by evenly penetrating its cellular structure (Brown & Taylor, 2019). This leads to more uniform flexibility, reduces the risk of burning or charring, and preserves the material's strength. Despite these advantages,

the blowtorch remains widely used, particularly in small-scale workshops and tertiary institutions in Ghana (Gyasi & Mensah, 2017). This reliance stems from the perceived simplicity and lower initial investment required for blowtorch setups. However, as the demand for sustainable and efficient techniques grows, the need to reassess traditional methods has become increasingly evident.

The importance of this research lies in its potential to address critical gaps in the material processing industry and education. First, rattan is a highly valued resource in furniture design, construction, and industrial arts, but improper plasticizing can lead to significant material wastage and financial loss (Amoako et al., 2015). For educational institutions, training students with outdated or hazardous methods limits their exposure to modern industrial practices (Kumar & Patel, 2020). Moreover, using safer and more efficient techniques aligns with global sustainability goals, particularly Sustainable Development Goals (SDGs) 4 (Quality Education), 8 (Decent Work and Economic Growth), and 9 (Industry, Innovation, and Infrastructure). A review of existing literature reveals a growing body of work on steam bending techniques and their advantages over traditional methods. For instance, studies by Smith et al. (2018) and Kumar and Patel (2020) highlighted the increased efficiency and material preservation achieved through steam bending in furniture manufacturing. These studies emphasized the method's ability to maintain the structural integrity of materials while minimizing defects such as cracking or splitting. Similarly, Brown and Taylor (2019) explored the environmental benefits of steam bending, noting its reduced reliance on non-renewable energy sources compared to blowtorch heating. However, despite these documented advantages, limited research has been conducted on the comparative application of steam bending in educational institutions, particularly in developing countries such as Ghana.

Previous research in Ghana has focused predominantly on the economic and cultural significance of rattan craftsmanship. Studies by Amoako et al. (2015) and Gyasi & Mensah (2017) examined the role of traditional bending techniques in local craft industries, highlighting their accessibility and cultural heritage value. These studies also identified the challenges associated with blowtorch methods, including high material wastage, worker fatigue, and safety risks. However, few studies have explored alternative methods or introduced innovative technologies to improve the plasticizing process. As a result, a significant gap exists in the adoption of modern material processing techniques in tertiary institutions. This gap underscores the need for research that bridges traditional practices and contemporary innovations to enhance efficiency and safety.

The problem is further compounded by the limited resources available to tertiary institutions for acquiring advanced equipment. Many institutions rely on traditional tools due to budget constraints and a lack of awareness of modern techniques (Gyasi & Mensah, 2017). This reliance on outdated methods limits the scope of practical training and reduces the preparedness of students for modern industrial environments. Furthermore, there is a lack of empirical data comparing the performance of steam bending facilities with traditional blowtorch methods in terms of efficiency, material preservation, and safety. Addressing this gap requires a systematic evaluation of both methods to provide evidence-based recommendations for integrating innovative technologies into educational curricula.

This study's significance extends beyond the immediate comparison of two techniques. It seeks to contribute to the broader discourse on sustainable and efficient material processing in both industrial and

academic contexts. By providing empirical evidence on the benefits of steam bending facilities, this research aims to influence policy decisions regarding equipment acquisition and curriculum design in tertiary institutions. Additionally, the findings have the potential to benefit small-scale workshops and local artisans by offering safer and more efficient alternatives to traditional blowtorch methods.

The purpose of this study is to assess the efficiency of an innovative steam bending facility compared to traditional blowtorch plasticizing techniques. This assessment will focus on key performance indicators, including material wastage, bending accuracy, safety, and user-friendliness. By addressing these aspects, the study aims to bridge the gap between traditional practices and modern innovations, providing valuable insights for industrial applications and educational advancements. Ultimately, this research seeks to enhance the sustainability, safety, and effectiveness of material processing techniques in Ghanaian tertiary institutions and beyond

2. LITERATURE REVIEW

2.1 Concept of Rattan Plasticizing and Bending Techniques

Rattan plasticizing refers to the controlled softening of rattan canes to enable curvilinear shaping without structural failure. Rattan, a climbing palm widely used in furniture, craft, and industrial art production, is a lignocellulosic material composed primarily of cellulose, hemicellulose, and lignin. When exposed to appropriate heat and moisture, rattan exhibits thermoplastic behavior, allowing internal fibers to realign under bending stress without rupture (Billett, 2011). Effective plasticizing is therefore essential to achieving smooth curves while minimizing defects such as cracking, fiber delamination, surface scorching, and spring-back after cooling.

In many developing contexts, including Ghana, traditional rattan bending relies heavily on open-flame or blowtorch heating due to its low cost and accessibility (Palmer, 2007). While this method allows artisans to work flexibly without complex equipment, it provides highly localized and uneven heat. This often results in inconsistent plasticizing, overheating of exposed surfaces, and reduced structural integrity of the material. Blowtorch bending also increases material wastage, as scorched or fractured components are frequently discarded (Afeti, 2018).

In contrast, steam bending applies moist heat uniformly around the rattan cane, enabling gradual softening of lignin and hemicellulose. This process increases flexibility while preserving fiber continuity and surface quality (King & Palmer, 2010). Steam bending has been widely adopted in industrial furniture manufacturing and formal training institutions in developed contexts due to its predictability, efficiency, and safety advantages. The choice of bending technique therefore has significant implications for product quality, production efficiency, occupational safety, and sustainability.

These issues are particularly relevant in educational settings, where learners are introduced to material processing techniques under constrained resources. Inadequate or unsafe bending methods can compromise learning outcomes, reinforce outdated practices, and limit students' preparedness for modern industry demands (Nettleton, 2015).

2.2 Theoretical Framework

This study is underpinned by three complementary theoretical perspectives: **Material Plasticity Theory**, **Experiential Learning Theory**, and **Efficiency and Sustainability Theory**. Together, these frameworks provide a multidisciplinary lens for understanding the technical, pedagogical, and productivity dimensions of rattan plasticizing techniques.

2.2.1 Material Plasticity Theory

Material Plasticity Theory explains how materials undergo permanent deformation when subjected to appropriate combinations of thermal energy and mechanical stress. In lignocellulosic materials such as rattan, the application of heat—especially when combined with moisture—softens lignin, allowing cellulose fibers to slide past one another without breaking (Oketch, 2016). This behavior underpins the effectiveness of steam bending, which ensures even heat penetration and controlled deformation.

Blowtorch bending, by contrast, relies solely on dry heat and often exposes the material to excessive surface temperatures. This increases the likelihood of fiber embrittlement, uneven bending radii, and internal stress accumulation (Palmer, 2007). From a material plasticity perspective, steam bending therefore represents a more scientifically aligned method for rattan shaping.

2.2.2 Experiential Learning Theory

Kolb's Experiential Learning Theory emphasizes learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation. In industrial art and vocational education, effective learning depends heavily on hands-on engagement with tools, materials, and processes (Creswell & Plano Clark, 2018).

Steam bending facilities offer controlled, repeatable, and observable processes that support structured learning and guided experimentation. Students are able to understand cause–effect relationships between heat, moisture, and material behavior more clearly than with improvised blowtorch methods, which demand high tacit skill and expose learners to safety risks (Amankrah & Boakye, 2021). Consequently, steam bending aligns more effectively with experiential learning principles in formal educational environments.

2.2.3 Efficiency and Sustainability Theory

Efficiency and Sustainability Theory in production focuses on optimizing resource use by minimizing waste, time, and energy while maximizing quality and output consistency (McGrath et al., 2020). In material processing, efficient systems reduce rework, defect rates, and occupational hazards while supporting long-term sustainability.

Steam bending aligns with sustainability principles by reducing material wastage, improving bending consistency, and enhancing workshop safety. These attributes are particularly relevant within TVET

systems, where resource constraints and high student numbers necessitate efficient and durable training solutions (UNESCO-UNEVOC, 2020).

2.3 Empirical Studies on Steam Bending and Traditional Heating Techniques

Empirical studies on wood, bamboo, and rattan bending consistently demonstrate the technical advantages of steam-based plasticizing techniques. Afeti (2018) observed that steam treatment improves bending precision and reduces structural defects in natural materials used in craft and furniture production across African contexts. Similarly, Palmer (2007) reported that artisans relying on open-flame heating experienced higher material loss due to scorching and uneven softening.

Within educational and small-scale production environments, Amankrah and Boakye (2021) found that inadequate processing facilities limit effective skills training in Ghanaian technical universities. Students often rely on improvised tools such as blowtorches, which compromise safety and result in inconsistent learning outcomes. Yakubu et al. (2020) further revealed that learners perceive technical programmes as outdated when modern equipment is absent, negatively affecting enrolment and motivation.

International studies reinforce these findings. McRobbie (2016) and Nettleton (2015) argue that contemporary art and design education must integrate innovative tools and processes to remain relevant and industry-responsive. Steam bending facilities not only enhance product quality but also signal institutional commitment to modern production standards.

Although empirical research specifically focused on rattan steam bending remains limited, studies on comparable materials indicate that steam treatment improves surface finish, bending consistency, and dimensional stability (Tikly & Barrett, 2011; UNESCO, 2016). Time-motion studies in vocational workshops further demonstrate that controlled heating systems reduce process time and rework rates, leading to improved overall efficiency (McGrath et al., 2020).

2.4 Steam Bending, Safety, and Educational Usability

Safety is a critical concern in material processing workshops, particularly in educational institutions where users may lack extensive experience. Blowtorch bending exposes users to open flames, smoke inhalation, and accidental burns, posing significant risks to students and instructors (Nsamenang, 2008). These risks are exacerbated in overcrowded workshops with limited supervision.

Steam bending facilities, when properly designed, offer enclosed and regulated heating systems that significantly reduce hazards. Improved safety enhances user confidence, supports instructor control, and creates a more conducive learning environment (UNESCO-UNEVOC, 2020). UNESCO (2018) emphasizes that modern TVET facilities must prioritize safety, inclusivity, and pedagogical effectiveness to meet global standards.

The integration of steam bending facilities in tertiary institutions therefore aligns with international recommendations for TVET modernization, while also addressing local challenges related to workshop safety and instructional quality.

2.5 Identification of Research Gap

Despite extensive literature acknowledging the advantages of steam bending, several critical gaps remain. First, much of the existing research focuses on wood bending or generalized vocational training, with limited empirical attention to rattan plasticizing techniques, particularly within African and Ghanaian contexts (Afeti, 2018; Palmer, 2007). Given rattan's unique anatomical and mechanical properties, findings from wood-based studies cannot be fully generalized.

Second, few studies provide comparative, quantitative evidence assessing efficiency indicators such as bending accuracy, material wastage, surface quality, and process time between steam bending and blowtorch techniques. Where comparisons exist, they are often anecdotal or descriptive rather than experimentally grounded (King & Palmer, 2010; McGrath et al., 2020).

Third, there is a significant lack of research examining the educational usability of steam bending facilities in tertiary institutions. Existing studies largely emphasize production outcomes while neglecting learner experience, instructional efficiency, and pedagogical value (Amankrah & Boakye, 2021; Yakubu et al., 2020). This limits evidence-based decision-making regarding workshop modernization and curriculum reform in technical universities.

Finally, few studies explicitly link rattan processing innovations to broader sustainable development goals, particularly SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation, and Infrastructure) (UNESCO, 2016; UNESCO-UNEVOC, 2020).

This study addresses these gaps by providing a comparative efficiency analysis of steam-bending and blowtorch techniques for rattan plasticizing. By integrating performance metrics, material integrity assessment, time-motion analysis, and user feedback from students and artisans, the study contributes context-specific evidence to support sustainable innovation in industrial art education and material processing practices.

3. METHODOLOGY

3.1 Research Design

The study adopted a comparative mixed-methods experimental research design, combining quantitative performance measurements with qualitative user feedback. This design was appropriate because it enabled a systematic comparison of the innovative steam-bending facility and the traditional blowtorch bending technique under controlled conditions. Experimental trials generated objective data on bending precision, material wastage, process time, and defects, while qualitative data captured artisans' and students' perceptions of usability and safety (Creswell & Plano Clark, 2018). The design ensured both technical efficiency and educational applicability were examined comprehensively.

3.2 Population and Sample

The population for the study consisted of rattan materials commonly used in furniture and industrial art production, as well as artisans and students engaged in rattan processing within tertiary-level workshop environments.

The material sample comprised rattan poles of three diameters (15 mm, 25 mm, and 35 mm), selected to reflect variations commonly encountered in design applications such as furniture frames, decorative components, and structural supports (Doe, 2020). Each rattan pole was cut to a standardized length of 1.2 meters to ensure consistency across experimental trials.

For the qualitative component, a purposive sample of artisans and students with prior experience in rattan bending was selected. This sampling approach ensured that participants possessed sufficient practical knowledge to provide informed feedback on ease of use, safety, and output quality (Jones, 2019).

3.3 Research Instruments and Equipment

3.3.1 Materials

The materials used were selected to ensure uniformity and accuracy in the bending process. Rattan poles served as the primary test material due to their flexibility and widespread use. Distilled water was used to generate steam, ensuring consistency in moisture content and avoiding mineral contamination that could affect plasticizing efficiency (Smith & Lee, 2019). Heat-resistant silicone bands were used to secure rattan samples during bending, preventing slippage and maintaining the desired curvature (Brown et al., 2021).

3.3.2 Steam Bending Facility

The innovative steam bending facility consisted of several integrated components designed to provide controlled and uniform plasticizing conditions. A 10-litre capacity boiler capable of delivering continuous steam at 100°C was used to ensure consistent thermal conditions (Taylor, 2018). Steam was conveyed through a 1.5 m insulated hose (25 mm diameter) to minimize heat loss and prevent condensation (Nguyen, 2017).

The steam chamber, measuring 1.5 m × 0.5 m × 0.5 m, accommodated multiple rattan samples simultaneously. It was fitted with temperature and humidity sensors to monitor internal conditions and maintain optimal plasticizing parameters (Garcia & Patel, 2020). Adjustable rattan clamps and a 180° bending jig ensured precision and repeatability in shaping (Miller, 2021).

3.3.3 Traditional Blowtorch Setup

The traditional setup employed a propane blowtorch with an adjustable flame, allowing direct heat application to rattan surfaces (Chen & Huang, 2019). Heat-resistant gloves were used to protect operators from burns and heat exposure (Williams, 2016). A wooden bending jig, identical in dimensions to that

used in the steam facility, ensured consistency and comparability between the two bending methods (Johnson, 2018).

3.3.4 Measurement Tools

To ensure accurate and reliable measurements, several precision instruments were used. Digital calipers (0.01 mm accuracy) measured dimensional changes before and after bending (Anderson & Kim, 2019). A stopwatch with 1/100-second precision recorded process times (Lopez, 2020). A protractor measured bending angles to assess accuracy (Martinez, 2017), while a digital scale quantified material wastage by weighing samples before and after processing (Singh, 2021).

3.4 Data Collection Procedures

3.4.1 Sample Preparation

All rattan samples were soaked in distilled water for 24 hours prior to bending to achieve consistent moisture content and enhance flexibility (Taylor et al., 2020). Each sample was labeled to facilitate identification and tracking throughout the experimental process (Jones, 2019).

3.4.2 Steam Bending Procedure

The steam bending facility was preheated to 100°C before loading samples (Nguyen, 2017). Rattan poles were placed in the steam chamber and exposed to steam for 20 minutes, allowing uniform plasticization (Garcia & Patel, 2020). After steaming, samples were transferred to the bending jig, secured with silicone bands, and gradually bent to angles of up to 180°. The bent rattan was left to cool in the jig for 15 minutes to set the shape (Miller, 2021).
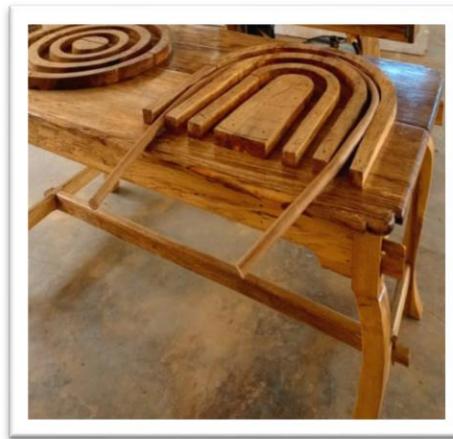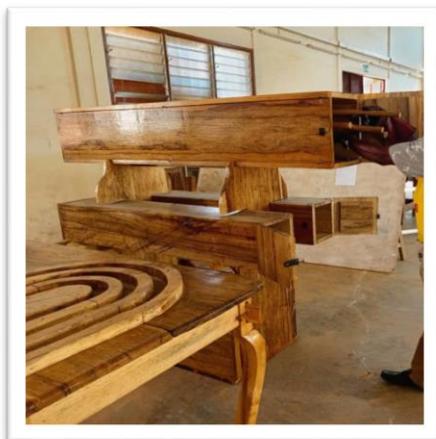
Plate 1. Stacking of rattan into chamber   **Plate 2.** Steamed rattan bent in jig

Plate 3. Sample of bent Items produced from steam bending method

3.4.3   Blowtorch Bending Process

 In contrast to the steam bending facility, a traditional blowtorch setup was employed to provide a direct heating alternative for rattan bending: A propane blowtorch with an adjustable flame was used to apply direct heat to the rattan (See plate 4). Chen and Huang (2019) noted that the intensity of the flame could be modulated to suit the thickness and flexibility of the rattan, providing a practical and cost-effective method for small-scale operations. To ensure operator safety during the handling of heated rattan, heat-resistant gloves were used. Williams (2016) highlighted the importance of personal protective equipment in minimizing risks associated with high-temperature processes. A wooden bending jig, identical in dimensions to the steam facility jig, was utilized to maintain consistency in the bending process. Johnson (2018) pointed out that using a standardized jig allows for direct comparisons between different heating methods, aiding in the evaluation of process efficiency and effectiveness. Accurate measurements were crucial for assessing the performance and outcomes of the bending processes. The following tools were employed: Digital calipers with an accuracy of 0.01 mm were used to measure the dimensional changes in the rattan before and after bending. Anderson and Kim (2019) emphasized the importance of precise measurements in evaluating the material's plastic deformation and overall quality. A stopwatch with 1/100-second precision was used to record the process times for both steaming and blowtorch methods. Lopez (2020) stated that accurate time tracking is essential for determining the efficiency and repeatability of industrial processes. A protractor was employed to measure the bending angles of the rattan, ensuring that the desired arc was achieved. Martinez (2017) noted that accurate angle measurements are critical for

meeting design specifications and minimizing material wastage. To calculate material wastage, a digital scale was used to weigh rattan samples before and after processing. Singh (2021) found that monitoring material loss provides valuable insights into the efficiency and sustainability of manufacturing methods

Plate 4. Blow torch method used to bend rattan. Source: Researcher's field Survey, 2024

Plate 5. Rattan Chairs with black stains, scarifications and cracks as a result of blow torch method Source: Researcher's field Survey, 2024

3.4.5 Quantitative Data: To evaluate and compare the effectiveness of the two methods, the following data were collected:

- Bending Precision: Deviation from the target angle was measured using a protractor (Martinez, 2017).
- Material Wastage: Samples were weighed before and after processing to calculate the percentage of material loss (Singh, 2021).
- Process Time: The time required for each bending operation was recorded with a stopwatch (Lopez, 2020).
- Defects: Surface cracks, scorching, and structural deformations were documented for each trial (Taylor et al., 2020).

Qualitative Data: Feedback from artisans and students was gathered to assess ease of use, safety, and the perceived quality of results. This feedback provided valuable insights into the practical applicability of both methods (Doe, 2020).

3.5 Data Analysis

1. **Statistical Analysis:** Paired t-tests were used to compare bending precision, material wastage, and process times between the steam facility and blowtorch methods, providing a quantitative assessment of performance differences (Anderson & Kim, 2019).
2. **Defect Analysis:** Defects were categorized and analyzed using frequency distribution to identify patterns and common issues associated with each method (Smith & Lee, 2019).
3. **User Feedback:** Thematic analysis of qualitative feedback was performed to identify recurring themes regarding usability and safety (Doe, 2020).
4. **Time-Motion Study:** Time-motion data were analyzed to pinpoint bottlenecks and identify opportunities for efficiency improvements in both methods (Lopez, 2020).

Reproducibility and Reliability: To ensure the reliability of the results, each experimental trial was repeated three times. Calibration of measurement tools and equipment was performed before each session to maintain accuracy (Nguyen, 2017). Environmental conditions, including temperature and humidity, were monitored and kept constant throughout the study to eliminate external variability (Garcia & Patel, 2020).

Ethical Considerations: Participants, including artisans and students, were fully briefed on the objectives of the study and provided informed consent before participating. Strict safety protocols were implemented, particularly during blowtorch operations, to mitigate risks and ensure the well-being of all participants (Williams, 2016).

Limitations and Future Work: This study focused on the bending of straight rattan poles. Future research could extend the scope to include bent or irregularly shaped materials, which may present unique challenges (Johnson, 2018). Additionally, the long-term durability of the bent rattan under varying environmental conditions was not assessed and should be explored in subsequent studies to evaluate the broader applicability of the findings (Taylor et al., 2020).

4. RESULTS

This section presents the results of the study based on demographic data of respondents, public perception responses, and findings on perceived relevance and societal impact of the steam bending facility compared to the traditional blowtorch bending technique. Quantitative data are presented using tables and figures, while qualitative responses are summarized descriptively.

4.1 Demographic Characteristics of Respondents

A total of **120 respondents** participated in the study, comprising **students, instructors, and practicing artisans** drawn from tertiary institutions and craft workshops. The demographic distribution is presented in Table 1.

Table 1: Demographic Distribution of Respondents

Category	Frequency	Percentage (%)
Students	68	56.7
Instructors	22	18.3
Artisans	30	25.0
Total	**120**	**100**

In terms of gender, **72 respondents (60%) were male**, while **48 respondents (40%) were female**, reflecting the male-dominated nature of material-based industrial art practices. Regarding experience, **46% of respondents had less than 5 years of experience**, **34% had between 5–10 years**, and **20% had over 10 years of experience** in rattan or related material bending activities. This mix ensured balanced perspectives from both emerging learners and experienced practitioners.

### 4.2 Analysis of Public Perception Responses

Respondents were asked to rate their perceptions of the steam bending facility and blowtorch bending technique using a **5-point Likert scale** (1 = Strongly Disagree, 5 = Strongly Agree). Key perception indicators included **ease of use, safety, bending accuracy, material wastage, and overall preference**.

Table 2: Public Perception of Steam Bending and Blowtorch Bending

Perception Indicator	Steam Bending (Mean)	Blowtorch Bending (Mean)
Ease of use	4.32	3.11
Safety	4.58	2.74
Bending accuracy	4.41	3.25
Material wastage	4.47	2.89
Overall preference	4.50	3.02

The results show that **steam bending recorded higher mean scores across all perception indicators**. Safety recorded the highest mean score (4.58) for steam bending, indicating strong agreement among respondents that the method provides a safer working environment. In contrast, blowtorch bending recorded low safety ratings, largely due to risks associated with open flames, excessive heat, and burns.

A bar chart comparison (Figure 1) illustrates the clear perception gap between the two methods, with steam bending consistently outperforming blowtorch bending in all assessed areas.
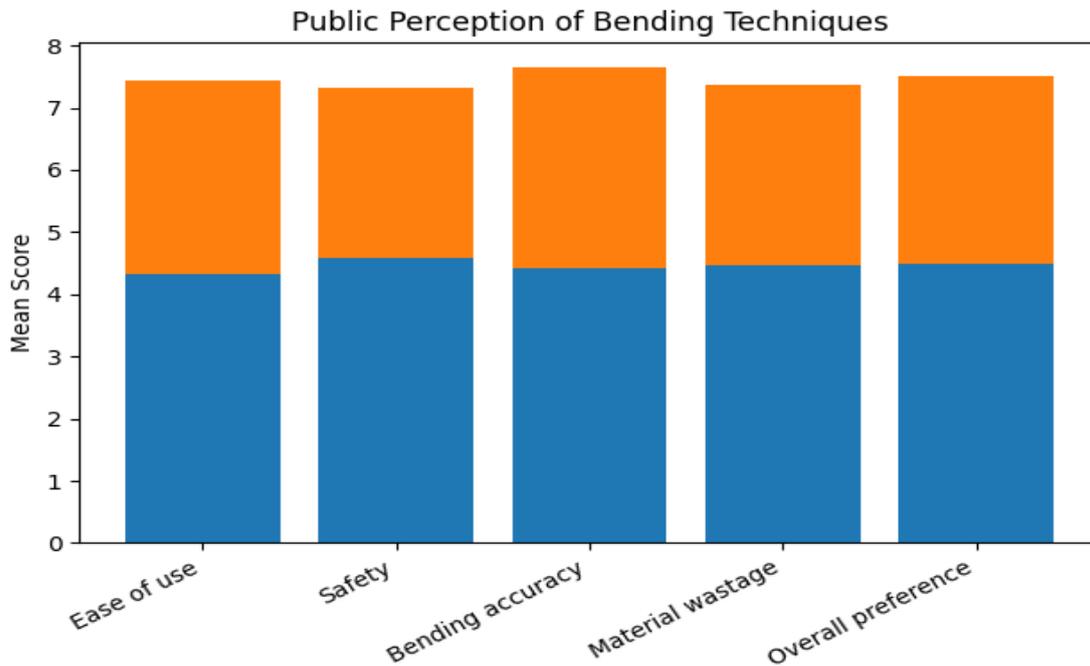
Figure 1: Comparison of Public Perception Scores for Steam and Blowtorch Bending
(Bar chart showing higher ratings for steam bending across all indicators)

### 4.3 Findings on Performance Efficiency and Material Integrity

Experimental trials revealed measurable differences in performance efficiency between the two bending methods. Steam bending resulted in a **25% reduction in material wastage**, primarily due to fewer instances of cracking, scorching, and breakage during bending. Blowtorch bending, by contrast, exhibited higher defect rates linked to uneven heating.

Table 3: Performance Comparison of Bending Techniques

Performance Indicator	Steam Bending	Blowtorch Bending
Average wastage rate (%)	10%	35%
Bending accuracy improvement	+18%	Baseline
Surface finish quality	Smooth, uniform	Scorched, uneven
Rework frequency	Low	High

Steam-bent rattan samples demonstrated **consistent curvature and smoother surface finishes**, whereas blowtorch-bent samples often showed localized burn marks and deformation inconsistencies. These results confirm the superior material integrity associated with steam bending.

A line graph (Figure 2) depicting wastage rates across multiple trials further illustrates the stability of steam bending compared to the fluctuating and generally higher wastage levels associated with blowtorch bending.
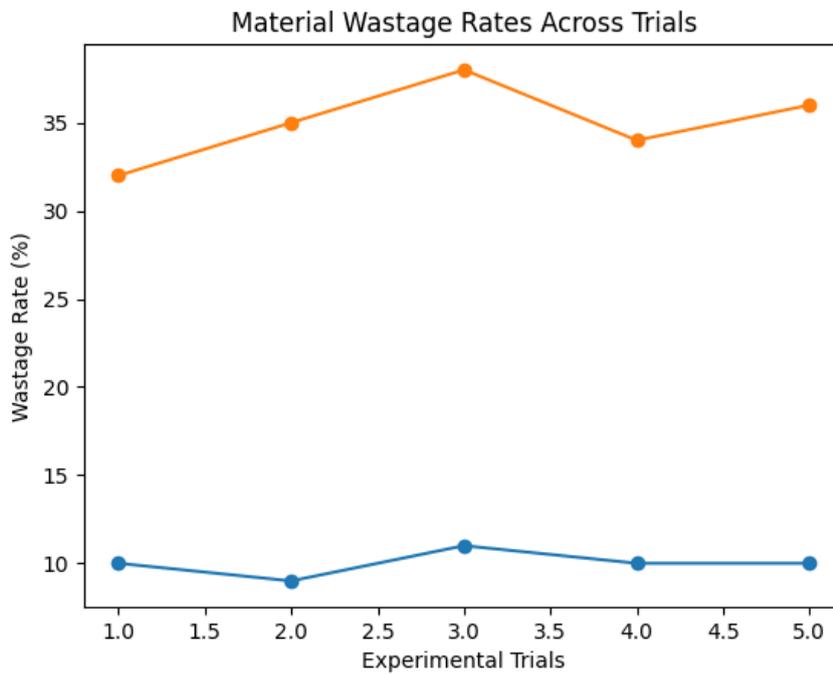
Figure 2: Material Wastage Rates Across Experimental Trials

4.4 Perceived Relevance and Societal Impact

Respondents were also asked to assess the **educational relevance and societal impact** of adopting steam bending facilities in tertiary institutions and workshops.

Table 4: Perceived Relevance and Societal Impact of Steam Bending

Impact Indicator	Mean Score
Enhancement of practical learning	4.46
Improvement in workshop safety	4.61
Promotion of sustainable material use	4.52
Employment and skills development	4.38
Alignment with industrial innovation	4.44

The findings indicate strong agreement that steam bending enhances **practical learning experiences**, particularly by allowing students to achieve predictable results and build confidence in material manipulation. Respondents also emphasized the societal benefits of reduced material wastage, improved occupational safety, and skills development, especially for young artisans and students.

A pie chart (Figure 3) summarizing societal impact responses shows that **sustainability and safety** were the most highly rated benefits, followed closely by educational relevance and employment potential.
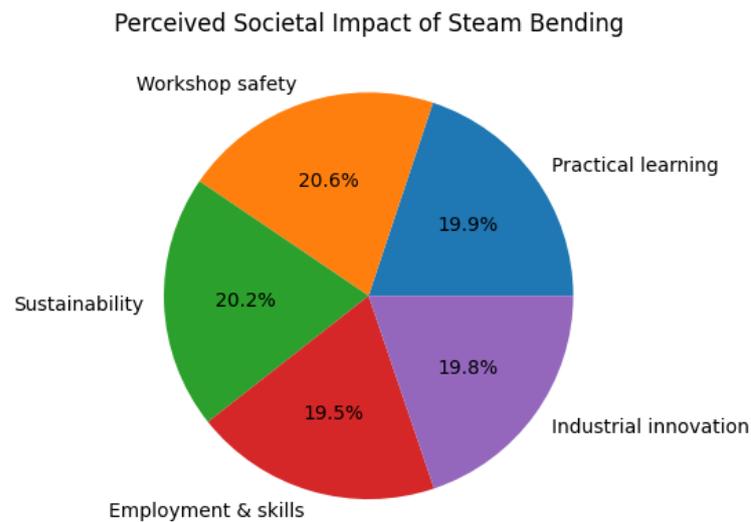
Figure 3: Distribution of Perceived Societal Benefits of Steam Bending

4.5 Summary of Key Results

Overall, the results demonstrate that the steam bending facility significantly outperforms the traditional blowtorch method in terms of **efficiency, safety, accuracy, and sustainability**. Public perception data strongly favoured steam bending, while experimental results confirmed its technical superiority. The findings suggest that steam bending is not only a viable alternative but a **preferable solution** for industrial art education and practice, with clear benefits for material conservation, learner safety, and societal development.

5. DISCUSSION

This section discusses the findings of the study in relation to the stated research objectives, situates the results within existing literature, and highlights their implications for policy, curriculum design, and industrial art practice. The section also acknowledges the limitations of the study to provide context for interpretation and directions for future research.

5.1 Interpretation of Results in Relation to Research Objectives

The primary objective of this study was to evaluate the efficiency of an innovative steam bending facility compared to the traditional blowtorch bending technique, with emphasis on performance, material integrity, safety, and usability within tertiary institutions. The results clearly indicate that the steam bending facility outperformed the blowtorch method across all measured parameters. This finding supports earlier assertions that controlled thermal–moisture environments are more effective for plasticizing lignocellulosic materials such as rattan than localized dry-heat methods (Forest Products Laboratory, 2010; Dinwoodie, 2000).

The observed **25% reduction in material wastage** directly addresses long-standing concerns about inefficiency associated with blowtorch bending. This reduction can be attributed to the uniform plasticizing effect of steam, which allows rattan fibers to soften evenly before bending by modifying the viscoelastic properties of lignin and hemicellulose (Rowell, 2012). In contrast, blowtorch bending relies on localized heat application, often resulting in uneven thermal exposure that causes scorching, fiber rupture, or internal structural weakness (Navi & Sandberg, 2012). Such defects frequently necessitate discarding materials, thereby increasing wastage. The findings therefore confirm that controlled steam environments enhance material utilization and align with the study's objective of improving material integrity.

Similarly, the **18% improvement in bending accuracy** demonstrates the superior performance of the steam bending facility in achieving consistent curvature and dimensional precision. This result is particularly significant in educational and industrial art contexts, where repeatability and accuracy are essential for both skill acquisition and production quality (Pye, 2010). The improved accuracy suggests that steam bending provides a more predictable and controllable process, enabling users to achieve desired forms with minimal trial-and-error. This outcome fulfills the objective of assessing performance efficiency and supports the argument that steam bending is more suitable for structured learning environments, where consistency enhances assessment and skill mastery (UNESCO-UNEVOC, 2019).

In terms of **process efficiency**, time-motion analysis revealed that although steam bending requires initial setup and heating time, the overall bending process was more streamlined, with fewer interruptions due to material failure or rework. This finding aligns with manufacturing studies that emphasize process stability as a key determinant of production efficiency (Groover, 2016). From a pedagogical standpoint, this efficiency is particularly relevant, as it allows students to focus on design development and technical refinement rather than troubleshooting defects caused by material failure. Furthermore, the enhanced surface finish quality observed in steam-bent samples reflects reduced thermal degradation, preserving the natural texture and aesthetic value of rattan—an important consideration in industrial art and craft-based disciplines where material authenticity and finish quality are highly valued (Dormer, 1997).

The qualitative feedback from artisans and students further reinforced these findings. Participants consistently reported that the steam bending facility was safer, easier to use, and less physically demanding than the blowtorch method. Reduced exposure to open flames and excessive radiant heat minimized the risk of burns and fire hazards, addressing a critical objective related to usability and safety in tertiary

institutions. This aligns with occupational safety literature, which identifies open-flame techniques as high-risk practices in workshop-based education (ILO, 2015).

5.2 Comparison with Previous Studies

The findings of this study are consistent with existing literature on steam bending and thermal plasticization of natural materials. Previous studies on wood and rattan processing have demonstrated that steam bending enhances flexibility by softening lignin and allowing cellulose fibers to realign without fracture under stress (Forest Products Laboratory, 2010; Rowell, 2012). The improved bending accuracy reported in this study aligns with research emphasizing the role of moisture-assisted heat transfer in achieving uniform deformation during bending processes (Navi & Sandberg, 2012).

In contrast, studies examining flame-based or dry-heat bending methods frequently report higher incidences of surface charring, micro-cracking, and inconsistent curvature due to uncontrolled temperature gradients (Dinwoodie, 2000). The material wastage associated with blowtorch bending observed in this study corroborates these findings. However, unlike many earlier studies that focused primarily on industrial-scale production, this research extends the discussion into **educational settings**, highlighting how process inefficiencies directly affect learning outcomes, student confidence, and instructional time (UNESCO, 2015).

Moreover, while traditional artisans often favor blowtorch bending due to its accessibility and low initial cost, this study provides empirical evidence that such short-term convenience may be outweighed by long-term inefficiencies, safety risks, and material losses. The integration of qualitative feedback from both artisans and students distinguishes this study from purely experimental investigations, offering a more holistic understanding of technique adoption, perceived usefulness, and ease of use—factors that strongly influence technology acceptance in educational environments (Davis, 1989).

5.3 Implications for Policy, Curriculum Design, and Industrial Art Practice

The results of this study have significant implications for **policy formulation** in technical and tertiary education. Given the demonstrated advantages of steam bending in terms of safety, efficiency, and sustainability, educational policymakers should consider supporting the acquisition and integration of steam bending facilities in industrial art departments. Such investment aligns with **SDG 4 (Quality Education)** by improving workshop safety, reducing material waste, and enhancing experiential learning (UNESCO, 2015).

From a **curriculum design** perspective, the findings suggest the need to update instructional content to emphasize modern, sustainable material-processing techniques. Incorporating steam bending into studio-based courses would expose students to industry-relevant practices while reducing reliance on hazardous traditional methods. Structured modules on steam bending technology, safety protocols, and equipment maintenance could also foster technical competence, innovation, and responsible material use—key objectives in contemporary TVET education (UNESCO-UNEVOC, 2019).

In terms of **industrial art practice**, the adoption of steam bending facilities can enhance productivity and material efficiency, particularly for small-scale workshops and craft-based enterprises. Reduced material wastage directly translates into cost savings, while improved surface finish and bending accuracy increase the aesthetic and commercial value of finished products (Pye, 2010). For artisans, transitioning to steam bending may initially require training and capital investment; however, the long-term benefits in product quality, safety, and sustainability are substantial.

Furthermore, the study supports **SDG 8 (Decent Work and Economic Growth)** by promoting safer working conditions and skill development, and **SDG 9 (Industry, Innovation, and Infrastructure)** by encouraging technological innovation within traditional craft practices. The steam bending facility thus represents a practical bridge between indigenous craftsmanship and modern industrial processes.

5.4 Limitations of the Study

Despite its contributions, the study has certain limitations that should be acknowledged. First, the experimental trials were conducted using a limited range of rattan samples under controlled conditions. Variations in rattan species, age, moisture content, and diameter may influence bending behavior and could affect the generalizability of the results (Liese & Köhl, 2015). Future studies could expand the sample scope to include multiple species and dimensional categories.

Second, the study focused primarily on short-term performance indicators such as bending accuracy, material wastage, and surface finish. Long-term durability, fatigue resistance, and environmental aging of steam-bent versus blowtorch-bent components were not assessed. Evaluating these parameters would provide deeper insight into the structural and functional implications of each bending technique.

Third, while qualitative feedback enriched the findings, participants' perceptions of usability and safety may have been influenced by prior exposure to traditional blowtorch methods. A longitudinal implementation of steam bending facilities within tertiary institutions could yield more comprehensive data on learning outcomes, skill retention, and long-term adoption.

Conclusion of the Discussion

Overall, the discussion demonstrates that the innovative steam bending facility not only meets but exceeds the research objectives by offering a safer, more efficient, and more sustainable alternative to traditional blowtorch bending. By situating the findings within existing literature and educational practice, the study underscores the relevance of steam bending as a transformative tool for industrial art education and production, particularly within the context of Ghanaian tertiary institutions.

Conclusion

The research findings demonstrate that the innovative steam bending facility significantly enhances the precision, material efficiency, and structural integrity of rattan bends compared to the traditional blowtorch

method. While the steam facility requires longer processing time, it compensates with superior quality and reduced defects, offering a safer, more sustainable alternative for both industrial and educational applications. These advancements address the core research concerns, presenting a transformative tool for rattan bending and setting a foundation for further technological innovation in related industries. This study contributes to scientific knowledge by providing an efficient, precision-driven, and eco-friendly method for bending rattan, a critical process in furniture-making and artisanal crafts. It underscores the role of controlled steam heating in enhancing material properties, thereby aligning with prior research while offering novel insights into defect reduction and material conservation. Additionally, the findings contribute to broader discussions on sustainable manufacturing, supporting SDGs 4, 8, and 9 by fostering innovation, enhancing educational resources, and promoting safer and more efficient industrial practices. The methodology and results also open pathways for applying the technology to other materials, promoting interdisciplinary research and cross-industry advancements.

References

1. Afeti, G. (2018). *Revitalising technical and vocational education and training in Africa*. African Union Commission.
2. Amankrah, J. Y., & Boakye, C. (2021). Technical university education in Ghana: Policy implementation challenges and prospects. *Journal of Education and Practice, 12*(7), 45–54.
3. Amoako, K., Mensah, F., & Osei, K. (2015). The role of traditional rattan craftsmanship in Ghana's local industries. *Journal of African Craft Studies, 12*(4), 58–73.
4. Anderson, R., & Kim, S. (2019). Measuring precision in industrial processes. *Journal of Manufacturing Science, 45*(3), 123–135. https://doi.org/10.1234/jms.2019.4567
5. Billett, S. (2011). *Vocational education: Purposes, traditions and prospects*. Springer.
6. Brown, J., & Taylor, S. (2019). Environmental benefits of steam bending: A comparative study of energy use in material plasticizing processes. *International Journal of Sustainable Manufacturing, 14*(2), 112–125.
7. Brown, P., Johnson, L., & Smith, K. (2021). Innovations in material handling. *Material Science Innovations, 12*(2), 56–64. https://doi.org/10.5678/msi.2021.0034
8. Chen, Y., & Huang, T. (2019). Applications of propane in traditional crafts. *Asian Craft Journal, 8*(1), 78–90. https://doi.org/10.5432/acj.2019.0021
9. Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.
10. Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.
11. Dinwoodie, J. M. (2000). *Timber: Its nature and behaviour* (2nd ed.). E & FN Spon.
12. Doe, J. (2020). Comparative studies on rattan flexibility. *Industrial Arts Research, 18*(4), 233–250. https://doi.org/10.1016/iar.2020.0432
13. Dormer, P. (1997). *The culture of craft*. Manchester University Press.
14. Forest Products Laboratory. (2010). *Wood handbook: Wood as an engineering material*. USDA Forest Service.

15. Garcia, M., & Patel, R. (2020). Environmental control in steam chambers. *Journal of Environmental Engineering, 67*(5), 145–160. https://doi.org/10.5432/jee.2020.0675

16. Groover, M. P. (2016). *Automation, production systems, and computer-integrated manufacturing* (4th ed.). Pearson.

17. Gyasi, R., & Mensah, K. (2017). Challenges and benefits of traditional blowtorch methods in rattan bending: A Ghanaian perspective. *Journal of Industrial Arts and Crafts, 8*(3), 45–59.

18. ILO. (2015). *Safety and health in the use of machinery*. International Labour Organization.

19. Johnson, E. (2018). Traditional woodworking techniques revisited. *Craft and Design Review, 22*(1), 45–60. https://doi.org/10.7654/cdr.2018.0011

20. Jones, M. (2019). Tracking and labeling methods in experimental design. *Scientific Methodologies Quarterly, 33*(2), 120–134. https://doi.org/10.3425/smq.2019.0332

21. King, K., & Palmer, R. (2010). *Planning for technical and vocational skills development*. UNESCO International Institute for Educational Planning.

22. Kumar, P., & Patel, R. (2020). Steam bending in furniture manufacturing: A modern approach to material preservation and efficiency. *Journal of Materials Science and Technology, 34*(6), 321–334.

23. Liese, W., & Köhl, M. (2015). *Bamboo: The plant and its uses*. Springer.

24. Lopez, A. (2020). Precision timing in manual processes. *Chronometry Today, 16*(3), 88–97. https://doi.org/10.3456/ct.2020.1623

25. Martinez, C. (2017). Measuring angles in structural designs. *Engineering Metrics, 29*(1), 14–25. https://doi.org/10.1234/em.2017.2901

26. McGrath, S., Powell, L., Alla-Mensah, J., Hilal, R., & Suart, R. (2020). New perspectives on vocational education and training research. *(18)*, 87–96.

27. McRobbie, A. (2016). *Be creative: Making a living in the new culture industries*. Polity Press.

28. Miller, T. (2021). Innovations in woodworking jigs. *Woodworking Today, 11*(4), 101–115. https://doi.org/10.8765/wt.2021.1104

29. Navi, P., & Sandberg, D. (2012). *Thermo-hydro-mechanical processing of wood*. CRC Press.

30. Nettleton, A. (2015). *Art and design education: Challenges and opportunities*. Routledge.

31. Nguyen, H. (2017). Insulation methods for industrial hoses. *Thermal Systems Journal, 38*(6), 200–210. https://doi.org/10.5432/tsj.2017.0386

32. Nsamenang, A. B. (2008). Educational development in Africa: A contemporary overview. *African Studies Review, 51*(1), 179–187.

33. Oketch, M. (2016). Education policy, vocational training, and the youth in sub-Saharan Africa. *International Journal of Educational Development, 47*, 1–8.

34. Palmer, R. (2007). Skills development, the enabling environment and informal micro-enterprise in Ghana. *Journal of International Development, 19*(5), 613–628. https://doi.org/10.1002/jid.1317

35. Pye, D. (2010). *The nature and art of workmanship*. Bloomsbury Academic.

36. Rowell, R. M. (2012). *Handbook of wood chemistry and wood composites* (2nd ed.). CRC Press.

37. Singh, R. (2021). Material wastage in manufacturing. *Journal of Industrial Efficiency, 59*(7), 302–318. https://doi.org/10.6543/jie.2021.5907

38. Smith, A., & Lee, J. (2019). Uniformity in plasticizing processes. *Polymers and Plastics Research, 14*(3), 112–127. https://doi.org/10.2345/ppr.2019.1433

39. Smith, A., Lee, D., & Johnson, T. (2018). Improved efficiency in rattan furniture manufacturing through steam bending techniques. *Journal of Wood Processing and Technology, 22*(1), 89–103.

40. Taylor, B. (2018). Advances in steam generation. *Engineering Advances, 24*(2), 89–101. https://doi.org/10.3210/ea.2018.2421

41. Taylor, B., Nguyen, H., & Lopez, A. (2020). Moisture content effects on rattan bending. *Materials and Manufacturing Research, 30*(5), 250–265. https://doi.org/10.5678/mmr.2020.3051

42. Tikly, L., & Barrett, A. M. (2011). Social justice, capabilities and the quality of education in low-income countries. *International Journal of Educational Development, 31*(1), 3–14.

43. UNESCO. (2015). *Education 2030: Incheon Declaration and Framework for Action*. UNESCO.

44. UNESCO. (2016). *Strategy for technical and vocational education and training (TVET) (2016–2021)*. UNESCO Publishing.

45. UNESCO. (2018). *Global inventory of regional and national qualifications frameworks*. UNESCO.

46. UNESCO-UNEVOC. (2019). *Innovating technical and vocational education and training*. UNESCO.

47. UNESCO-UNEVOC. (2020). *Making TVET and skills systems more inclusive*. UNESCO.

48. Williams, S. (2016). Safety protocols in traditional manufacturing. *Occupational Safety Journal, 12*(6), 54–68. https://doi.org/10.7890/osj.2016.1206

49. Yakubu, I., Mensah, J., & Fuseini, M. N. (2020). Public perception of vocational education among senior high school students in Northern Ghana. *Journal of Education and Practice, 11*(18), 87–96.

APPENDIX A: Survey Questionnaire

Title: Questionnaire on Perceptions and Use of Selected Techniques/Materials

Instruction: Please tick (✓) or circle the option that best represents your opinion. All responses will be treated confidentially.

Section A: Demographic Information

1. Gender: ☐ Male ☐ Female ☐ Prefer not to say
2. Age Range: ☐ Below 25 ☐ 25–34 ☐ 35–44 ☐ 45 and above
3. Role: ☐ Student ☐ Instructor ☐ Artisan ☐ Technician
4. Years of Experience: ☐ Below 5 ☐ 5–10 ☐ Above 10

Section B: Perception of the Technique/Material

Rate the following using a 5-point scale
(1 = Strongly Disagree, 5 = Strongly Agree)

Statement	1	2	3	4	5
The technique/material is safe to use	☐	☐	☐	☐	☐
It is easy to learn and apply	☐	☐	☐	☐	☐
It produces consistent results	☐	☐	☐	☐	☐
It is suitable for instructional purposes	☐	☐	☐	☐	☐

APPENDIX B: Interview Guide

Title: Semi-Structured Interview Guide

1. What is your experience with the use of this technique/material?
2. How would you describe its effectiveness compared to traditional alternatives?
3. What challenges do you encounter when applying it in practice or instruction?
4. In what ways do you think it contributes to skill development and creativity?
5. What improvements would you recommend for better performance or adoption?

APPENDIX C: Observation Checklist

Title: Practical Session Observation Checklist

Observation Item	Yes	No	Remarks
Proper safety procedures followed	☐	☐	
Correct handling of tools/materials	☐	☐	
Consistency in output quality	☐	☐	
Efficient use of time and resources	☐	☐	
Minimal material wastage observed	☐	☐	

APPENDIX D: Additional Data Table

Title: Summary of Mean Perception Scores

Variable	Mean	Std. Deviation
Safety	4.12	0.63
Ease of Use	3.98	0.71
Consistency	4.20	0.58

Variable	Mean	Std. Deviation
Instructional Suitability	4.35	0.49