

Design and Development of a Portable Manual Rebar Stirrup Bender

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ABSTRACT

Manual stirrup fabrication remains common in small construction projects, training workshops, and locations where powered rebar-bending equipment is unavailable or impractical. Improvised bending methods, however, can demand substantial physical effort and produce inconsistent results. This study developed and evaluated a portable manual rebar stirrup bender intended for construction and instructional use. A developmental, descriptive-evaluative design was employed at Palompon Institute of Technology during Academic Year 2025–2026. The prototype combined a rigid steel base, adjustable positioning and clamping elements, forming and support pins, and a lever-operated bending assembly. Development proceeded through planning, design, material procurement, fabrication, assembly, initial trials, adjustment, final functionality testing, and user evaluation. Forty purposively selected respondents—20 steelman workers and 20 faculty members from the College of Technology and Engineering—rated the device using validated researcher-made checklists and a five-point acceptability scale. Weighted means summarized design adequacy, performance, satisfaction, and proposed improvements. The design specifications and features were rated Acceptable ($M = 4.03$), while overall performance was Highly Acceptable ($M = 4.21$). Functionality ($M = 4.31$) and portability ($M = 4.27$) were the strongest performance domains; durability ($M = 4.15$), ease of operation ($M = 4.16$), and safety ($M = 4.16$) were Acceptable. Overall user satisfaction was Acceptable ($M = 4.07$), and the consolidated evaluation was Acceptable ($M = 4.12$). Respondents most strongly recommended protective covering ($M = 4.30$) and corrosion-resistant materials ($M = 4.25$). The documented material and fabrication budget was PHP 6,938. The prototype was positively received as a low-cost, non-electric bending aid, but the evidence is primarily perceptual. Objective measurements of bend geometry, operating force, cycle time, allowable bar sizes, fatigue life, and comparison with conventional methods are required before claims of structural compliance, productivity gain, or long-term field reliability can be made.

Keywords: rebar bending; stirrup fabrication; portable construction tools; manual bending device; product development; usability evaluation; occupational safety; metalworking education

INTRODUCTION

Reinforcing-steel stirrups are essential transverse elements in reinforced-concrete members. Their geometry, spacing, and placement help confine concrete, support longitudinal reinforcement, and resist shear. Before placement, straight reinforcing bars must be measured and bent into specified configurations. Large fabrication shops may use hydraulic, electric, or computer-controlled machines, but small contractors, field crews, schools, and geographically dispersed projects often continue to rely on manual tools. These settings create a practical design problem: the equipment must generate adequate bending leverage and repeatable geometry while remaining affordable, transportable, maintainable, and safe to operate without electrical power.

Improvised bending practices commonly use fixed pipes, makeshift pins, bench fixtures, or other locally available objects. Such arrangements can be inexpensive, yet their geometry and restraint may change from one

operation to the next. The operator must frequently reposition the bar, estimate bend locations, stabilize the workpiece, and apply force while avoiding slips and pinch points. Variation in these conditions can lead to irregular bend angles, inconsistent stirrup dimensions, physical fatigue, or damage to the bar surface. Although a powered bender can reduce effort and increase throughput, its acquisition cost, mass, maintenance requirements, and dependence on electricity may not suit low-volume or mobile work.

A portable manual bender occupies the middle ground between improvised tools and powered machinery. It can use the mechanical advantage of a lever, control the location of the bend through fixed or adjustable pins, and stabilize the workpiece with a base and guide system. The design challenge is not simply to make the bar bend. The device must remain stable while torque is applied, its high-stress components must resist deformation and wear, the lever must provide useful mechanical advantage without becoming awkward to transport, and the operator must be protected from exposed moving parts and unexpected bar movement. Repeatability also depends on guides, stops, and clear operating procedures.

The present study responded to this need by designing and fabricating a portable manual rebar stirrup bender at Palompon Institute of Technology (PIT). The project was grounded in local fabrication capability and intended to support both construction work and technology education. Faculty evaluators could assess design and instructional suitability, while steelman workers could judge the device from the perspective of practical rebar handling. This dual-user approach aligns the prototype with an applied-development context rather than treating it as a purely theoretical mechanism.

The study also illustrates an important distinction in engineering evaluation. Favorable ratings of functionality, safety, or durability represent users' perceptions under the conditions they observed; they are not substitutes for calibrated measurements of force, dimensional error, material stress, or fatigue life. A publication-ready account should therefore report the strong acceptance results while clearly marking the technical questions that remain unresolved. This distinction is especially important when reinforcement fabrication is linked to structural safety and compliance with standards.

Engineering and human-factors foundations

The bender's mechanical concept is based on the relationship between applied force, lever-arm length, and bending moment. A longer effective lever can reduce the force required to generate a given moment at the bending point, but it may increase device size, handle travel, and instability if the base is not adequately restrained. The frame, pivot, lever, pins, welds, and fasteners experience different combinations of bending, shear, bearing, and contact stress. Their material properties and geometry must therefore be selected for repeated loading rather than for appearance or availability alone (Budynas & Nisbett, 2020; Hibbeler, 2020). High-wear contact surfaces may need harder materials or replaceable elements, whereas the base benefits from rigidity and weldability.

Ergonomics influences the device's practical success as strongly as basic mechanics. Handle height, diameter, texture, and travel affect grip, posture, wrist position, and whole-body effort. A mechanically functional design can still create unacceptable strain if the operator must bend excessively, reach across the mechanism, or use sudden force near a pinch point. Human-factors design therefore seeks a predictable operating sequence, stable work positioning, suitable clearances, visible alignment references, comfortable hand contact, and guards where contact with moving parts is foreseeable (Sanders & McCormick, 2019). The prototype incorporated a lever mechanism and compact arrangement, but the evaluation results indicate that ergonomics and injury protection remain improvement priorities.

Reinforcement standards provide context for material and bending requirements. ASTM A615/A615M specifies properties for deformed and plain carbon-steel bars used for concrete reinforcement, while ACI 318 addresses structural-concrete requirements and reinforcement detailing. CRSI guidance supports accepted practices for reinforcing-steel fabrication and placement. Referencing these documents is appropriate during design, but survey agreement with a statement about compliance cannot demonstrate that every bend meets code. Verification requires identification of the bar grade and diameter, required inside bend diameter, dimensional tolerances, inspection method, and evidence that the bending procedure does not damage the bar.

Objectives

The study aimed to design, develop, and evaluate a portable manual rebar stirrup bender as a basis for an improved device. Specifically, it sought to: (1) assess design specifications and features in terms of structural components, material selection, and stated compliance with relevant standards; (2) evaluate performance in terms of functionality, durability, portability, ease of operation, and safety; (3) determine user satisfaction with usability and output quality; and (4) identify improvements for structural stability, ergonomics, safety, durability, and portability. This article condenses the full development report into an integrated methods-results-discussion format and preserves the reported numerical findings.

MATERIALS AND METHODS

Research design and setting

A developmental and descriptive-evaluative research design was used. The developmental phase covered problem identification, design, fabrication, assembly, testing, adjustment, and completion of the prototype. The descriptive-evaluative phase gathered structured assessments from intended users and technical educators. This design is suitable for an applied product-development study because it links the creation of a physical artifact with systematic feedback on its perceived performance and acceptability.

Fabrication and initial testing were conducted in the Mechanical Technology Laboratory at PIT Main Campus, Palompon, Leyte, Philippines, during Academic Year 2025–2026. The laboratory provided welding machines, grinders, drills, vices, measuring devices, and other metalworking resources. Additional evaluation occurred in PIT campus areas associated with ongoing construction work and in nearby construction settings in Palompon. These sites allowed the device to be handled under workshop and field-like conditions. Fabrication activities were supervised by Mechanical Technology instructors and technical staff, with attention to safe cutting, drilling, welding, grinding, assembly, and alignment.

Participants and sampling

The study included 40 purposively selected respondents. Twenty were steelman workers who regularly performed rebar bending and related construction tasks, and 20 were faculty members from the College of Technology and Engineering with relevant knowledge of metalworking, fabrication, or machine operation. Equal representation gave practical and academic perspectives the same numerical weight. Because the sample was non-probabilistic and confined to one locality and institution, the results describe the participating evaluators and should not be generalized statistically to all construction workers or educators.

Table 1. Distribution of respondents

Respondent group	n	%
Steelman workers	20	50.0
Faculty members, College of Technology and Engineering	20	50.0
Total	40	100.0

Prototype design

The developed device combined a supporting structure, positioning elements, a restraint system, and a manually operated bending assembly. The base frame and plate established a stable working platform. A guide slot and adjustable guide bolts helped locate the reinforcing bar for different stirrup dimensions. A clamp or holder plate limited unintended movement. The forming pin defined the bend location, while a support or roller pin guided the bar as the bending arm rotated around the pivot. Locking fasteners retained adjustments, and mounting ears or flanges allowed the unit to be secured during operation. A mechanical stop was incorporated to assist repeatability.

Structural steel was selected for load-bearing members because it is strong, rigid, readily available, and compatible with local welding and machining processes. Components subjected to concentrated contact and wear, such as pins or forming surfaces, were intended to use harder steel. Material selection also considered availability, cost, corrosion exposure, reparability, and the skills and equipment available in the institutional workshop. The design remained fully manual and required no external power source.

Table 2. Principal components and intended functions

Component	Intended function
Base frame and plate	Support the mechanism, distribute reaction forces, and reduce movement during bending.
Guide slot and adjustable bolts	Position the bar and permit adjustment for the required stirrup configuration.
Clamp or holder plate	Restrain the bar and limit slippage before force is applied.
Forming and support pins	Establish the bend location and guide the bar around the bending radius.
Lever and pivot assembly	Convert operator force into bending moment and controlled rotational movement.
Stops and locking fasteners	Retain settings and support repeatable bend angles or dimensions.
Mounting ears or flanges	Allow the device to be anchored to a stable surface for operation.

Fabrication and testing procedure

The work proceeded over an 11-week implementation sequence. During planning, the researchers identified the limitations of conventional manual stirrup bending and translated them into requirements for portability, stability, durability, safety, and ease of operation. Sketches and technical drawings were then prepared, dimensions were selected, and the bending mechanism was configured. Materials were procured and prepared through measuring, cutting, drilling, grinding, and shaping. The frame and principal components were welded and assembled, after which the base, bending plate, pins, lever, pivot shaft, bearings, support elements, and fasteners were installed.

Initial bending trials examined whether the assembled prototype could produce the intended stirrup form. These trials revealed the need for minor adjustments in bar positioning, alignment, and operating sequence. The relevant components were repositioned or tightened before final functionality trials. The source report states that repeated trials yielded acceptable and consistent stirrup outputs and that no noticeable structural deformation was observed during the study period. However, it does not report the number of cycles, the bar sizes and grades tested, the measured bend radii and angles, the applied force, or dimensional-error statistics. Accordingly, these observations are reported as preliminary functional findings rather than certified performance limits.

Table 3. Development and evaluation sequence

Stage	Principal activity	Time
Planning	Identify the need, intended users, design requirements, and constraints.	Week 1
Design	Prepare drawings and configure the bending mechanism and support structure.	Week 2
Procurement	Select and obtain steel, hardware, and fabrication supplies.	Week 3
Fabrication	Measure, cut, drill, grind, weld, and shape components.	Weeks 4–5
Assembly	Install the base, bending plate, pins, lever, pivot, bearings, and supports.	Week 6
Initial testing	Conduct trial bends and identify alignment or operational problems.	Week 7
Adjustment	Refine positioning, alignment, and component settings.	Week 8
Final testing	Repeat bending trials and inspect stirrup outputs.	Week 9

User evaluation	Administer the structured evaluation and satisfaction instruments.	Week 10
Analysis	Compute weighted means and derive improvement priorities.	Week 11

Instruments, scoring, and analysis

A researcher-made structured checklist assessed structural components, material selection, stated compliance with standards, and performance. Performance items covered functionality, durability, portability, ease of operation, and safety. A separate survey measured overall satisfaction, output quality, meeting expectations, willingness to recommend the device, and ease of adoption in actual work. An open-ended or recommendation section asked respondents to assess potential design improvements. The source reports face and content validation by experts in mechanical engineering and construction technology, but does not provide the number of validators, a content-validity coefficient, pilot reliability, or internal-consistency statistics.

Respondents observed a demonstration and, when appropriate, operated the device under supervision before completing the instruments. Items were rated on a five-point scale. Weighted mean was computed as the sum of each response frequency multiplied by its scale weight, divided by the number of respondents. Means from 4.21 to 5.00 were classified as Highly Acceptable, 3.41 to 4.20 as Acceptable, 2.61 to 3.40 as Moderately Acceptable, 1.81 to 2.60 as Slightly Acceptable, and 1.00 to 1.80 as Less Acceptable. Recommendations used corresponding labels of Highly Recommended or Recommended at the upper ranges.

Table 4. Rating scale used in the study

Scale	Mean range	Interpretation
5	4.21–5.00	Highly Acceptable
4	3.41–4.20	Acceptable
3	2.61–3.40	Moderately Acceptable
2	1.81–2.60	Slightly Acceptable
1	1.00–1.80	Less Acceptable

Note. The labels summarize perceived acceptability and should not be interpreted as objective engineering certification.

RESULTS

Prototype completion and documented cost

The development sequence produced a compact, manually powered prototype with an adjustable guide-and-pin arrangement and a lever-actuated bending mechanism. It could be transported between work areas and operated without electricity. Initial trials identified alignment and positioning concerns; adjustment improved the researchers' reported consistency of operation. The device was subsequently demonstrated and evaluated by the 40 respondents.

The documented expenditure for materials and fabrication supplies was PHP 6,938, financed from the researchers' personal funds. Planning, testing, adjustment, user evaluation, and analysis were recorded without additional direct cost. This figure demonstrates the local project's expenditure, not a complete commercial manufacturing cost. Labor valuation, tool depreciation, electricity used during welding and machining, transportation, consumables not itemized, overhead, quality control, taxes, and future maintenance were not separately reported. A production-cost claim would require those elements and a bill of materials with quantities and unit prices.

Design specifications and features

The overall mean for design specifications and features was 4.03, interpreted as Acceptable. Structural components averaged 4.03, material selection 4.04, and stated compliance with standards 4.03. Within the structural assessment, support-frame strength and bending-die alignment each scored 4.08, whereas the bending

arm or lever-handle attachment was the lowest-rated item at 3.93. The pattern suggests that the basic configuration was accepted but that the force-transmission and operator-contact assembly deserves further refinement.

For material selection, safety and comfort of the handle material received the highest item mean of 4.15, while suitability of materials for rebar bending received the lowest mean of 3.90. The latter result is important because perceived suitability does not identify yield strength, hardness, weld quality, or wear behavior. The compliance domain included favorable ratings, but the quality of stirrup output was its weakest reported item at 3.78. This supports the need for dimensional measurement rather than relying solely on visual judgment.

Table 5. Summary of design evaluation

Domain	Mean	Interpretation
Structural components	4.03	Acceptable
Material selection	4.04	Acceptable
Stated compliance with standards	4.03	Acceptable
Grand mean, design specifications and features	4.03	Acceptable

Note. “Stated compliance” reflects respondent ratings; the study did not report an independent standards audit or calibrated dimensional verification.

Performance evaluation

Overall performance received a grand mean of 4.21, classified as Highly Acceptable. Functionality ranked first at 4.31, followed by portability at 4.27. Durability scored 4.15, and both ease of operation and safety scored 4.16; these three domains were classified as Acceptable. The narrow range from 4.15 to 4.31 indicates broadly favorable perceptions, but the interpretation threshold at 4.21 places functionality and portability in a higher verbal category even though their numerical advantage over other domains is modest.

Table 6. Performance evaluation of the developed device

Rank	Performance domain	Weighted mean	Interpretation
1	Functionality	4.31	Highly Acceptable
2	Portability	4.27	Highly Acceptable
3=	Ease of operation	4.16	Acceptable
3=	Safety	4.16	Acceptable
5	Durability	4.15	Acceptable
	Grand mean, performance	4.21	Highly Acceptable

Within functionality, speed of the bending process received the strongest item rating at 4.55, followed by reliability during continuous use at 4.45. Perceived accuracy of output scored 4.15 and consistency of operation 4.10. These ratings suggest that respondents noticed a practical and direct operating sequence, but no stopwatch data, production counts, or dimensional measurements were provided. Consequently, the study supports perceived speed and reliability, not a quantified improvement over pipe bending, bench jigs, or powered machines.

Portability's strongest item was mobility of design at 4.40, followed by suitability of size and weight at 4.32 and ease of transport at 4.30. Ease of handling during transfer was lower at 4.08, suggesting that the unit may still be awkward under some site conditions. The device's exact mass, overall dimensions, number of people required for transport, and setup time were not reported. These measurements should accompany future portability claims.

Durability averaged 4.15. Resistance to deformation and resistance to rust or corrosion each received 4.18, while the remaining durability items were close to 4.13–4.15. No visible deformation was reported during the testing period. Nevertheless, respondent observation over a short development cycle cannot establish fatigue life,

corrosion resistance, or safe working limits. Repeated-cycle tests and post-test inspection of the pivot, pins, holes, weld toes, fasteners, and lever are needed.

Ease of operation averaged 4.16. A simple operating procedure was its highest item at 4.30; minimal effort required scored 4.03. This difference is informative: users can understand the procedure while still finding the physical demand less favorable. Measurement of handle force, operator posture, perceived exertion, and task time across different users would reveal whether the selected lever length and work height are ergonomically appropriate.

Safety averaged 4.16. Risk reduction in use (4.35) and stability during operation (4.23) were rated Highly Acceptable, while protection from accidental injury was the weakest safety item at 3.93. The contrast indicates that the prototype appeared safer than improvised methods but did not fully isolate users from foreseeable hazards. Potential hazards include pinch and crush zones near the forming pin, sudden lever movement, bar springback, sharp edges, loss of anchorage, weld or fastener failure, and manual-handling strain.

User satisfaction

User satisfaction obtained a grand weighted mean of 4.07, interpreted as Acceptable. Satisfaction with output quality ranked highest at 4.18, followed by overall satisfaction at 4.10 and ease of adoption in actual work at 4.08. Recommendation for use scored 4.03. Meeting user expectations was lowest at 3.95, indicating that the prototype was positively received while still falling short of some preferred features or operating characteristics.

Table 7. User-satisfaction results

Indicator	Weighted mean	Interpretation
Satisfaction with output quality	4.18	Acceptable
Overall satisfaction	4.10	Acceptable
Ease of adoption in actual work	4.08	Acceptable
Recommendation for use	4.03	Acceptable
Meeting user expectations	3.95	Acceptable
Grand weighted mean	4.07	Acceptable

The consolidated evaluation combined the three design domains, five performance domains, and user-satisfaction result. Design specifications and features averaged 4.03, performance 4.21, and user satisfaction 4.07. The reported overall grand mean was 4.12, interpreted as Acceptable. Performance was therefore the strongest broad category, while design detail and user expectations identify the more immediate opportunities for improvement.

Table 8. Consolidated evaluation

Evaluation category	Mean	Interpretation
Design specifications and features	4.03	Acceptable
Performance	4.21	Highly Acceptable
User satisfaction	4.07	Acceptable
Overall grand mean	4.12	Acceptable

Recommended improvements

Respondents evaluated five proposed improvements. Protective covering to reduce injury risk received the highest mean of 4.30 and was Highly Recommended. The use of corrosion-resistant materials received 4.25 and was also Highly Recommended. Reinforcement of the base frame scored 4.20, ergonomic improvement of the lever handle 4.05, and reduction of overall weight 3.95; these were Recommended. The grand mean was 4.15, interpreted as Recommended.

Table 9. Respondent-rated improvement priorities

Rank	Proposed improvement	Mean	Interpretation
1	Add protective covering to reduce risk of injury	4.30	Highly Recommended
2	Use corrosion-resistant materials for longer durability	4.25	Highly Recommended
3	Reinforce the base frame for added stability	4.20	Recommended
4	Improve the ergonomic design of the lever handle	4.05	Recommended
5	Reduce overall weight to improve portability	3.95	Recommended
	Grand weighted mean	4.15	Recommended

DISCUSSION

The study demonstrates the feasibility of constructing a locally fabricated, non-electric stirrup-bending prototype and obtaining favorable feedback from both construction workers and technology faculty. The strongest results—functionality and portability—match the core design proposition. A manual lever and guided forming arrangement can make the bending sequence more organized than an improvised setup, while the compact frame supports movement between a laboratory and a field work area. The modest documented expenditure also makes the concept relevant to schools and small organizations that cannot justify powered industrial equipment.

The results should nevertheless be read as an early-stage design evaluation. The means summarize ordinal questionnaire responses from a purposive sample; they do not quantify mechanical capacity or code compliance. The study did not report dispersion, confidence intervals, group-specific means, reliability coefficients, or inferential comparisons between faculty and steelman workers. A grand mean may be useful for ranking domains, but it can obscure disagreement among respondents and differences between technical and practical perspectives. Future reporting should include standard deviations or response distributions and analyze the two groups separately.

Functionality's high mean is encouraging because the device's first obligation is to bend the bar into the intended configuration. The particularly high perceived speed and continuous-use reliability suggest that the lever mechanism and work sequence were useful. Yet accuracy and consistency were less highly rated than speed. In stirrup fabrication, rapid bending has limited value if dimensions drift, corners are not repeatable, or bend radii are unsuitable. Adjustable guides, positive stops, etched scales, templates, and replaceable forming dies could convert the prototype's basic function into a more repeatable production method.

The acceptability of the design and material domains indicates that the prototype was structurally credible to its evaluators, but several item-level results expose development needs. The lever-handle attachment was the lowest structural item, and material suitability for bending was the lowest material item. These are located directly in the load path. Engineering refinement should begin with a free-body analysis and design calculation for the maximum intended bar, followed by checks for lever bending, pin shear and bearing, pivot wear, base reaction, weld strength, and anchorage. Material specifications, heat treatment where appropriate, weld procedures, and replaceable wear parts should be documented.

Safety requires equal priority. The relatively low score for protection from accidental injury and the top-ranked request for protective covering identify a gap between general risk reduction and physical guarding. A guard should not merely cover the mechanism; it must preserve visibility and access while keeping hands away from the pinch zone. A non-slip handle, rounded edges, a controlled stop, secure anchoring points, clear hand-placement markings, and an inspection checklist would strengthen the system. Operators should wear appropriate personal protective equipment and be trained to stand outside the path of possible bar or lever movement. A formal hazard analysis should identify severity, likelihood, and mitigation for each failure mode.

Durability was positively perceived, but long-term conclusions are premature. The device uses repeated high-contact loading, and the likely wear locations are the pivot, pin surfaces, guide holes, clamp interfaces, fasteners, and welded joints. Outdoor or semi-outdoor construction use also introduces moisture, dust, and corrosive contaminants. The recommendation for corrosion-resistant materials may be addressed through suitable steel selection, protective coatings, drainage and cleaning features, lubrication points, and dry storage. A maintenance

schedule should state inspection frequency, allowable wear, tightening requirements, lubrication, coating repair, and replacement criteria.

Portability creates a structural trade-off. Weight reduction can improve transport but may reduce stability and stiffness; reinforcement of the base can improve stability but add mass. The design should therefore be optimized rather than simply made lighter or heavier. Options include high-strength sections placed along the load path, removable or folding handles, compact modular supports, carrying grips positioned near the center of mass, and an anchoring interface that uses the work surface to provide reaction without permanently increasing device mass. Measured weight, packed dimensions, setup time, and one-person or two-person handling limits should guide decisions.

The device has educational value beyond its immediate construction function. Students can use it to connect mechanics, materials, welding, machining, tolerancing, ergonomics, safety, and experimental methods. The prototype can serve as a platform for instrumented testing: a force gauge at the handle, angle encoder at the pivot, dimensional jig for output inspection, and cycle counter for durability. Such additions would transform a successful fabrication project into a reproducible engineering experiment and would allow learners to see where subjective acceptability agrees—or fails to agree—with measured performance.

Standards and validation pathway

The source report refers to ACI 318, ASTM A615/A615M, and CRSI guidance. These references should guide a verification plan rather than appear as a blanket claim of compliance. For each intended bar diameter and grade, the researchers should specify the required bend geometry, select the forming-pin diameter accordingly, produce a defined number of samples, and measure leg length, diagonal or squareness, internal dimensions, bend angle, and inside bend diameter. Visual inspection should record cracking, gouging, flattening, or other damage. If rebending is contemplated, the applicable restrictions and procedures must be reviewed.

A comparative test should evaluate the portable bender against the locally used conventional method. Operators should complete the same stirrup specification under controlled conditions. Outcomes should include setup time, bending time per stirrup, total output per hour, handle force or exertion, dimensional error, rejected pieces, and safety observations. A randomized or counterbalanced sequence would reduce learning and fatigue effects. Reporting the actual bar material, temperature, tool configuration, operator experience, and sample size would make the results reproducible.

Table 10. Proposed technical validation matrix

Claim	Required measurement	Suggested evidence
Accurate output	Leg lengths, internal dimensions, bend angle, bend diameter, and squareness.	Calibrated measurements; mean absolute error; tolerance pass rate.
Reduced effort	Peak and average handle force, posture, and perceived exertion.	Force gauge; ergonomic assessment; operator-stratified results.
Faster operation	Setup time, cycle time, and acceptable stirrups per hour.	Timed comparison with the current manual method.
Durability	Wear, looseness, deformation, cracking, and functional drift over cycles.	Defined cyclic test with scheduled inspection and end-point criteria.
Portability	Mass, packed dimensions, setup time, handling distance, and personnel required.	Measured values and field-handling trials.
Safety	Hazards, near misses, guarding effectiveness, stability, and failure modes.	Risk assessment, checklist, and supervised operational trials.
Standards conformity	Bar grade/diameter, required bend diameter, geometry, and surface condition.	Documented clause-by-clause verification by a qualified reviewer.

Design roadmap for the improved prototype

An improved version should begin with the two highest-rated user recommendations: injury protection and corrosion resistance. Guarding, hand-clearance zones, a non-slip grip, and a positive stop can be developed together because they influence the operator's interface with the lever and forming region. Protective coating and material upgrades should be selected after identifying wear surfaces; a coating alone will not correct abrasion or excessive bearing pressure at a pin.

The next priority is to reconcile base stability with portability. The device should include a clearly rated anchoring method and should be tested on the types of surfaces expected in field use. Ergonomic optimization should use a range of operator statures and strengths rather than a single preferred handle length. Finally, precision features should be standardized through interchangeable dies, adjustable stops with readable scales, and a setup guide for each supported stirrup configuration. Every change should be followed by both mechanical testing and user evaluation so that one improvement does not introduce a new hazard or reduce portability.

Table 11. Prioritized development roadmap

Priority	Design action	Acceptance criterion
1	Guard pinch zones; add hand-clearance markings, non-slip grip, and controlled stop.	No unintended hand access during normal use; hazard review completed.
2	Specify wear-resistant contact parts and corrosion-protection system.	No unacceptable wear or corrosion after defined exposure and cycle tests.
3	Strengthen and standardize anchoring while optimizing structural mass.	Stable operation at rated load; measured transport requirements remain acceptable.
4	Improve lever geometry and handle ergonomics for varied operators.	Lower measured force and acceptable posture without excessive handle travel.
5	Add calibrated guides, stops, and interchangeable forming dies.	Specified dimensional-tolerance pass rate across supported bar sizes.
6	Document capacity, operation, inspection, maintenance, and retirement limits.	Complete user manual and traceable inspection records.

LIMITATIONS AND FUTURE RESEARCH

The study is limited by its small, purposively selected sample from one institution and locality. Equal participation by steelman workers and faculty supplied useful perspectives, but it does not constitute a representative sample of the construction sector. The analysis relies on weighted means and reports no measures of variation, instrument reliability, between-group comparison, or qualitative coding of comments. Respondents evaluated a demonstrated prototype, and their amount of direct operating experience may not have been uniform.

Technical reporting is also incomplete. The source does not specify the prototype's dimensions, total mass, lever ratio, maximum safe input force, supported bar diameters and grades, forming-pin diameters, anchoring requirements, number of trial bends, dimensional tolerances, cycle count, or comparative baseline. Observations of acceptable output and lack of visible deformation therefore establish proof of concept only. The reported PHP 6,938 expenditure does not include a complete economic analysis.

Future research should publish a dimensioned design, bill of materials, material certificates, fabrication tolerances, weld details, and calculated working capacity. Mechanical tests should evaluate multiple bar diameters and grades at defined temperatures, with force, cycle time, bend geometry, surface condition, and component strain recorded. Repeated-cycle testing should establish wear and failure modes. A larger, multi-site user study should measure workload, discomfort, usability, learning time, and error rate, and should compare experienced and novice operators.

Further development may explore modular dies, faster adjustment, a detachable or folding lever, wheels or handles for transport, and replaceable bushings or rollers. A semi-automatic or motor-assisted version could be investigated if it retains the original goals of portability and affordability, but any powered version would require

additional guarding, emergency control, electrical safety, and maintenance provisions. Life-cycle costing should compare acquisition, labor, maintenance, energy, throughput, and service life across manual and powered alternatives.

CONCLUSION

A portable manual rebar stirrup bender was designed, fabricated, adjusted, and evaluated at Palompon Institute of Technology. Forty purposively selected evaluators rated its design specifications and features Acceptable ($M = 4.03$), its performance Highly Acceptable ($M = 4.21$), its user satisfaction Acceptable ($M = 4.07$), and its consolidated evaluation Acceptable ($M = 4.12$). Functionality and portability were the leading strengths. The documented project expenditure of PHP 6,938 indicates that the prototype was developed with locally accessible fabrication resources and without reliance on electrical power during operation.

The device is best regarded as a promising proof-of-concept and instructional platform rather than a fully validated production machine. Users' favorable judgments support further development, but they do not establish bend accuracy, code conformity, productivity gain, ergonomic force reduction, safe load capacity, or fatigue life. Protective covering, corrosion resistance, base stability, lever ergonomics, weight optimization, and calibrated positioning should guide the next design iteration. Objective, comparative, and repeated-cycle tests are required before routine field deployment or claims of standards compliance.

DECLARATIONS

Ethics approval and consent to participate. The source reports that institutional permission was obtained and that respondents were coordinated with before evaluation. The formal approval or exemption number, approval date, consent procedure, and data-protection arrangements should be inserted before submission.

Consent for publication. The article contains aggregate evaluation results and no respondent quotations. Permission should be confirmed for any prototype photographs or institutional identifiers included in the submitted version.

Data availability. The analyzed rating summaries are reported in this article. The author should state whether anonymized item-level data, instruments, drawings, and test records can be made available and under what conditions.

Conflict of interest. The author should declare any financial, institutional, or personal interests that could influence the work.

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Author contributions. Jerameel Aberilla Collamat: conceptualization, design, fabrication supervision, methodology, investigation, analysis, and manuscript preparation. This statement must be checked against the contributions of all actual researchers and revised before submission.

REFERENCES

1. American Concrete Institute. (2023). Building code requirements for structural concrete and commentary (ACI 318). American Concrete Institute.
2. ASTM International. (2023). ASTM A615/A615M-23: Standard specification for deformed and plain carbon-steel bars for concrete reinforcement. ASTM International.
3. Brown, T. (2008). Design thinking. *Harvard Business Review*, 86(6), 84–92.
4. Budynas, R. G., & Nisbett, J. K. (2020). *Shigley's mechanical engineering design* (11th ed.). McGraw-Hill Education.
5. Concrete Reinforcing Steel Institute. (2022). *Manual of standard practice*. Concrete Reinforcing Steel Institute.

-
6. Hibbeler, R. C. (2020). *Mechanics of materials* (11th ed.). Pearson.
 7. International Organization for Standardization. (2019). *ISO 9241-210:2019 ergonomics of human-system interaction—Part 210: Human-centred design for interactive systems*. International Organization for Standardization.
 8. Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 22(140), 1–55.
 9. Sanders, M. S., & McCormick, E. J. (2019). *Human factors in engineering and design* (8th ed.). McGraw-Hill Education.
 10. Ulrich, K. T., Eppinger, S. D., & Yang, M. C. (2020). *Product design and development* (7th ed.). McGraw-Hill Education.