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# DESIGN AND PERFORMANCE EVALUATION OF A SIMPLE METAL-BASED SPHEROMETER FOR MEASURING SURFACE CURVATURE

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**ABSTRACT**

Developing physics measurement instruments from simple materials is necessary to provide economical, easily constructed alternatives to laboratory equipment. This study aims to design and evaluate a simple, metal-based spherometer for measuring surface curvature. The research employs a descriptive experimental approach, encompassing fabrication, component assembly, zero-point calibration, and testing on three objects: an eraser, a marker, and a coin. The instrument uses an aluminum pulley as the main body, steel bolts as supporting legs, a central screw as the measuring mechanism, and a main scale and rotating scale made from basic materials. We evaluated the instrument by comparing spherometer readings with ruler readings, using the absolute difference as the metric. The test results show a discrepancy of 0.10 cm for the eraser, 0.10 cm for the marker, and 0.72 cm for the coin. These differences indicate that the instrument's readings are not yet consistent with the reference tool. Key limitations include the manual division of the rotating scale, the lack of a measured thread pitch, and the absence of data from repeated measurements or an assessment of instrument uncertainty. This study has produced a prototype of a simple spherometer that could be further developed as a tool for physics experiments. Future refinements, such as improving the construction and scale system and testing on curved surfaces with known radii of curvature, are needed to evaluate the instrument's measurement capabilities quantitatively.

## 1. INTRODUCTION

Physics experiments require measurement instruments that generate quantitative data from systematically observable quantities. Measurement is a crucial part of experimental work, as it determines a quantity's value by comparing it with an established unit or standard (Gunoto & Kamil, 2021; Pratama et al., 2025; Tambunan et al., 2026). Measurement quality depends not only on the observer's ability to read a scale but also on the instrument's characteristics, the precision of the procedures used, and the alignment between the instrument's design and the quantity being measured. Various instruments have been developed to meet the need for length measurement,

ranging from rulers, calipers, and micrometer screws to the spherometer, which serves a specialized function in measuring surface geometry (Darmawan & Kurniawan, 2026; Sudarsono et al., 2025).

A spherometer is a precision measurement instrument used to determine the relative height of a curved surface and calculate its radius of curvature (Sudarsono et al., 2025). The instrument features three supporting legs that establish a reference plane, along with a central measuring screw. Movement of this central screw relative to the plane formed by the three legs yields a vertical displacement value that can be used to determine the "sagitta" (the height of the arc). This configuration allows the spherometer to measure the curvature of lenses, mirrors, and other objects with curved surfaces. The spherometer's measurement principle is based on the geometric relationship between the radius of curvature, the radial distance of the supporting legs, and the sagitta. Measurement accuracy is heavily dependent on the instrument's ability to detect minute displacements of the central screw. Consequently, factors such as mechanical dimensions, thread characteristics, scale graduations, and supporting-leg stability are critical to spherometer design.

Developing simple measurement instruments from easily accessible materials is one way to increase the availability of physics experimental equipment. Building such devices independently lets you tailor the design to specific measurement needs while also helping you understand the relationship between mechanical construction and measurement principles (Kusnadi et al., 2026). Metal materials are well suited as the primary components of a spherometer, as they can be shaped into robust support structures and mechanical frameworks. Careful attention must be paid to material selection, component dimensions, and joint quality to ensure the instrument’s structural stability during measurement.

The design and construction of a simple spherometer should not focus solely on assembling its components; it must also account for the metrological characteristics of the resulting instrument. The main scale and the rotating scale must be designed based on the specifications of the screw thread employed, ensuring that displacement values can be read consistently. Errors in determining the thread pitch, the number of scale divisions, or the index line position can cause discrepancies between the actual mechanical displacement and the displayed value. Furthermore, a zero-point adjustment is necessary to ensure the instrument’s initial reading is set to the correct reference state before use.

A simple metal-based spherometer was also developed using readily available components. This spherometer was constructed using an aluminum pulley, screws, bolts, and, for the scale, a piece of canopy and paper. The resulting instrument was used to measure everyday objects such as an eraser, a marker, and a coin; the findings were then compared with measurements taken with a standard ruler. This endeavor shows that simple materials can create measuring instruments, although challenges remain in determining vernier scale divisions and positioning the rotating scale.

Performance evaluation is a crucial stage for determining whether a designed instrument can produce reliable and accountable measurements. Assessment should not be based solely on the device's ability to display a numerical value; rather, it must encompass characteristics such as resolution, accuracy, precision, repeatability, and measurement error. Resolution refers to the smallest change that an instrument can detect, while accuracy indicates how close a measurement is to a reference value. Precision and repeatability relate to the consistency of results when measurements are performed repeatedly under identical conditions (Ayunita & Hidayatullah, 2026; Malik, 2023). These parameters are essential for identifying a design's strengths and limitations, as well as determining which aspects of its construction require further improvement.

Comparing measurement results against a reference instrument is essential for determining the deviations produced by a simple spherometer. While using a ruler during initial testing can indicate discrepancies in readings, it is insufficient to establish the spherometer's accuracy in measuring surface curvature, as the two instruments operate on different principles and have different levels of resolution. A more rigorous evaluation requires objects with known geometric characteristics or a higher-precision reference instrument. Repeated measurements, relative error calculations, and uncertainty analysis can provide a more objective assessment of the instrument's performance (Afifudin & Budisusila, 2025; Rahmawati et al., 2026).

Although a simple spherometer can be constructed using readily available materials, the integrity of the mechanical design, the characteristics of the scale readings, and the evaluation of measurement performance still warrant further attention. Developing an instrument involves more than simply creating a functional tool; it also requires explaining the relationship between component specifications and measurement capabilities. These considerations provide a crucial foundation for examining how accessible metal materials and components can be used to build a simple, functionally sound spherometer. Furthermore, evaluating the design is necessary to identify sources of deviation and determine the potential to further develop the instrument as an alternative tool for physics laboratory experiments.

This research aims to design and construct a simple metal-based spherometer and evaluate its performance in measuring surface curvature. Specifically, the study covers component identification and fabrication stages, determining scale characteristics based on mechanical specifications, zero-point calibration, and practical instrument testing. The evaluation focuses on reading characteristics and measurement results from experimental data, including identifying design limitations. This research is expected to provide technical insights into the feasibility of constructing a simple spherometer and contribute to the development of affordable, easily replicable physics experimental instruments that can serve as educational tools for teaching precision measurement and surface geometry.

## 2. METHOD

### 2.1 Research Type and Test Objects

This research uses a descriptive experimental approach, focusing on designing and building a mechanical measuring instrument and initially evaluating its measurement results. The research activities encompass component identification, fabrication, mechanical assembly, zero-point calibration, and testing of a simple spherometer. The evaluation compares spherometer readings with those from a ruler using three test objects: an eraser, a marker, and a coin. This comparison identifies discrepancies between the two instruments. The test data are analyzed descriptively based on the measurement results documented in the original experimental report.

### 2.2 Tools and Materials

The primary materials for constructing the spherometer include an aluminum pulley (type A2, 25 mm in diameter), a 12 cm long threaded bolt (0.5-inch gauge), three iron nuts, three steel bolts (8 × 120 mm), and three black-colored nuts. These components form the instrument's body,

support legs, and the central vertical measurement mechanism. Supplementary materials include Alteco adhesive, wood glue, canopy material scraps, cardboard, colored craft paper (asturo), graph paper (millimeter grid), and a marker used for construction and scale marking. Fabrication tools utilized include a drill and scissors. Material specifications and component sizes are presented as recorded in the experimental documentation; however, the final geometric dimensions of the instrument cannot be fully determined because they were not fully captured in the source documents.

### 2.3 Spherometer Design and Fabrication Process

The fabrication of the spherometer begins by preparing the aluminum pulley as the main body, then drilling three holes to accommodate the steel-bolt support legs. A nut is installed at the center of the pulley to mount the measuring screw, while the three support legs are secured with nuts and adhesive to ensure stability. Next, the main scale is constructed from a 10.5 × 1 cm strip of stiff cardstock (canopy material), covered with colored paper and marked with a millimeter-grid scale. The rotating scale consists of a circular piece of cardboard divided into ten segments, attached to a central screw. All components assemble into an instrument with three supporting legs, a central measuring screw, a main scale, and an integrated rotating scale.

### 2.4 Zero-Point Calibration and Measurement Procedure

Before use, calibrate the spherometer to zero by aligning the zero marks on both the main scale and the rotating scale. To measure, place the instrument on the test object and slowly turn the central screw until it contacts the object's surface. This contact is verified using a thin piece of paper; subsequently, the values on the main scale (MS) and the rotating scale (RS) are observed and recorded. The final reading is obtained by summing the values from both scales. However, as the thread pitch is not yet known, the resolution and the precise conversion of the readings cannot be determined at this stage.

### 2.5 Data Processing and Analysis Techniques

Measurement data obtained with the spherometer and ruler were recorded in centimeters and compared for each test object. The discrepancy between the results was calculated using the absolute difference formula (Equation 1), where $\Delta X$ is the absolute difference between the spherometer reading ( $Xs$ ) and the ruler reading ( $Xp$ ) represents the measurement difference. This difference indicates the disparity between the two instruments' readings, rather than an error relative to a true value. The evaluation is limited by the lack of information on the ruler's specifications and calibration status, the absence of repeated measurements, and the unavailable thread pitch. Consequently, the analysis is descriptive and does not quantitatively determine accuracy, precision, repeatability, or measurement uncertainty.

$$\Delta X = Xs - Xp \tag{1}$$

## 3. RESULTS AND DISCUSSION

### 3.1 Development and Characteristics of the Spherometer

The developed device is a simple, metal-based spherometer consisting of an aluminum body, three steel-bolt support legs, a central measuring screw, a vertical scale, and a rotary scale. Its construction follows the operating principle of a conventional spherometer: measuring the vertical displacement of a central screw relative to a reference plane established by three support legs. The fabrication process involved drilling the device body, installing the support legs, assembling the central screw, and setting up the measurement reading system. The reading system comprises a main scale made from a 10.5 × 1 cm strip covered with colored craft paper and marked using millimeter-grid paper, plus a circular rotary scale made of cardboard, divided into ten segments and attached to the central screw. While simple materials facilitate fabrication, manually creating scale divisions may result in non-uniform spacing between markings, which could affect the readability of measurement results.

The central screw mechanism converts rotational motion into vertical displacement based on its thread characteristics. The thread pitch determines displacement per full rotation. At the same time, the rotary scale resolution is the pitch divided by the number of divisions per rotation. As the actual thread pitch has not been documented, the instrument's resolution cannot yet be quantitatively determined. To evaluate the device's measurement characteristics, measure the pitch and verify alignment between the screw's movement and the scale readings.

### 3.2 Measurement Results for Test Objects

Initial testing was conducted on three objects: an eraser, a marker, and a coin. We compared the spherometer readings with ruler measurements. All results are recorded in centimeters, in accordance with the experimental documentation. This comparison identifies discrepancies between the assembled instrument's readings and the reference tool. These data represent a preliminary descriptive evaluation and cannot yet be used to determine the spherometer's accuracy, as the ruler's specifications and calibration status are unknown.

Table 1. Comparison of measurement results: Spherometer vs. Ruler

| Test Object | Spherometer (cm) | Ruler (cm) | Stated Difference (cm) | Calculated Difference (cm) |
|---|---|---|---|---|
| Eraser | 1,40 | 1,50 | 0,10 | 0,10 |
| Marker | 1,80 | 1,90 | 0,10 | 0,10 |
| Coin | 0,82 | 0,10 | 0,80 | 0,72 |

The eraser measured 1.40 cm with the spherometer and 1.50 cm with the ruler, for an absolute difference of 0.10 cm. For the marker, the results were 1.80 cm and 1.90 cm, respectively, with an identical difference. Meanwhile, the coin measured 0.82 cm with the spherometer and 0.10 cm with the ruler; a recalculation shows a difference of 0.72 cm, which differs from the 0.80 cm stated in the original report. These discrepancies indicate a lack of alignment between the two instruments' readings. However, the cause of these deviations cannot be determined, as no data are

available on repeated measurements, resolution specifications, or calibration information for the reference instrument. Therefore, this test describes differences in readings only and does not establish the spherometer's accuracy or precision.

### 3.3 Analysis of Results and Sources of Measurement Deviation

Test results show a measurement discrepancy of 0.10 cm for two objects, while the discrepancy for a coin reached 0.72 cm. These differences suggest that the spherometer readings are not consistent with those obtained using a ruler. One potential factor influencing these results is the manual graduation of the rotating scale, which may lead to non-uniform spacing between the scale markings. Furthermore, imprecise alignment between the rotating scale and the vertical scale can cause a shift in the reference point, resulting in a mismatch between the readings and the actual displacement of the screw. Other mechanical factors that could contribute to deviations include thread backlash, non-uniform support-leg heights, the positioning of the central screw, and the downward force applied during measurement. The zero-point adjustment also warrants attention, as an inaccurate initial setting can introduce a systematic shift in the readings. However, it cannot be concluded that these factors alone caused the observed deviations, as no repeated mechanical testing or systematic zero-point verification was performed. Consequently, improvements to the instrument's construction, scale system, and measurement procedures are necessary to enhance the consistency of its results.

### 3.4 Performance Evaluation and Instrument Development

The advantage of this simple spherometer lies in its use of readily available metal materials and a relatively straightforward assembly process. Its aluminum body and steel-bolt support legs result in a robust construction, making the device's components easier to observe during laboratory activities. However, the reading system remains limited, as the scale divisions are marked manually and the thread pitch is still unknown. Furthermore, the testing phase has not yet included repeated measurements, uncertainty analysis, or comparisons with a calibrated reference instrument; consequently, the device's accuracy and precision cannot yet be determined. Future development should focus on measuring the thread pitch, refining the rotary scale, verifying the stability of the support legs, and testing the screw mechanism. Additionally, repeated measurements should be conducted using objects with known radii of curvature to evaluate the instrument's capabilities quantitatively. Overall, this research has produced a simple, metal-based spherometer prototype while identifying specific construction and measurement aspects that require improvement to enhance its functionality as an instrument for physics experiments.

## 4. CONCLUSION

This research produced a simple, metal-based spherometer prototype using an aluminum pulley, steel bolts, a central screw, and a scale system comprising a main scale and a rotating scale built from basic materials. Initial testing on an eraser, a marker, and a coin revealed discrepancies between spherometer measurements and ruler measurements of 0.10 cm, 0.10 cm, and 0.72 cm, respectively, based on recalculations. These differences indicate that the instrument’s reading

system and mechanical construction require further refinement, specifically regarding the uniformity of scale divisions, the determination of thread pitch, the stability of the zero point, and the precision of the central screw mechanism. While this study shows that a spherometer can be designed using readily available materials and simple fabrication processes, its accuracy, precision, and repeatability remain undetermined because no repeated testing or calibration against a reference instrument has been conducted. Future development should focus on refining the construction, characterizing the resolution, and testing on curved surfaces with known radii of curvature, allowing a quantitative evaluation of the spherometer's ability to measure surface curvature.

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