

Ethnomathematics Analysis: Integral Calculus in Traditional Vessel Forms of Cirebon Kasepuhan Palace

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ABSTRACT

This study aims to examine the concept of definite integrals embedded in traditional vessel forms from the Kasepuhan Cirebon Palace through an ethnomathematical perspective. A qualitative descriptive approach was employed, using artifact observation, visual documentation, and limited interviews as data collection techniques. The objects of study included small cups, bowls, jars, and cylindrical containers. The analysis was conducted by modeling the vessel profiles as continuous functions rotated about an axis to form solids of revolution. The results indicate that traditional vessels exhibit rotational symmetry and smooth curvature, allowing the application of definite integrals to determine volume and surface area. These forms reflect principles of efficiency, stability, and material optimization that align with formal calculus concepts. The findings suggest that traditional cultural practices embody intuitive and contextual mathematical knowledge. This study contributes to ethnomathematics by highlighting the potential of cultural artifacts as contextual learning resources for enhancing students' understanding of abstract integral concepts.

Keywords: Ethnomathematics, Definite Integral, Traditional Vessels, Solid of Revolution

ABSTRAK

Penelitian ini bertujuan mengkaji konsep integral tentu pada bentuk bejana tradisional Keraton Kasepuhan Cirebon dalam perspektif etnomatematika. Penelitian menggunakan pendekatan kualitatif deskriptif dengan teknik pengumpulan data berupa observasi artefak, dokumentasi visual, dan wawancara terbatas. Objek kajian meliputi cawan kecil, mangkuk, kendi/guci, dan wadah silinder. Analisis dilakukan melalui pemodelan matematis dengan memandang profil lengkung bejana sebagai fungsi kontinu yang diputar terhadap suatu sumbu sehingga membentuk benda putar. Hasil kajian menunjukkan bahwa bentuk bejana tradisional memiliki simetri putar dan kelengkungan halus yang memungkinkan penerapan konsep integral tentu untuk menentukan volume dan luas permukaan. Desain bejana mencerminkan prinsip efisiensi, stabilitas, dan optimasi material yang selaras dengan konsep kalkulus formal. Temuan ini menunjukkan bahwa praktik budaya masyarakat mengandung pengetahuan matematis yang bersifat intuitif dan kontekstual. Penelitian ini berkontribusi dalam memperkuat peran etnomatematika sebagai pendekatan pembelajaran kontekstual untuk menjembatani konsep integral yang abstrak dengan pengalaman budaya lokal.

Kata kunci: Etnomatematika, Integral Tentu, Bejana Tradisional, Benda Putar

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1. INTRODUCTION

Mathematics is frequently perceived as an abstract and isolated discipline, detached from daily life. This perception often leads to significant challenges for students in grasping advanced mathematical concepts, particularly calculus. One of the most challenging topics is the concept of integrals, especially their application in calculating the volume and surface area of solids of revolution. These difficulties generally stem from the high demands on spatial visualization skills and a deep understanding of continuous functions.

In reality, mathematical concepts fundamentally evolve from human activities rooted in culture and social environments. An approach that examines the interconnection between mathematics and culture is known as ethnomathematics. Ethnomathematics posits that every cultural group possesses its own unique way of constructing, understanding, and applying mathematical ideas in daily life



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(D'Ambrosio, 2001). Through this approach, mathematics is understood not merely as a collection of formal formulas, but as a living and meaningful cultural product.

The ethnomathematical approach has been widely utilized in mathematics education to link formal concepts with local cultural contexts. Integrating cultural elements into learning serves not only as an illustrative context but also as a vehicle for building conceptual understanding, increasing student engagement, and strengthening the relevance of mathematics to real life (Rosa & Orey, 2016; Zulkardi & Putri, 2019).

Various studies indicate that cultural artifacts, such as traditional buildings, decorative patterns, and household utensils, contain formal mathematical concepts that can be analyzed rigorously. The integration of cultural contexts in mathematics education has been proven to enhance conceptual understanding and learning motivation while reducing mathematics anxiety among students (Prahmana & D'Ambrosio, 2020). In the context of calculus, the utilization of real objects with complex geometric shapes can help bridge the gap for students in understanding abstract integral concepts.

The Kasepuhan Palace in Cirebon is one of Indonesia's cultural centers that preserves various artifacts of high historical and philosophical value, including traditional vessels such as bowls, jars, pitchers (kendi), and urns. These vessels do not only function as household or ritual tools but also exhibit regular, symmetrical, and proportional geometric forms. The curves on the surface of these vessels can be viewed as curve profiles that, when rotated around an axis, form a three-dimensional solid.

Mathematically, the shapes of these traditional vessels are highly relevant to the concept of solids of revolution in calculus. Definite integral concepts can be employed to analyze the volume and surface area of the vessels through continuous function modeling. Consequently, these cultural artifacts hold significant potential as contextual learning resources for teaching integrals, while simultaneously serving as a means to connect formal mathematics with local cultural reality.

Previous ethnomathematical research has explored the relationship between cultural artifacts and mathematical concepts, particularly in geometry and contextual arithmetic. However, studies specifically examining calculus concepts, particularly definite integrals, in cultural artifacts remain relatively limited. Furthermore, research focusing on the modeling of the volume and surface area of traditional vessels as solids of revolution within the local cultural context of Cirebon is still scarce. Most studies tend to conclude at the identification of geometric shapes without establishing a profound connection to integral concepts as formal mathematical representations. Therefore, a study that integrates mathematical integral analysis with ethnomathematical interpretation is necessary to uncover the mathematical meanings embedded in cultural artifacts more comprehensively.

Based on the aforementioned background, this study aims to examine integral concepts within the forms of traditional vessels at the Kasepuhan Palace in Cirebon through an ethnomathematical approach. This research is expected to reveal the mathematical dimensions contained within cultural artifacts and demonstrate their potential as contextual, meaningful, and relevant calculus learning resources for students' cultural environments.

2. METHODS

2.1 Research Design

This study employs a descriptive qualitative approach with an ethnographic-ethnomathematical design. The descriptive qualitative approach was selected to uncover and describe the mathematical concepts embedded in cultural artifacts in depth without manipulating any variables. Meanwhile, the ethnographic design was used to understand cultural artifacts as products of human activity imbued with cultural values, functions, and meanings, consistent with the characteristics of ethnomathematical studies.

The descriptive qualitative approach in this study is operationalized through an ethnomathematical research syntax, which includes: (1) identification of cultural artifacts, (2)

exploration of the geometric characteristics of the artifacts, (3) mathematical modeling of the artifact shapes, (4) analysis of definite integral concepts, and (5) mathematical interpretation within a cultural context. This syntax is utilized to ensure a systematic link between the empirical data of cultural artifacts and the formal mathematical concepts being analyzed.

2.2 Research Location and Objects

The research was conducted at the Kasepuhan Palace, Cirebon. The objects of this study are cultural artifacts in the form of traditional vessels, including bowls, basins, pitchers (kendi), and urns. These artifacts were selected through purposive sampling because they possess geometric characteristics such as rotational symmetry and curved profiles relevant to the concept of solids of revolution in integral calculus.

2.3 Data Collection Techniques

Data collection was carried out through triangulation, encompassing observation, documentation, and interviews. Direct observations were conducted at the Kasepuhan Palace to examine the geometric shapes and physical structures of the traditional vessels. Documentation involved photographing the artifacts from various perspectives to obtain accurate cross-sectional profiles and recording dimensional measurements. Limited interviews were conducted with one or two palace administrators or local cultural experts as key informants. These interviews aimed to gather supporting information regarding the practical functions, usage, and cultural significance of the analyzed traditional vessels, thereby strengthening and validating the interpretation of observation results and mathematical modeling from an ethnomathematical perspective.

2.4 Research Procedures

The research procedure began with the identification of cultural artifacts in the form of traditional vessels found at the Kasepuhan Palace, Cirebon. This identification was performed to select artifacts with geometric characteristics relevant to integral concepts, specifically those exhibiting rotational symmetry and consistent curved profiles, such as bowls, basins, pitchers, and urns.

Once the artifacts were determined, the study proceeded with an exploration of geometric forms through direct observation and visual documentation. At this stage, the researcher performed a detailed examination of the physical forms of the vessels, including height, diameter variations, surface curvature, and symmetry characteristics. The dimensional data obtained served as the basis for understanding the spatial structure mathematically.

The subsequent stage involved mathematical modeling, transforming the physical forms into mathematical representations. The curved profile of the vessel is viewed as a continuous function defined over a specific interval $[a,b]$ and is considered to rotate around an axis, thereby forming a solid of revolution. This modeling was conducted to refine the real-world shape of the artifact into an abstract model that permits calculus analysis.

Based on these mathematical models, an analysis of definite integral concepts was performed to calculate the volume and surface area of the vessels. Integral calculations were utilized as analytical tools to explain capacity, distribution volume, and the efficiency of the vessel shapes from a mathematical standpoint.

Furthermore, the results of the mathematical analysis were interpreted through an ethnomathematical perspective. At this stage, the researcher analyzed the mathematical findings in relation to the practical functions, cultural values, and local wisdom of the Kasepuhan Palace community. This interpretation aimed to reveal the mathematical meanings internalized within cultural practices, even if not formally stated.

The final stage of the research involved drawing conclusions by synthesizing all observation results, modeling, and integral analysis to explain the connection between cultural artifacts and integral concepts, as well as their potential as ethnomathematics-based learning resources.

Overall, the research flow positions the observation of cultural artifacts as the starting point of the analysis. The observation results were then converted into mathematical models to formally reveal the geometric structure of the vessels. The mathematical modeling and integral calculation results were subsequently re-interpreted within the cultural context through an ethnomathematical perspective, forming a cohesive analysis between empirical data, mathematical representation, and cultural meaning.

This procedure demonstrates that the study does not merely aim for quantitative measurement but rather interprets the vessel shapes as representations of mathematical knowledge internalized in cultural practices. Thus, the integral analysis serves as an interpretative tool for understanding the mathematical meaning of cultural artifacts, rather than an experimental numerical test.

2.5 Data Analysis Techniques

Data analysis in this study was conducted qualitatively and interpretatively by integrating empirical observation results, mathematical modeling, and ethnomathematical interpretation. The data analysis was performed in a hierarchical and continuous manner, starting from the identification of geometric characteristics of the traditional vessels, followed by mathematical modeling in the form of continuous functions, and concluding with the interpretation of mathematical meanings within the local cultural context.

Data from observations and documentation were analyzed to identify curved profiles, symmetry, and variations in vessel dimensions. These characteristics were then mathematically modeled as solids of revolution to be analyzed using definite integral concepts. The mathematical calculation results were not treated as an end goal but rather as a foundation for interpreting the principles of efficiency, stability, and vessel function from an ethnomathematical perspective.

The data analysis process was conducted iteratively, where the mathematical modeling results were continuously linked back to the cultural context and artifact function, ensuring a comprehensive understanding of the relationship between cultural artifacts and integral concepts.

3. RESULTS AND DISCUSSION

The results of this study are presented through qualitative descriptions of the characteristics of traditional vessel shapes, supported by mathematical integral modeling. The analysis focuses on the relationship between the physical forms of the cultural artifacts and the concept of definite integrals as a mathematical representation of the volume and surface area of solids of revolution. Figure 1 illustrates the visual appearance of the artifacts located in the exhibition display at the Kasepuhan Palace, Cirebon.



Figure 1. Traditional vessel artifacts in the display case at Kasepuhan Palace, Cirebon
(Source: Researcher's documentation, 2025)

3.1. Traditional Vessel Shapes of Kasepuhan Palace, Cirebon

Based on visual observations of the artifacts in the display cases at Kasepuhan Palace, Cirebon (Figure 1), several types of traditional vessels were identified, as follows:

1. Small Bowl

The small bowl features a simple form with a curved profile that gradually widens from the base toward the rim. Geometrically, the bowl's shape exhibits rotational symmetry around a vertical axis, allowing it to be modeled as a solid of revolution generated by a simple curve, such as a linear or quadratic function. This design results in a stable and proportional volume distribution, which functionally supports the use of the bowl as a liquid container in both daily activities and rituals. From an ethnomathematical perspective, the bowl's shape reflects an understanding of balance and volumetric efficiency. The following is the visual representation of the bowl at Kasepuhan Palace, Cirebon.



Figure 2. Traditional bowl of Kasepuhan Palace, Cirebon
(Source: Researcher's documentation, 2025)

2. Medium-sized Bowl

Traditional bowls are larger than the small bowls (*cawan*), featuring a smoother curved profile that widens toward the top. Mathematically, the shape of the bowl can be viewed as a solid of revolution with radius variations that increase relative to its height. This characteristic allows for a larger holding capacity without compromising stability. The bowl's shape demonstrates the interconnection between functional requirements and geometric principles, where integral concepts can be employed to explain the relationship between height, radius, and volume. The following is a visual representation of the bowl found at the Kasepuhan Palace, Cirebon.



Figure 3. Traditional bowl of Kasepuhan Palace, Cirebon
(Source: Researcher's documentation, 2025)

3. Pitcher/Urn (*Kendi/Guci*)

The pitcher or large urn situated in the upper-right section of the display case exhibits a more complex geometric shape, comprising a relatively narrow neck, a bulbous body, and a flatter base. The curved profile of the *kendi* can be modeled as a composite of multiple functions, such as a linear function for the neck and a quadratic or elliptical function for the body section. Mathematically, this configuration achieves maximum volume within the body, while the narrow neck functions to regulate liquid flow. This design illustrates principles of volume optimization and stability that can be analyzed through the concept of definite integrals. The following is the visual representation of the *kendi/guci* at Kasepuhan Palace, Cirebon.



Figure 4. Traditional pitcher/urn of Kasepuhan Palace, Cirebon
(Source: Researcher's documentation, 2025)

4. Red Cylindrical Container

The red cylindrical container located in the lower-right section of the display case exhibits the simplest form compared to the other artifacts. Geometrically, this shape resembles a cylinder with a relatively constant radius throughout the vessel's height. The cylindrical form allows for more straightforward mathematical modeling using the concepts of volume and surface area of a cylinder. In an ethnomathematical context, this container indicates that traditional communities also utilized basic geometric shapes that were efficient and easy to construct while remaining functional and meaningful. The following is the visual representation of the red cylindrical container..



Figure 5. Traditional cylindrical container at Kasepuhan Palace, Cirebon
(Source: Researcher's documentation, 2025)

Geometrically, all of these artifacts exhibit rotational symmetry about a vertical axis, allowing them to be modeled as solids of revolution. This characteristic enables the application of integral-based volume and surface area concepts within the mathematical analysis.

3.2. Mathematical Modeling of Traditional Vessels

In ethnomathematical analysis, the physical forms of artifacts are converted into abstract models to reveal the underlying spatial logic. The shape of a small bowl can be accurately modeled as a truncated cone or as the result of a linear function $f(x) = mx + c$ revolving around a specific axis. In contrast, the shapes of the kendi (pitcher) and urn, which possess more complex curvatures, can be modeled as the result of revolving elliptical curves or higher-degree polynomial functions (Putra et al., 2022). This modeling is not merely a simulation; rather, it is a scientific method to validate the functional precision of vessels crafted by traditional artisans who did not utilize modern measuring tools.

This modeling facilitates the use of definite integrals as the primary instrument for calculating the volume and surface area of the vessels. For instance, if the curvature profile of a vessel is mapped onto a coordinate plane and modeled as a solid of revolution generated by the function $f(x)$ about the x-axis over the interval $[a,b]$, the volume of the vessel can be calculated exactly using the formula:

$$V = \pi \int_a^b [f(x)]^2 dx$$

The application of this formula demonstrates that integral concepts play a vital role in determining the capacity or holding volume of traditional vessels. Research suggests that utilizing the context of solids of revolution from cultural artifacts can assist students in understanding the

relationship between continuous functions, limits of integration, and three-dimensional space (Widiatsih et al., 2023).

Through this technique, the physical dimensions of the vessels, such as height and diameter variations at every point, can be interpreted as variables within the integral function. This analysis reveals that the vessel designs of the Kasepuhan Palace do not merely consider aesthetic aspects but also prioritize spatial and material efficiency, which are intrinsically mathematical in nature (Huda & Sholihah, 2024). Consequently, the integral becomes the "language" capable of articulating the technical ingenuity behind cultural heritage.

For instance, the shapes of the bowls and small bowls in Figure 1 exhibit curved profiles that widen at the top and narrow at the base. These profiles can be approximated by a quadratic function, with the following formula:

$$y = ax^2 + bx + c$$

Where:

x : represents the vertical distance from the base

y : represents the radius of the vessel at a given height

If the curve profile is rotated about the x -axis, the volume of the bowl can be calculated using the disk method:

$$V = \pi \int_0^h [f(x)]^2 dx$$

The results of the integral calculations indicate that the volume of the small bowl is relatively proportional to its height and rim width. Furthermore, the bowl's design facilitates a stable volume distribution, rendering it less prone to tipping over during use.

3.3. Integral Modeling of Small Bowls and Bowls



(2)



(3)

Based on the visual representations of the small bowl and the bowl in Figure 2 and Figure 3, both artifacts exhibit curved profiles that gradually widen from the base toward the top. These curved profiles can be represented as a continuous function $f(x)$, where x denotes the vertical distance from the base of the vessel and y represents the radius of the vessel at a specific height, as shown in the following illustration:

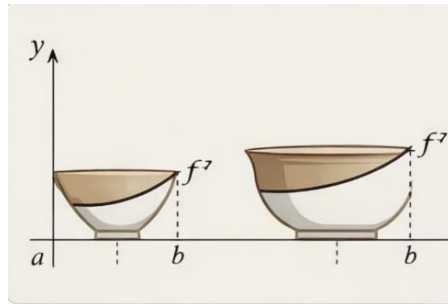


Figure 6. Illustration of the curved profiles of the small bowl and bowl as solids of revolution
(Source: Researcher's illustration, 2025)

In mathematical modeling, the profiles of the small bowl and the bowl are assumed to revolve around a vertical axis (x-axis), thereby forming a solid of revolution. Based on this assumption, the volumes of the small bowl and the bowl can be analyzed using the disk method:

$$V = \pi \int_0^h (ax^2 + bx + c)^2 dx$$

This modeling is consistent with the visual characteristics of the small bowls and bowls, which are relatively symmetrical and lack cavities or narrow necks. The analysis results indicate that the volume of these vessels is directly proportional to their height and rim diameter. Furthermore, the upward-widening design provides functional stability, which mathematically relates to the volume distribution and the vessel's center of mass.

From an ethnomathematical perspective, the integral modeling of the small bowls and bowls demonstrates that traditional artisans have transmissively applied principles of balance and volumetric efficiency through simple yet functional curved forms.

3.4. Integral Volume Analysis of the Pitcher/Urn (*Kendi/Guci*)



Figure 4. Traditional pitcher/urn of Kasepuhan Palace, Cirebon
(Source: Researcher's documentation, 2025)

Unlike the small bowls and bowls, the pitcher or urn shown in Figure 4 possesses a more complex geometric shape. Visually, the kendi is composed of several primary components: a narrow neck, a bulbous body, and a relatively flat base. The curved profile of the kendi cannot be represented by a single function; instead, it is modeled as a composite of several continuous functions, namely a linear function for the neck section and a quadratic or elliptical function for the body section.

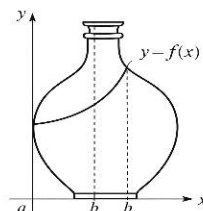


Figure 7. Illustration of the traditional pitcher/urn of Kasepuhan Palace, Cirebon
(Source: Researcher's illustration, 2025)

In the mathematical modeling, the neck of the *kendi* is represented by a linear function or a function with a shallow gradient, reflecting its relatively constant and narrow radius. Meanwhile, the body of the *kendi* is modeled using a quadratic or elliptical function, which produces a more pronounced curvature. Both functions are defined over distinct intervals and satisfy specific transition boundaries to ensure continuity.

The volume modeling of the *kendi* is conducted by applying definite integrals piecewise to each section of the profile and then summing the results to obtain the total volume. This approach reflects the visual form of the *kendi*, which exhibits significant radius variations along the vertical axis. The analysis demonstrates that the body section contributes the largest portion of the volume, while the narrow neck serves to regulate the flow of liquid. The total volume of the *kendi* or urn can be calculated using piecewise integration as follows:

$$V = \pi \left(\int_a^c [f_1(x)]^2 + \int_c^b [f_2(x)]^2 dx \right)$$

Where:

- $f_1(x)$ = the neck profile function
- $f_2(x)$ = the body profile function
- c : the transition boundary between the two sections.

From an ethnomathematical perspective, the integral modeling of the *kendi* and urn demonstrates an empirical understanding within traditional communities regarding the optimization of volume and function. The shape of the *kendi* is not merely aesthetic but also efficient and stable, which can be mathematically explained through the concept of integrals for solids of revolution.

3.5 Surface Area of Vessels as an Integral Concept

In addition to volume, the surface area of the vessels is analyzed by treating the curved surface as a result of revolving a curve profile about an axis. This surface represents the outer boundary of the vessel, which can be mathematically calculated using the surface area integral for solids of revolution. The modeling scheme for the vessel's surface indicates that the surface area depends on the shape of the curvature and the radius variations throughout the height of the vessel. The surface modeling scheme is shown in Figure 8.

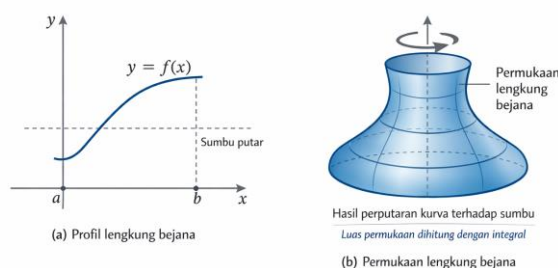


Figure 8. Modeling scheme of the vessel surface area as a solid of revolution
(Source: Researcher's illustration, 2025)

The surface area of the vessel's body can be calculated using the following integral:

$$L = 2\pi \int_a^b f(x) \sqrt{1 + [f'(x)]^2} dx$$

The results of the analysis indicate that vessels characterized by smooth contours and gradual changes in curvature possess a surface area that is relatively minimal in relation to their volume. This

signifies efficiency in material utilization during the crafting process. From a cultural perspective, such efficiency is linked to local wisdom regarding the optimal use of raw materials. Mathematically, this condition aligns with the principles of optimization in calculus.

3.6 Discussion from an Ethnomathematical Perspective

The findings of this study demonstrate that traditional vessel artifacts from the Kasepuhan Palace in Cirebon embody formal calculus concepts, specifically definite integrals, even though they were not symbolically expressed by traditional artisans. This mathematical knowledge is internalized within cultural practices through empirical experience, functional requirements, and the intergenerational transmission of skills.

These findings are consistent with ethnomathematical research asserting that mathematics is a product of human activity developed within specific cultural contexts. The symmetrical, efficient, and stable forms of the vessels reflect the intuitive application of continuity, curvature, and optimization. Consequently, cultural artifacts such as traditional vessels can be utilized as contextual learning resources to assist students in understanding abstract integral concepts.

By linking integral concepts to local cultural artifacts, mathematics education becomes more meaningful and relevant to the students' environment. This study reaffirms that integrating ethnomathematics into calculus instruction not only enriches the learning context but also strengthens conceptual understanding and fosters an appreciation for local culture.

4. CONCLUSION

Based on the results of the ethnomathematical study of traditional vessels from the Kasepuhan Palace in Cirebon, it can be concluded that cultural artifacts such as small bowls, bowls, pitchers (*kendi*), and urns possess geometric characteristics that are consistent, symmetrical, and structured. Mathematically, these vessels can be modeled as solids of revolution formed by the rotation of continuous functions. The application of definite integral concepts in calculating volume and surface area demonstrates that the design of traditional vessels considers not only aesthetic aspects but also volumetric efficiency, stability, and the optimization of material usage. This indicates the existence of an intuitive mathematical understanding internalized within the cultural practices of the traditional Cirebon community.

This study reaffirms that local cultural artifacts embody formal calculus concepts relevant to mathematics education. Consequently, the traditional vessels of the Kasepuhan Palace in Cirebon hold significant potential to be utilized as ethnomathematics-based contextual learning resources, particularly in teaching integrals, thereby bridging abstract concepts with the cultural reality of the students.

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