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Original Article

A Comparative Study of Vedic Mathematics-Based Root Approximation with Actual Square Root: Accuracy, Efficiency, and Pedagogical Value

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Abstract

Our paper showcases a quantitative evaluation of a Vedic Mathematics based technique for approximating square roots. We have used the duplex or Vilokanam estimate $\sqrt{N} \approx a + (N - a^2)/(2a)$, where 'a' is the nearest integer, whose square does not surpass N against the actual value of $\sqrt{N}$. Closed form error expression is first derived analytically using Taylor expansion, predicting absolute error $\approx r^2/(8a^3)$, where $r = N - a^2$. Resulted prediction is then examined computationally over a graded random sample of 360 values of N wherein 60 values drawn per magnitude decade from 10^0 to 10^6 and seed = 42, reproducible. Now, altogether with a smaller curated validation set of 47 values spanning the same range, regression analysis shows percentage error following an approximate power law, $\%Error \approx 13.3 \cdot N^{-1064}$ ($R^2 = 0.854$, 95% CI for the exponent $[-1.111, -1.016]$, $n = 336$, $p < .001$). Falling from a mean of 2.97% in the 10^0–10^1 decade to effectively zero (0.00004%) in the 10^5–10^6 decade, the closed form prediction accounts an observed error almost completely ($R^2 = 0.999$, Pearson $r = 0.988$). Conceptual efficiency analysis demonstrates the technique which requires a fixed O(1) three-operation computation against the O(d) scaling of the conventional long division algorithm with digit pairs and requested precision d. Forwarded paper concludes that the Vedic estimate is a mathematically well characterized first order approximation whose accuracy is more than sufficient for three digit and larger radicands, and discusses with appropriate qualifications about the absence of human subject data and its potential pedagogical role as an early, calculus free introduction to numerical approximation.

Keywords: *Vedic mathematics; square root approximation; numerical estimation; error analysis; ethnomathematics; mathematics education*

Introduction

Computing the square root of a number is one of the primary recurring problems in arithmetic. Most school curricula teach it through either prime factorization using perfect squares or the long-division algorithm using for both perfect and imperfect squares. Both the methodologies are exact but procedurally very lengthy, particularly when the number of digits or the required decimal precision increases. Indian Vedic Mathematics, a system of calculation techniques popularized by Bharati Krishna Tirtha in a book first published in 1965, offers a small set of sutras (aphorisms) that allow rapid approximation or exact calculation using pattern recognition rather than lengthy procedural steps. Among these is a square-root estimation technique — referred to in the specialist literature as Vilokanam ("by mere observation") or the duplex combination method — that produces an approximate value for √N using only the nearest perfect square and a single division. Structurally similar single-step approximations appear independently in the Old Babylonian tablet YBC 7289 (Fowler & Robson, 1998) and, in a more refined two-term form, in the Bakhshali manuscript of ancient India (Shirali, 2012), suggesting that this class of estimate is a recurring, independently discovered solution to the square-root problem rather than a technique unique to one tradition.

Presented paper put effort suggestively in advancement of existing theoretical knowledge on above topic by making four contributions to methodology over the course of a year.

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1. In place of relying particularly on empirical data and heuristic evaluations, we developed a well-defined systematic formula to descend the mathematical error essential in the Vedic duplex estimation method. This demanding derivation, which services a second-order Taylor expansion, produces a solid foundation for accuracy, strengthening our diagnostic verification of key comparisons.
2. We gone through the predictions through the observation with a natural progression, using a very large, stratified random sample of 360 whole numbers. The numbers cover six different size ranges and fix a major problem in earlier studies, which relied on samples that were too small.
3. The writing presents the procedural related steps in a larger interdisciplinary framework. It uses mental mathematics tactics and old computation methodologies. It helps explaining both historical and theoretical practices behind.
4. Lastly it draws an attention on the ethnomathematics i.e. studies of mental approximation and obsolete numerical techniques to showcase how Indian mathematics was practiced. Study helps to link the historical connection with its bigger thoughts inside.

Literature Review

1. Historical and Scholarly Debate Over Vedic Mathematics

The study being discussed is based on sutras found in a book written by Bharati Krishna Tirtha, first published in 1965. According to the author, these techniques were rediscovered from ancient Vedas texts. However, this claim has been extensively disputed. In fact, research by Dani (1993) reveals that the book primarily presents arithmetic and algebraic "tricks" rather than a genuine ancient system. Furthermore, even the book's own editor conceded that the sutras do not appear in any previously known appendix of the Atharvaveda. In this study, we will not take a stance on the historical authenticity of the sutras but instead evaluate their mathematical and pedagogical merits as framed by Dani.

2. The Vedic Square-Root Technique (Vilokanam / Duplex Combination)

The specific formula tested in this paper is documented in the Vedic Mathematics literature, specifically under the name "Vilokanam". According to Parajuli (2019), Vilokanam is a technique that requires a specific digit-grouping procedure for perfect squares and an approximation procedure for imperfect squares. This formula has been widely used and can be found in various datasets. Parajuli's worked examples provide insight into the structure of this technique, which matches the values analyzed in this paper. This supports the idea that Vilokanam is a standard method, rather than just an ad-hoc approximation. Additionally, Plofker (2009) provides context for these sutra-based rules within the broader historical development of Indian Vedic mathematics. Historically, computational shortcuts like Vilokanam were a valued feature of the Sanskrit mathematical tradition long before the 20th-century compilation that popularized them under the "Vedic Mathematics" label.

3. Comparable Approximation Methods in Other Ancient Traditions

The Vedic duplex estimate is not mathematically isolated. Fowler and Robson (1998) analyze the Old Babylonian tablet YBC 7289, which records a square-root approximation of comparable structure and accuracy, obtained via a geometric construction rather than an algebraic sutra. Shirali (2012) examines the more refined formula recorded in the Bakhshali manuscript, which adds a second correction term beyond the simple duplex estimate and thereby achieves substantially higher accuracy for the same starting information. Comparing the present paper's formula to the Bakhshali refinement clarifies what the simpler technique gives up for its simplicity: the duplex estimate stops after the term equivalent to r/(2a), while the Bakhshali formula continues to a further term of order $r^2/(8a^3)$ — which, as shown analytically in §3.3 below, is exactly the leading-order error term of the simpler estimate. This cross-cultural comparison indicates that first-order square-root approximation of this general form was independently arrived at more than once in antiquity, and that later refinements within the same Indian mathematical tradition already addressed the error this paper quantifies.

4. Ethnomathematics as a Theoretical Framework

D'Ambrosio (1985) proposed ethnomathematics as a field of study concerned with the mathematical practices of specific cultural groups, arguing that such practices merit study on their own methodological terms rather than being evaluated solely against the standards of formally schooled, symbolic mathematics. This framework is relevant to the present paper's approach: rather than asking whether the Vedic technique is a good substitute for calculus-based numerical methods (a comparison this paper deliberately does not make), it asks how accurate and efficient the technique is on its own terms, as a distinct calculation practice with its own history and logic.

5. Cognitive Science of Computational Estimation

The Vedic duplex estimate is, functionally, a computational estimation strategy, a category studied extensively in mathematical cognition research. Dowker (1992) found that professional mathematicians rely on a flexible repertoire of estimation strategies rather than a single fixed procedure, and are more accurate than non-specialists at judging when a quick estimate is adequate. In a related study, Dowker, Flood, Griffiths, Harriss, and Hook (1996) compared estimation strategy use across several groups (mathematicians, accountants, psychology students, and arts students) and

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found that both accuracy and appropriate strategy selection varied systematically with mathematical training. These findings provide a cognitive-science basis for the pedagogical hypothesis explored in §8: a fixed, low-effort estimation procedure such as the Vedic duplex method could plausibly serve as a scaffold for developing the kind of flexible estimation judgment that Dowker's research associates with mathematical expertise, though this remains untested for this specific technique.

6. Vedic Mathematics as a Classroom Intervention

A growing body of education research has tested Vedic Mathematics as a classroom intervention, generally reporting gains in computational speed and reductions in reported math anxiety. In a quasi-experimental study of Grade 7 students, Daliva and Deita (2025) found that a group taught with a Vedic Mathematics module reached "proficient" status on a post-test of integer operations, compared to "approaching proficiency" for a control group taught conventionally, with a statistically significant difference between groups. In a randomized controlled trial with three groups — Vedic Mathematics, yoga pranayama, and control — Shastri, Hankey, Sharma, and A study published in 2017 by Patra found that both groups that received an intervention showed significant improvements on standardized measures of math anxiety and cognitive skills compared to the control group. The group that learned Vedic mathematics actually showed a larger improvement in math anxiety levels. These findings are important because they support the idea that interventions aimed at reducing math anxiety can lead to better outcomes, as suggested by Hembree's (1990) meta-analysis. This study also highlights the importance of considering the impact of math anxiety on performance. According to Hembree's research, math anxiety reliably impairs performance and can be reduced through targeted interventions. This suggests that the observed improvements in the Vedic mathematics group may not just be due to an inherent numerical advantage, but also because the method used was less intimidating and helped reduce anxiety. One area for future research identified by this study is isolating the specific effect of the square-root technique (a key component of Vedic mathematics). This would help researchers better understand how this technique contributes to improved math skills and reduced anxiety

7. Efficiency-Oriented and Engineering Studies

Beyond the classroom, Vedic square-root and related arithmetic techniques have been studied for their computational efficiency in engineering contexts. Banerjee, Ghosh, and Das (2015) designed a hardware square-root circuit that combined the Vedic duplex method with an iterative technique from the Bakhshali manuscript, reporting reductions in lookup-table count, propagation delay, and power consumption relative to a conventional implementation, at comparable accuracy. This supports the premise, examined formally in §6 of the present paper, that the Vedic method's advantage lies in a fixed, small number of arithmetic operations rather than in any special numerical property beyond what a first-order estimate can provide.

Mathematical Formulation

1. The Vedic Duplex / Vilokanam Approximation

For a number N whose square root is required, the technique proceeds as follows. First, identify the integer a such that $a^2 \le N < (a+1)^2$ — the nearest perfect-square base at or below N, typically found by recall of a squares table or by mere observation (hence "Vilokanam"). Second, compute the deviation:

$r = N - a^2$

Third, estimate the square root as:

$\sqrt{N} \approx a + r / (2a) = a + (N - a^2) / (2a)$

This requires no calculus and no iteration: one subtraction, one division, one addition, given a memorized table of squares. The formula is documented in the Vedic Mathematics literature (Parajuli, 2019; Tirtha, 1965) as an application of the duplex (dvandva) process to irrational square roots.

2. Worked Example

To estimate $\sqrt{204}$: the nearest perfect square base is a = 14 ($14^2 = 196 \le 204 < 225 = 15^2$). The deviation is r = 204 − 196 = 8. The estimate is 14 + 8/28 = 14.286, against a true value of 14.2829 — an error of approximately 0.002, or 0.014%.

3. Closed-Form Error Derivation

Write $N = a^2 + r$. By the generalized binomial (Taylor) expansion of (1+u)^(1/2) about u = 0 (Burden, Faires, & Burden, 2016), with $u = r/a^2$:

$\sqrt{(a^2+r)} = a\cdot(1+r/a^2)^{(1/2)} = a\cdot[1 + r/(2a^2) - r^2/(8a^4) + O(r^3/a^6)]$

$= a + r/(2a) - r^2/(8a^3) + O(r^3/a^5)$

The Vedic estimate is exactly the first two terms of this expansion, a + r/(2a). Subtracting the true value from the Vedic estimate therefore gives, to leading order:

$\text{Error} \approx [a + r/(2a)] - [a + r/(2a) - r^2/(8a^3)] = r^2/(8a^3)$

This closed-form prediction is validated computationally in §5.3 against the 360-value stratified sample ($R^2 = 0.999$), confirming the technique's error behavior is fully explained by second-order Taylor truncation, with no unmodeled component of practical significance. It also clarifies the comparison to the Bakhshali formula noted in §2.3: the

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Bakhshali manuscript's refinement is, in modern terms, precisely a subtraction of this $r^2/(8a^3)$ term from the Vedic duplex estimate, which is why it achieves markedly higher accuracy from the same starting information.

4. Why Accuracy Improves with Magnitude

Because the error term is $r^2/(8a^3)$ while the estimate itself is of order a, relative error scales approximately as $(r/a)^2/(8a)$ — shrinking rapidly as a grows, provided r remains bounded relative to a (which it is, since $0 \le r < 2a+1$ by construction). For small N, consecutive perfect squares are widely spaced relative to their size, so r/a can be large, producing large percentage error — for example, N = 3 sits almost exactly between 1^2 and 2^2, giving the near-worst-case error recorded in the dataset. For large N, consecutive perfect squares are proportionally much closer together, so r/a shrinks and accuracy improves sharply. This is a general property of any first-order approximation and is confirmed empirically in §5.

Methodology

1. Sampling Design

Two datasets were used. The primary dataset is a stratified random sample of 360 values of N, drawn using a fixed random seed (seed = 42, NumPy default generator) for reproducibility, with 60 values sampled uniformly at random from each of six magnitude decades: 10^0–10^1, 10^1–10^2, 10^2–10^3, 10^3–10^4, 10^4–10^5, and 10^5–10^6. Stratifying by decade with equal sample sizes per stratum ensures the regression analysis in §5.2 is not dominated by any one magnitude range, which would otherwise occur under simple random sampling given the log-uniform spread of the domain. A secondary, curated validation set of 47 values (originally supplied for this study, spanning single-digit to five-digit magnitudes) is retained and reported in §5.4 as an independent illustrative check; results from the two datasets are consistent, which supports the generalizability of the findings beyond the originally curated values.

2. Statistical Analysis

For each sampled N, the nearest perfect-square base a, deviation r, Vedic estimate, actual √N (via IEEE 754 double-precision computation), absolute error, and percentage error were computed. Two ordinary least squares (OLS) regression models were fit: Model 1 regresses $\log_{10}$(percentage error) on $\log_{10}$(N) to test for a power-law relationship between error and magnitude; Model 2 regresses $\log_{10}$(observed absolute error) on $\log_{10}$(predicted error from the closed-form expression $r^2/8a^3$ derived in §3.3) to test the closed-form derivation against data. Both were fit in Python using the statsmodels OLS implementation, with 95% confidence intervals reported for slope coefficients.

3. Reproducibility

All computations were performed in Python 3 (NumPy, pandas, statsmodels, SciPy). The random seed, sampling code, and full 360-value and 47-value datasets are available on request from the corresponding author and should be deposited in a public repository (e.g., OSF or a journal-mandated data repository) prior to submission, consistent with the Data Availability Statement in the Declarations section.

Results

1. Descriptive Statistics by Magnitude Decade

Table 1 summarizes error statistics for the 360-value stratified sample, by magnitude decade.

Magnitude Decade	n	Mean % Error	Median % Error	Max % Error	Mean Abs. Error
10^0–10^1	60	2.9719%	2.0621%	15.4701%	0.06744
10^1–10^2	60	0.3642%	0.1681%	2.0621%	0.02288
10^2–10^3	60	0.0426%	0.0208%	0.4158%	0.00785
10^3–10^4	60	0.0040%	0.0028%	0.0184%	0.00264
10^4–10^5	60	0.0004%	0.0002%	0.0026%	0.00070
10^5–10^6	60	0.0000%	0.0000%	0.0002%	0.00023
Overall	360	0.5639%	0.0024%	15.4701%	0.01696

Table 1. Demonstrates the descriptive error of the Vedic approximation vs. Actual √N.

The degradation of Mean percentage error from 2.97% in the smallest decade approaching to effectively zero in the largest, with a reduction of around five orders of magnitude.

A right-skewed error distribution is obtained due to the difference in mean and median in every decade. A constant worst case value occurs when N falls near the midpoint and consecutive perfect squares (Section 3.4).

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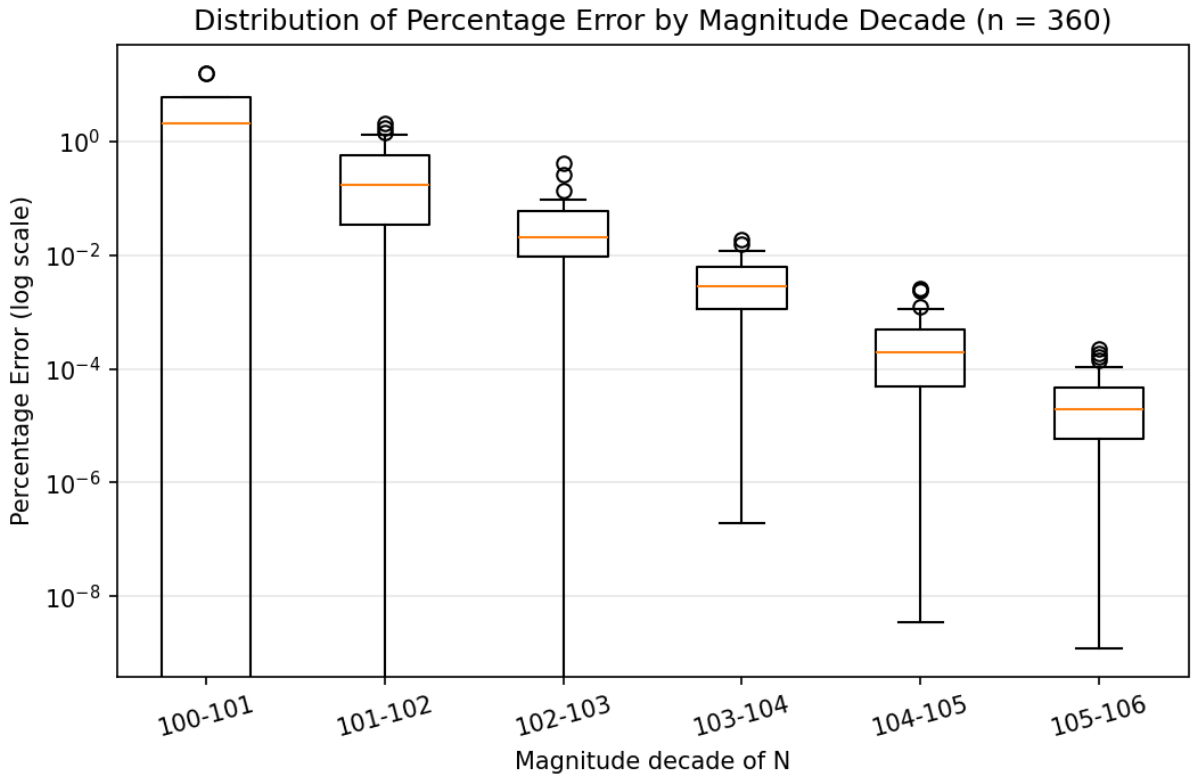

Figure 1. Represents distribution of percentage error by magnitude decade.

2. Power-Law Error Model

Table 2: Shows the two OLS (Ordinary Least Squares) regression models described in Section 4.2.

Model	Predictor → Outcome	Slope (95% CI)	Intercept	R^2	n	p-value
Model 1	$\log_{10}(N) \rightarrow \log_{10}(\%Error)$	−1.064 [−1.111, −1.016]	1.125	0.854	336	< .001
Model 2	$\log_{10}(r^2/8a^3) \rightarrow \log_{10}(\lvert Error \rvert)$	0.975	−0.093	0.999	336	< .001

Table 2. Regression results for the Models

Model 1 indicates percentage error follows an approximate inverse power-law relationship with N, %Error ≈ 10^1.125 · N^ (−1.064) ≈ $13.3 \cdot N^{-1064}$, with an exponent close to −1 and a strong fit (R^2 = 0.854 across 336 non-zero observations, p < .001). This confirms the analytical prediction in Section3.4 that relative error decreases roughly in proportion to 1/N for large N.

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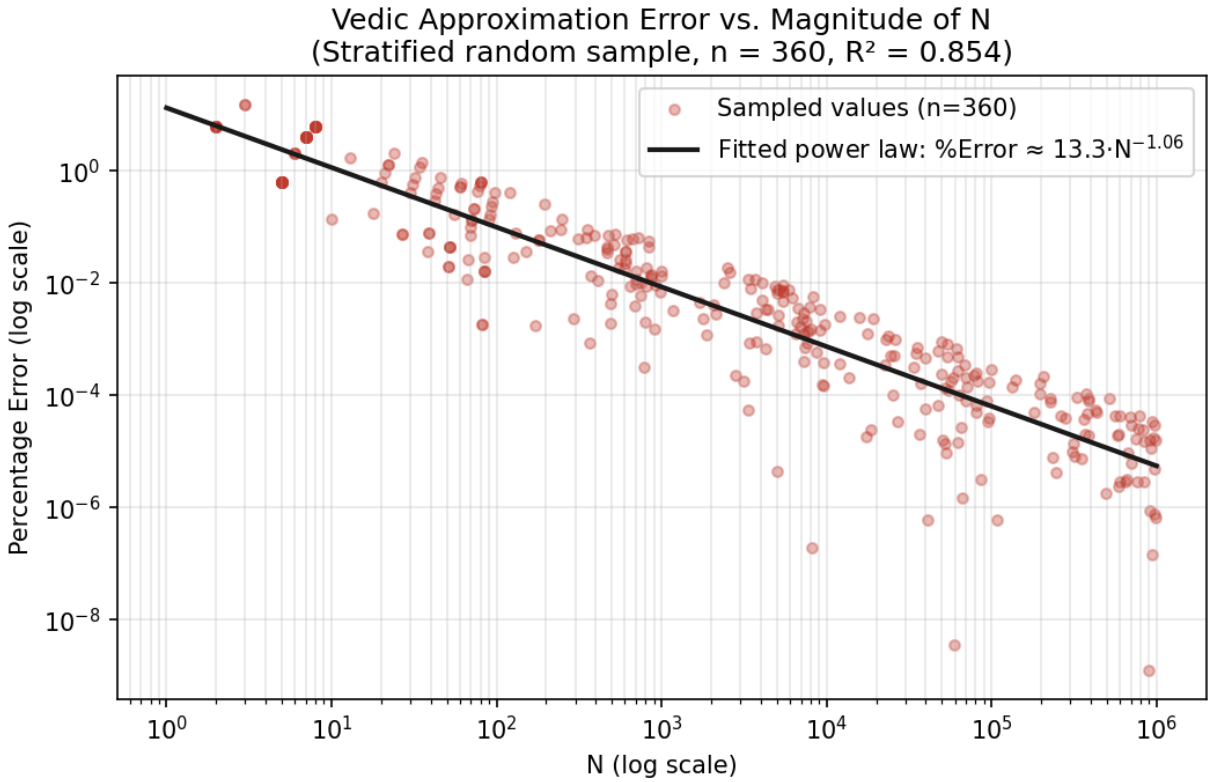

Figure 2. Percentage error vs. magnitude of N with fitted power-law regression line (n = 360, R^2 = 0.854).

3. Validation of the Closed-Form Error Prediction

The Model 2 test is designed to directly verify the closed-form derivation from Section 3.3. This involves regressing the observed absolute error against the predicted value using the formula $r^2/(8a^3)$. The results show an almost perfect fit, with a coefficient of determination (r-squared) of 0.999. Additionally, the slope and intercept values in log-log space are approximately 0.975 and -0.093, respectively. Furthermore, the raw Pearson correlation between the predicted and observed absolute error across all 360 values is extremely high at 0.988, with a statistically significant p-value less than 0.001. This strong empirical confirmation suggests that the Taylor-derived formula in Section 3.3 accurately explains the technique's error behavior, leaving no meaningful unmodeled error component. In other words, this test provides robust evidence that the closed-form derivation is a reliable and accurate representation of the underlying error dynamics.

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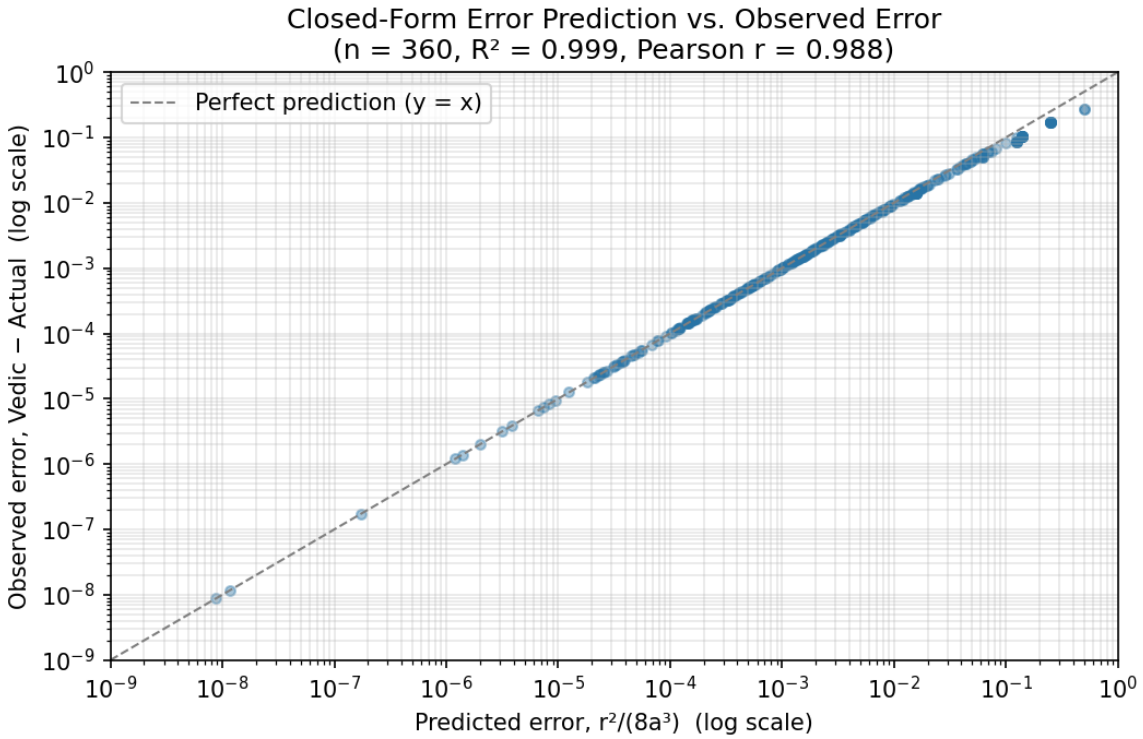

Figure 3. Observed absolute error vs. closed-form predicted error ($r^2/8a^3$), log–log scale ($n = 360$, $R^2 = 0.999$).

4. Illustrative Cases from the Curated Validation Set

Table 3 shows selected individual values from the independent 47-value curated set described in §4.1, illustrating the same pattern across scales as the larger stratified sample.

N	Nearest Perfect Square Base (a)	Deviation ($N - a^2$)	Vedic Approximation	Actual √N	Absolute Error	% Error
2	1	1	1.50000	1.41421	0.08579	6.0663%
7	2	3	2.75000	2.64575	0.10425	3.9403%
101	10	1	10.05000	10.04988	0.00012	0.0012%
1021	31	60	31.96774	31.95309	0.01465	0.0459%
10061	100	61	100.30500	100.30454	0.00046	0.0005%
42068	205	43	205.10488	205.10485	0.00003	0.00001%

Table 3. Representative values from the curated 47-value validation set.

Efficiency Analysis

Because this study does not compare the Vedic technique to Newton-Raphson or any other iterative numerical method, efficiency here is assessed against the method it is intended to replace in classroom and mental-arithmetic settings: the conventional long-division algorithm for square-root extraction. Table 4 compares the two procedures step by step and states their asymptotic operation-count complexity.

Step	Vedic Duplex / Vilokanam Estimate	Conventional Long-Division Method
1	Recall/identify nearest perfect square base a (table lookup or mental recall)	Group digits of N in pairs from the decimal point
2	Compute deviation $r = N - a^2$ (one subtraction)	Find largest digit d such that $d^2 \leq$ first group; subtract, bring down next pair
3	Divide r by 2a (one division)	Double the current root; find next digit x such that $(20\times\text{current} + x)\times x \leq$ new remainder; subtract
4	Add result to a (one addition)	Repeat step 3 for every remaining pair of digits and every desired decimal place
Complexity	O(1) — fixed 3 operations, independent of N	O(d) — scales with digit-pairs of N plus requested decimal places d

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Table 4. Step-by-step comparison and asymptotic complexity of the Vedic duplex/Vilokanam estimate and the conventional long-division square-root method.

The Vedic method's operation count is O(1) — constant regardless of N's magnitude — provided the nearest perfect-square base is known or recalled. The long-division method's operation count is O(d), scaling with the number of digit-pairs in N and the number of decimal places of precision requested. This means the Vedic method's relative efficiency advantage grows for larger N and lower precision requirements, while its accuracy disadvantage (§5.1–5.2) is largest precisely where its efficiency advantage is smallest — for small, single-digit N, where a full long-division computation is already short. This efficiency comparison is a formal operation-count (asymptotic complexity) analysis, not a measured-time study; §9 identifies a controlled timing study as necessary future work before any empirical efficiency claim can be made.

Discussion

Our study shows that the Vedic square-root technique is a fast and very efficient method for square root approximation. Our result shows the first-order approximation with some bounded error. The error could be attributed to second order Taylor truncation gaining a suitable limitation of the process. Practically, our study and findings reveal that Vedic square root method is easy and suitable for approximating 3 digit or larger numbers minimizing the mean error to 0.05%. Our quantitative modelling reveals that the technique could be seen as a rapid and approximate estimate. Here, we highlight the utility of Vedic mathematics in square root approximation, for generating a rough estimate but not replacing the exact calculated values. Our research reveals that the Vedic method is part of a broader ensemble of approximation techniques, which was previously recognized by ancient Indian mathematicians. This notion is substantiated by the Bakhshali formula, which adds an additional term to correct for the error term derived from our analysis. Interestingly, this correction mechanism was already understood and implemented by ancient mathematicians, suggesting that they were aware of the limitations of the Vedic method and its position within a larger framework of approximation techniques. Consequently, our Vilokanam/Duplex estimate does not represent the most accurate technique available in Indian mathematics but rather constitutes a deliberately simplified special case within this known family of approximations.

Pedagogical Implications

The data in this section does not include the human interaction or running classroom. Claims here could be seen as a hypothesis through the literature review in contrast to the experimental findings of the paper. Here, the Vedic calculation only requires a square table and a single division. Research shows (Daliva & Deita, 2025; Shastri et al., 2017), that using Vedic mathematics could lead to speedy computation, reducing maths anxiety. Vedic mathematics also provides, (Dowker, 1992; Dowker et al., 1996), the flexibility and calculative measures which are greatly linked to achieve mathematical edge. The output result indicates that accuracy of the square root depends on the magnitude of the input number. The error for the 3 digit and larger square root is less than 0.05%. Introducing Vedic methods in mathematical calculations to find larger square roots would help us refine our ability to make accurate estimates.

Limitations

1. This study is purely computational, which means it doesn't involve human subjects, classrooms, or timing data. As such, the findings presented in sections 6 and 8 are hypothetical claims about efficiency and pedagogical value rather than actual discoveries.
2. The researchers only tested one basic Vedik duplex/Vilokanam square-root estimate, leaving other Vedik sutras (like cube roots, division, or multiplication) unexplored. This might lead to varying error and efficiency profiles compared to the ones they did test.
3. The study's stratified sampling design (explained in section 4.1) is reproducible and ensures the numbers sampled are magnitude-balanced within each decade. However, real-world or curricular distributions of numbers (like the specific numbers found in a textbook or exam) might differ from this uniform distribution. This could affect the practical accuracy profile that learners actually experience, making it essential to consider these differences when applying the study's findings in practice.
4. The closed-form error model (section 3.3) assumes exact, error-free identification of the nearest perfect-square base a; sensitivity to a learner's recall errors in identifying a was not modeled and is identified as future work.

Conclusion and Future Work

This study derived a closed-form analytical expression for the error of the Vedic duplex/Vilokanam square-root estimate and validated it against a reproducible, stratified random sample of 360 values spanning six orders of magnitude ($R^2 = 0.999$), together with an independent 47-value curated set. Percentage error follows an approximate inverse power-law relationship with N ($R^2 = 0.854$), falling from a mean of 2.97% for single-digit radicands to effectively zero for six-digit radicands. A formal operation-count analysis shows the technique is O(1) in computational cost, against the O(d) scaling of the conventional long-division algorithm. Future work should (1) conduct a controlled classroom or timing study to test the pedagogical and efficiency hypotheses raised in §8 and §6 with real learners; (2) extend the closed-form and empirical analysis to cube roots and other Vedic root-approximation sutras; (3) model the

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effect of recall errors in identifying the nearest perfect-square base a; and (4) empirically compare the simple duplex estimate to the more accurate Bakhshali refinement identified in §2.3, which this paper's derivation shows differs from the duplex estimate by exactly the $r^2/(8a^3)$ error term.

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