SJME (Supremum Journal of Mathematics Education)
Vol.10, No.2, January 2026, pp. 303-314
ISSN: 2548-8163 (online)| ISSN: 2549-3639 (print)
DOI: 10.35706/sjme.v10i2.13601

Evaluating the Golden Ratio Claim in Water Spinach Internode Distances: An Inquiry-STEM Activity Design for Ratio Learning

Ika Meika[1*], Rizki Amsyarul Firdaus[2], Ika Yunitasari[3], and Asep Sujana[4]
[1*,2,3,4] Universitas Mathla'ul Anwar Banten
**Corresponding author*
Email: ikameikamulhat@gmail.com[1*], amsyarulrizki@gmail.com[2], ikayunitasari35@gmail.com[3], ikasep123@gmail.com[4]

Article Information
Received June 22nd, 2026
Revised July 02nd, 2026
Accepted July 13rd, 2026

Diterima 22 Juni 2026
Direvisi 02 Juli 2026
Disetujui 13 July 2026

Keywords:
golden ratio; inquiry-STEM; water spinach; ratio learning; robust statistics

Kata kunci:
rasio emas; inquiry-STEM; kangkung; pembelajaran rasio; statistik robust

ABSTRACT

The claim that the golden ratio appears in nature is frequently used as a context for mathematics learning; however, such claims require rigorous examination through precise variable definitions and appropriate analysis. This study critically examined whether internode-distance patterns in water spinach (Ipomoea aquatica) approximate the golden ratio. The objectives were to: (1) describe the pattern of five consecutive internode distances across 30 water spinach stems, (2) examine the closeness of adjacent-distance ratios to $\varphi = 1.618$, and (3) translate the findings into an inquiry-STEM activity for ratio learning. The data comprised 150 distance measurements and 120 adjacent paired ratios collected using AR Meter, a smartphone-based augmented reality measurement application. The analysis retained directional ratios to identify positional changes and used symmetric ratios, defined as the longer distance divided by the shorter distance, to evaluate proximity to φ. Differences among the five positions were tested using the Friedman test, while stem-level geometric means were compared with φ using the Wilcoxon signed-rank test. The results showed significant differences in internode distance by position, $\chi^2(4) = 22.744$, $p < 0.001$, Kendall's $W = 0.190$. The arithmetic mean of the 120 symmetric ratios was 1.629, which appeared close to φ but was influenced by two extreme ratios, 11.25 and 11.67. Only 11 of the 120 ratios (9.17%) fell within a 5% tolerance of φ. Therefore, the data did not support a consistent golden-ratio pattern in water spinach internode distances. The educational value of this study lies in using an unconfirmed popular claim as a context for teaching measurement, reciprocal ratios, robust statistics, and evidence-based argumentation through inquiry-STEM.

ABSTRAK

Pernyataan bahwa rasio emas muncul di alam sering digunakan sebagai konteks pembelajaran matematika; namun, pernyataan semacam itu memerlukan pemeriksaan yang cermat melalui definisi variabel yang tepat dan analisis yang sesuai. Penelitian ini secara kritis mengkaji apakah pola jarak antar-ruas pada kangkung (Ipomoea aquatica) mendekati rasio emas. Tujuan penelitian ini adalah: (1) mendeskripsikan pola jarak lima ruas berturut-turut pada 30 batang kangkung, (2) menguji kedekatan rasio jarak yang berdekatan dengan $\varphi = 1{,}618$, dan (3) menerjemahkan temuan tersebut ke dalam kegiatan STEM berbasis penyelidikan untuk pembelajaran tentang rasio. Data terdiri dari 150 pengukuran jarak dan 120 rasio pasangan jarak yang berdekatan, yang dikumpulkan menggunakan AR Meter, sebuah aplikasi pengukuran realitas tertambah berbasis ponsel pintar. Analisis mempertahankan rasio arah untuk mengidentifikasi perubahan posisi dan menggunakan rasio simetris—yang didefinisikan sebagai jarak yang lebih panjang dibagi dengan jarak yang lebih pendek—untuk mengevaluasi kedekatan terhadap φ. Perbedaan di antara kelima posisi diuji menggunakan uji Friedman, sedangkan rata-rata geometris pada tingkat batang dibandingkan dengan φ menggunakan uji Wilcoxon signed-rank. Hasil menunjukkan perbedaan yang signifikan pada jarak antar-ruas berdasarkan posisi, $\chi^2(4) = 22{,}744$, $p < 0{,}001$, Kendall's W = 0,190. Rata-rata aritmetika dari 120 rasio simetris tersebut adalah 1,629, yang tampak mendekati φ tetapi dipengaruhi oleh dua rasio ekstrem, yaitu 11,25 dan 11,67. Hanya 11 dari 120 rasio (9,17%) yang berada dalam toleransi 5% dari φ. Oleh karena itu, data tersebut tidak mendukung adanya pola rasio emas yang konsisten pada jarak antar-ruas daun kangkung. Nilai edukatif dari penelitian ini terletak pada penggunaan klaim populer yang belum terkonfirmasi sebagai konteks untuk mengajarkan pengukuran, rasio timbal balik, statistik robust, dan argumentasi berbasis bukti melalui pendekatan STEM berbasis penyelidikan.

INTRODUCTION

School mathematics should help students use concepts to interpret, examine, and explain phenomena. This expectation goes beyond computational ability. Students need to determine relevant quantities, select representations, evaluate the appropriateness of models, and communicate decisions based on data. The PISA 2022 results show that only 18% of Indonesian students reached at least Level 2 in mathematics. At this level, students begin to recognize how simple situations can be represented mathematically (OECD, 2022). This condition reinforces the need for learning that connects concepts with measurement, modelling, data interpretation, and claim evaluation.

Ratio and proportion are foundational concepts for percentages, scale, similarity, rates, functions, probability, and modelling. However, students often treat ratios merely as procedures involving division or cross multiplication without understanding the multiplicative relationship between two quantities. Difficulties also arise when the direction of comparison changes because a/b and b/a produce different values and meanings. Studies on ratio learning in Realistic Mathematics Education (RME) and Pendidikan Matematika Realistik Indonesia (PMRI) indicate that mathematizable contexts, multiple representations, and strategic discussion help students move from informal comparison toward formal proportional reasoning (Ben-Chaim et al., 2012; Risdiyanti et al., 2024).

One attractive context is the golden ratio. This value is denoted by φ and satisfies $\varphi = (1 + \sqrt{5}) / 2 \approx 1.618$. Geometrically, a segment is divided according to the golden ratio when the ratio of the whole segment to the longer part is equal to the ratio of the longer part to the shorter part. The golden ratio is also the limiting ratio of two consecutive Fibonacci numbers. This relationship has made the golden ratio popular in discussions of art, architecture, and natural patterns.

The popularity of the golden ratio also carries the risk of oversimplification. The closeness of a single measurement to 1.618 is often treated as evidence of a biological pattern. In plants, however, phyllotaxis primarily concerns the arrangement of lateral organs around the growing point, divergence angles, and changes in phyllotactic fractions. The golden angle of approximately 137.5° is related to angular arrangement, not to all morphological dimensions of plants (Godin et al., 2020; Okabe, 2015). Models of phyllotaxis also show that Fibonacci patterns can emerge through local interactions among primordia and do not necessarily have to begin from a fixed golden angle (Yin & Tsukaya, 2022). In addition, angles other than the golden angle can produce efficient light capture under certain conditions (Strauss et al., 2020).

Internode distance in plant stems has a biological basis that differs from divergence angle. Internode length is influenced by plant age, position on the stem, light, water, nutrients, and growth responses. Studies have shown that watering intervals and nutrient provision significantly affect plant height and leaf number in water spinach (Wibowo & Sitawati, 2017; Apriastuti et al., 2023). Therefore, there is no theoretical reason why internode ratios should always approach φ. Nevertheless, this uncertainty has educational value. Students can learn that mathematics is not only used to find expected patterns; it is also used to reject claims when the data do not support them.

An inquiry-STEM approach is appropriate for this purpose. Science provides questions about plant morphology and growth. Technology supports data recording, visualization, and processing. Engineering appears when students design consistent measurement protocols, test instruments, and improve procedures. Mathematics is used to construct ratios, choose measures of central tendency, assess error, and build arguments. A recent meta-analysis found that STEM education has a moderate positive impact on learning outcomes, although the magnitude of the effect depends on educational level, outcome type, duration, and implementation quality (Cao et al., 2025). Teles et al. (2024) also showed that the golden ratio can be used as a STEAM theme, but learning activities must distinguish popular knowledge from empirical evidence.

Previous studies on the golden ratio in nature have more frequently emphasized identification activities or improvements in understanding after intervention, often with the implicit assumption that the pattern exists and simply needs to be confirmed. Few mathematics education studies have positioned the failure to confirm a popular pattern as a learning resource for robust statistics and claim evaluation, rather than merely reporting a negative result as a methodological footnote. The novelty of this study lies in using findings that do not support the golden-ratio pattern as an authentic context for teaching robust statistics and data literacy. The purpose is not to validate the mathematical beauty of nature but to train students to evaluate claims critically using evidence. Moreover, arithmetic means of ratios can be misleading when the data are skewed and contain extreme values because ratios are multiplicative. The geometric mean and median are more appropriate for describing typical values when comparisons can change sharply.

This study used raw data from five internode distances across 30 water spinach stems. The scientific name used in this study was Ipomoea aquatica Forssk.; Ipomoea reptans Poir. is recorded as a synonym in modern taxonomic databases (Royal Botanic Gardens, Kew, 2026). The term "leaf distance" in the initial document was operationalized as the longitudinal distance between stem nodes where leaves emerge. This study had three objectives: first, to describe the variation in five consecutive distances; second, to examine whether paired distance ratios showed consistent closeness to φ; and third, to formulate the findings into an inquiry-STEM activity design for ratio learning. The research questions were: (1) What is the distribution pattern of D1 to D5? (2) How does the conclusion about the golden ratio change when arithmetic and robust measures are used? and (3) How can the data be used to construct an inquiry-STEM activity that requires evidence-based argumentation?

METHOD

This study employed an exploratory quantitative design followed by pedagogical translation. The quantitative component examined the golden-ratio claim using plant-measurement data, whereas the pedagogical component translated the research process and findings into an inquiry-STEM activity. The study did not examine the effectiveness of the proposed instructional design. Therefore, the pedagogical output was positioned as an evidence-based activity design that still requires expert validation, classroom implementation, and empirical evaluation.

The data were obtained from the "data Kangkung" file and the research proposal document. The dataset contained measurements from 30 water spinach stems selected through purposive sampling. Purposive sampling allows researchers to select cases based on predefined characteristics that are directly aligned with the objectives and methodological requirements of a study (Campbell et al., 2020). The inclusion criteria were stems with at least six active nodes and no visible physical damage or pest infestation. Each stem had five consecutive internode distances, identified as D1 to D5 and measured in millimetres. D1 referred to the segment closest to the root, whereas D2 to D5 referred to the consecutive segments toward the shoot apex.

Figure 1. Internode distances in water spinach

Based on Figure 1, the raw dataset consisted of 150 measurements. Because five consecutive distances produced four adjacent pairs for each stem, a total of 120 adjacent-distance ratios were analyzed. The primary instruments were the AR Meter application and an observation sheet containing the stem code, internode position, and measurement result in millimetres. The activity was designed for implementation at MTs Mathla'ul Anwar Cikaliung, Pandeglang. AR Meter was used by setting the measurement unit to millimetres and allowing the application to scan the surrounding surface before measurement. This calibration stage was important because the accuracy of smartphone-based augmented-reality measurement depends on device tracking, camera positioning, and environmental conditions (Hasler et al., 2020). Two ratio forms were used so that growth direction and closeness to φ would not be conflated. The directional ratio preserved positional order and was calculated as follows:

$$\text{Directional internode ratio} = D_{i+1} / D_i$$

A directional internode ratio greater than 1 indicates that the next distance is longer, a ratio less than 1 indicates that the next distance is shorter, and a ratio equal to 1 indicates that both distances are the same. To compare two lengths with the golden ratio, which is greater than one, a symmetric ratio was used. This ratio divides the longer distance by the shorter distance. This transformation removes direction while preserving the magnitude of dissimilarity between the two distances.

$$\text{Symmetric internode ratio} = \text{Dlonger} / \text{Dshorter}, \text{ so the internode ratio} \geq 1$$

Numerical closeness to φ was expressed as relative error. Tolerances of 5% and 10% were used as descriptive categories, not as botanical standards. These categories were not used as the sole basis for drawing conclusions.

$$\text{Relative error} = |\text{internode ratio} - \varphi| / \varphi \times 100\%$$

Each stem had four symmetric ratios. Because ratios are multiplicative and their distribution was skewed, the representative value for each stem was calculated using the geometric mean (Limpert et al., 2001). This measure reduced the influence of extreme values compared with the arithmetic mean.

$$g_s = (r_{s1} \times r_{s2} \times r_{s3} \times r_{s4})\text{^}(1/4)$$

Descriptive analysis for D1 to D5 included mean, standard deviation, median, quartiles, minimum, and maximum. Differences among the five repeated-measurement positions were tested using the Friedman test, with effect size reported using Kendall's W (Hollander et al., 2014). When the omnibus test was significant, pairwise Wilcoxon comparisons were conducted with Holm correction (Holm, 1979).

For the symmetric ratios, this article reports the arithmetic mean, median, interquartile range, 10% trimmed mean, the number of values within the 5% and 10% tolerance ranges, and extreme values. The 5% and 10% tolerance thresholds were established to maintain methodological consistency between the descriptive criteria and the inferential framework of the study. The main conclusion was based on the distribution of geometric means across the 30 stems. Normality was examined using the Shapiro-Wilk test (Shapiro & Wilk, 1965). Because the distribution was not normal, the median g_s was compared with φ using a two-sided one-sample Wilcoxon signed-rank test.

RESULTS AND DISCUSION

Table 1 shows that the mean distance decreased from 45.07 mm at D1 to 30.77 mm at D5. However, the large standard deviations in several positions indicate considerable variation among plants. The median of D1 was 44.50 mm, whereas the median of D5 was 30.00 mm. D3 and D4 each had a minimum value of 4 mm. D5 had the widest range, from 3 to 85 mm. These data indicate a decline from D1 to D5, which can be understood because internode distances toward the shoot apex are usually shorter than those in the lower and middle parts of the stem.

Table 1. Descriptive statistics of internode distance by position

Position	n	Mean	SD	Median	CV (%)	Q1	Q3	Min	Max
D1	30	45.07	16.26	44.50	36.1%	37.00	56.50	10	75
D2	30	42.03	13.64	37.00	32.5%	34.25	49.25	18	71
D3	30	40.77	13.10	38.50	32.1%	34.00	46.50	4	66
D4	30	40.90	16.08	37.50	39.3%	30.25	45.00	4	75

D5	30	30.77	13.52	30.00	43.9%	26.50	34.75	3	85

The Friedman test showed that internode distance differed by position, $\chi^2(4) = 22.744$, $p < 0.001$, with Kendall's $W = 0.190$, indicating a small-to-moderate effect. This means that although differences among positions were statistically consistent, the strength of the pattern was not large, and individual variation among stems still contributed substantially to data variability. Follow-up tests showed that D5 was shorter than D1, D2, D3, and D4 after Holm correction, with adjusted p-values between 0.004 and 0.012. No significant differences were found among D1 to D4. These results indicate statistically consistent positional change with moderate strength, but not a fixed ratio pattern.

The directional ratios showed a tendency for the next distance to be shorter. From D1 to D2, 18 of the 30 stems had $q < 1$. From D2 to D3, 18 stems had $q < 1$. From D3 to D4, 16 stems had $q < 1$. From D4 to D5, 20 stems had $q < 1$. This direction is consistent with the lower median at D5, but it does not form a constant ratio.

Table 2 shows a large difference between the mean and median of the symmetric ratios. This difference occurred because of biological variation, as some internode distances did not follow the pattern of becoming progressively shorter toward the shoot apex. In the D2–D3 segment, the mean of 1.644 appeared close to φ, but the median was only 1.150. A value of 11.25 in one stem increased the mean. The same pattern occurred in D4–D5, with a mean of 2.026, a median of 1.333, and a maximum value of 11.667. Therefore, the arithmetic mean should not be used alone to evaluate the typical value.

Table 2. Distribution of symmetric ratios for adjacent internode pairs

Segment	n	Mean	SD	CV (%)	Median	Q1	Q3	Min	Max	≤5 %	≤10 %
D1–D2	30	1.449	0.420	28.99	1.344	1.169	1.62	1.00	3.000	3	5
D2–D3	30	1.644	1.850	112.53	1.150	1.054	1.41	1.00	11.25	2	2
D3–D4	30	1.398	0.406	29.04	1.233	1.132	1.53	1.00	2.696	4	6
D4–D5	30	2.026	2.191	108.14	1.333	1.107	1.80	1.00	11.66	2	4
All ratios	120	1.629	1.466	89.99	1.276	1.100	1.60	1.00	11.66	11	17

The arithmetic mean of all ratios was 1.629, only 0.69% above φ. If this value were interpreted without considering the distribution, the data could be concluded to approximate the golden ratio. This conclusion changes when robust measures are used. The coefficient of variation (CV) for all ratios reached 89.99%, with two of the four segments (D2–D3 and D4–D5) showing CV values above 100% (112.53% and 108.14%, respectively). A CV approaching or exceeding 100% indicates that the standard deviation is comparable to or even greater than the mean, which is a strong sign of data heterogeneity and the dominant influence of extreme outliers rather than a distribution clustered consistently around φ. By contrast, the D1–D2 and D3–D4 segments showed much lower CV values of approximately 29%, indicating that ratio consistency was local and not uniform across the entire dataset. The median of all ratios was 1.276, and the 10% trimmed mean was 1.348. Only 11 of the 120 ratios, or 9.17%, were within a 5% tolerance. Seventeen ratios, or 14.17%, were within a 10% tolerance. Numerical closeness occurred in only a small proportion of pairs and did not form a dominant pattern. The geometric mean of the four ratios was calculated for each stem. The values ranged from 1.063 to 3.087. The distribution was not normal, Shapiro-Wilk $W = 0.757$, $p < 0.001$. All confidence intervals were below φ.

The one-sample Wilcoxon signed-rank test showed that the location of the g_s distribution differed from φ. Twenty-five of the 30 stems had g_s values below φ. Four stems were within a 5% tolerance, while seven stems were within a 10% tolerance. The closeness of several stems was insufficient to demonstrate a general pattern.

Table 3. Summary of robust stem-level analysis

Analysis	n/statistic	Result	Additional information	Interpretation
Median g_s	30	1.403	IQR 1.188-1.556	The typical value was below φ.
95% bootstrap median	100,000 resamples	1.276-1.506	Does not include 1.618	Closeness to φ was not supported
One-sample Wilcoxon	W = 86	p = 0.0026	r = 0.55	Significant difference with a large effect size
Within 5% tolerance	4 of 30	13.33%		The pattern was not dominant
Within 10% tolerance	7 of 30	23.33%		Most stems were outside the tolerance range

Table 3 has important implications for mathematics education, particularly for training students to distinguish apparent numerical closeness from strong statistical evidence. Bootstrap resampling shows that a single median value (1.403) is not sufficient to conclude closeness to φ. Students need to understand the range of uncertainty, or confidence interval, that would arise if sampling were repeated. This helps them recognize that strong conclusions must consider data variability, not merely a single value obtained from one measurement process. The median difference from φ was then tested using a one-sample Wilcoxon test, a non-parametric test appropriate for non-normal data. The result, W = 86, p = 0.0026, with an effect size of r = 0.55, indicates that the difference was statistically significant and practically meaningful, not merely a weak significance produced by a large sample size.

The arithmetic mean is calculated by summing all 120 symmetric ratio values and dividing the total by the number of observations. Thus, each ratio receives equal weight and contributes directly and proportionally to the total. The results showed that the arithmetic mean of the 120 symmetric ratios was 1.629, almost identical to φ. However, this mean did not represent most of the data. Two very large ratios, 11.25 and 11.67, increased the aggregate value. The median of 1.276 and the 10% trimmed mean of 1.348 provided a different picture. Therefore, the closeness of the mean to φ emerged through compensation between many low values and a few very high values.

This phenomenon is important in learning statistics and modelling. Students often regard the mean as a neutral summary. This dataset shows that the choice of statistic must consider the shape of the distribution. For ratio data, values of 2 and 1/2 indicate changes of the same magnitude but in opposite directions. After the ratios are made symmetric, extreme values can occur when one distance is very small. The geometric mean is more appropriate for summarizing multiplicative change because it operates on a logarithmic scale.

The results also emphasize the distinction between exploration and confirmation. Exploration may begin with the conjecture that a ratio is close to 1.618. Confirmation, however, requires a consistent pattern, correct variable definitions, explicit criteria for closeness, and analysis that is resistant to extreme values. One or several close samples are insufficient to assert a law of growth.

The context of water spinach is relevant because it is easily obtained, measurable, and produces data that are not constructed to fit textbook answers. In RME, a context functions as a source of mathematization, not merely as a story background (Van den Heuvel-Panhuizen & Drijvers, 2020). Concretely, students measure internode distances from 30 water spinach stems and construct consecutive distance ratios from D1–D2 to D4–D5, representing horizontal mathematization from physical measurement to a ratio model. From the 120 ratios obtained, students calculate the percentage error relative to φ and find that only 9.17% fall within a 5% tolerance. They then compare the mean (1.629) and median (1.276) to understand the skewed distribution. These data allow students to develop an understanding of ratios through real comparisons before moving toward percentage error, distribution, and inference.

The main value of the activity is not finding the golden ratio but testing a claim. Students learn to evaluate whether a numerical claim is supported by distributional evidence or merely by arithmetic coincidence. They are invited to compare D2/D1 with D1/D2 to understand that a ratio and its reciprocal cannot be used interchangeably. This error in the direction of variable definition is a common misconception in early statistical reasoning. Students then observe how a single data point, such as a ratio of 45/4, produces an extreme symmetric value of 11.25 that functions as a leverage point and shifts the mean disproportionately. By comparing the mean, median, and geometric mean within the same dataset, students build evidence-based arguments following the scientific argumentation structure of claim, evidence, and justification (Faizah et al., 2021): whether closeness to φ is a systematic pattern or an artefact of a skewed distribution. This process turns the activity from a mere computational exercise into a critical reasoning exercise with data.

Risdiyanti et al. (2024) found that RME-based ratio and proportion designs require contexts that support progressive modelling and strategic discussion. This study adds a context that produces non-ideal results. The irregularity of the data forces students to discuss measurement precision, biological variation, outliers, and the limits of generalization. This context is closer to scientific and modelling practice than tasks that always produce exact numerical answers.

Based on the results shown in Table 4, the activity was organized into five phases: (1) formulating the problem, (2) designing and testing the measurement, (3) processing the data, (4) testing the model, and (5) communicating the decision. Each phase connects inquiry practices with STEM components. The design can be used for ratio, statistics, or modelling topics at the Islamic junior secondary school level. The activity is planned for four meetings and may use rulers, simple calipers, scaled photographs, or measurement applications.

Table 4. Syntax of an inquiry-STEM activity based on water spinach data

Phase	Main activity	STEM integration	Guiding question	Achievement indicators
1. Formulating the problem	Students evaluate the claim that “water spinach leaf distances follow the golden ratio”	Science: stem morphology. Mathematics: ratio definition.	What variables must be measured so that the claim can be tested?	Students can transform a claim into a testable research question. Students can identify the variables that

Phase	Main activity	STEM integration	Guiding question	Achievement indicators
	and identify the required data.			must be measured.
2. Designing and testing the measurement	Groups determine measurement points, units, instruments, repetitions, and procedures for handling missing leaves.	Technology: AR Meter digital measurement tool. Engineering: protocol and calibration.	Do two observers produce the same data?	Students can prepare measurement steps. Students can conduct measurements appropriately.
3. Processing the data	Students calculate directional ratios, symmetric ratios, relative error, mean, median, and geometric mean.	Mathematics: ratios, percentages, and statistics.	Why do the mean and median tell different stories?	Students can calculate the directional ratio (D2/D1) and explain how it differs from its reciprocal (D1/D2). Students can correctly calculate relative error of a ratio with respect to φ.
4. Testing the model	Students create graphs, identify outliers, conduct a simple sensitivity analysis, and compare the results with φ.	Science: evidence and uncertainty. Mathematics: distribution and modelling.	Are several close values sufficient to state a general pattern?	Students can create graphs showing the distribution of ratios. Students can test whether there is clear evidence supporting the golden-ratio claim.
5. Communicating the decision	Groups write their claim, evidence, reasoning, limitations, and a plan for further measurement.	Integrated STEM: argumentation and design improvement.	What evidence can support or reject the group's conclusion?	Students can formulate a conclusion about the golden-ratio claim. Students can communicate their conclusions to other groups and respond to

Phase	Main activity	STEM integration	Guiding question	Achievement indicators
				other groups' conclusions.

This study provides three main contributions. First, it uses a popular but unconfirmed golden-ratio claim as an authentic context for learning ratios, measurement, and data-based reasoning. Second, the analysis distinguishes among directional ratios, symmetric ratios, mean, median, and geometric mean, showing how the choice of statistic can change the conclusion. Third, the negative result is translated into an inquiry-STEM design that positions uncertainty and model revision as part of mathematics learning.

Teles et al. (2024) demonstrated the potential of the golden-ratio theme for STEAM learning. This study complements that work by offering the methodological message that popular themes need to be tested and may be rejected. This approach supports an understanding of STEM as a process of seeking evidence rather than merely producing a product.

For future research in mathematics education, the next design should test the learning trajectory. Researchers may compare students' understanding of ratios before and after the activity, analyse students' strategies when determining the direction of ratios, and observe changes in their ability to evaluate claims. Design-based research can be used to refine guiding questions, table formats, and statistical scaffolding.

CONCLUSION

Data from 30 water spinach stems showed substantial variation in the five internode distances. Position D5 tended to be shorter than D1 to D4, but the change did not follow a fixed ratio. The arithmetic mean of the 120 symmetric ratios was 1.629, which appeared close to the golden ratio. However, this value was influenced by two extreme ratios. Robust measures produced a different result. The median ratio was 1.276, while the median stem-level geometric mean was 1.403, with a 95% bootstrap interval of 1.276 to 1.506. The Wilcoxon test showed a significant difference from φ. Only 11 of the 120 ratios were within a 5% tolerance. Sensitivity analysis led to the same conclusion. Therefore, the data do not support a consistent golden-ratio pattern in water spinach internode distances. The main contribution of this study is not the validation of the golden ratio but an empirical example of how ratio definitions, outliers, and statistical choices affect conclusions. The data can be used as an inquiry-STEM context for developing proportional reasoning, data literacy, and evidence-based argumentation. The effectiveness of the instructional design still needs to be tested empirically.

REFERENCES

Apriastuti, N. P. E., Putra, A. A. G., & Karnata, I. N. (2023). Respon pertumbuhan tanaman kangkung darat (Ipomoea reptans Poir.) terhadap dosis pupuk urea. 01(01), 45–49. https://doi.org/10.58878/jissiwirabuda.v1i1.186 [accessed July 1, 2026].

Ben-Chaim, D., Keret, Y., & Ilany, B. S. (2012). Ratio and proportion: Research and teaching in mathematics teachers' education. Sense Publishers. https://doi.org/10.1007/978-94-6091-784-4 [accessed June 20, 2026].

Bergeron, F., & Reutenauer, C. (2019). Golden ratio and phyllotaxis, a clear mathematical link. Journal of Mathematical Biology, 78(1–2), 1–19. https://doi.org/10.1007/s00285-018-1265-3 [accessed June 20, 2026].

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. *Journal of Research in Nursing*, *25*(8), 652–661. https://doi.org/10.1177/1744987120927206

Cao, X., Lu, H., Wu, Q., & Hsu, Y. (2025). Systematic review and meta-analysis of the impact of STEM education on students' learning outcomes. Frontiers in Psychology, 1579474(August), 1–15. https://doi.org/10.3389/fpsyg.2025.1579474 [accessed June 20, 2026].

Faizah, S., Rahmawati, N. D., & Murniasih, T. R. (2021). Investigasi struktur argumen mahasiswa dalam pembuktian aljabar berdasarkan skema Toulmin. AKSIOMA: Jurnal Program Studi Pendidikan Matematika, 10(3), 1466–1476. https://doi.org/10.24127/ajpm.v10i3.3781 [accessed July 2, 2026].

Godin, C., Gole, C., & Douady, S. (2020). Phyllotaxis as geometric canalization during plant development. Development. https://doi.org/10.17226/13165 [accessed June 20, 2026].

Hasler, O., Blaser, S., & Nebiker, S. (2020). Performance evaluation of a mobile mapping application using smartphones and augmented reality frameworks. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, V-2-2020, 741–747. https://doi.org/10.5194/isprs-annals-V-2-2020-741-2020 Hollander, M., Wolfe, D. A., & Chicken, E. (2014). *Nonparametric statistical methods* (3rd ed.). John Wiley & Sons.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70. https://doi.org/10.2307/4615733

Limpert, E., Stahel, W. A., & Abbt, M. (2001). Log-normal distributions across the sciences: Keys and clues. *BioScience*, *51*(5), 341–352. https://doi.org/10.1641/0006-3568(2001)051[0341:LNDATS]2.0.CO;2

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. The National Academies Press. https://doi.org/10.17226/13165 [accessed June 20, 2026].

OECD. (2022). PISA 2022 results (Volume I): The state of learning and equity in education: Vol. I. OECD Publishing. https://doi.org/10.1787/53f23881-en [accessed June 20, 2026].

Okabe, T. (2015). Biophysical optimality of the golden angle in phyllotaxis. Scientific Reports, 3–5. https://doi.org/10.1038/srep15358 [accessed June 20, 2026].

Okabe, T., Ishida, A., & Yoshimura, J. (2019). The unified rule of phyllotaxis explaining both spiral and non-spiral arrangements. Journal of the Royal Society Interface, 16(151), Article 20180850. https://doi.org/10.1098/rsif.2018.0850 [accessed June 20, 2026].

Prahmana, R. C. I., Sagita, L., Hidayat, W., & Utami, N. W. (2020). Two decades of realistic mathematics education research in Indonesia: A survey. Infinity Journal, 9(2), 223–246. https://doi.org/10.22460/infinity.v9i2.p223–246 [accessed June 20, 2026].

Revina, S., & Leung, F. K. S. (2019). How the same flowers grow in different soils? The implementation of realistic mathematics education in Utrecht and Jakarta classrooms. International Journal of Science and Mathematics Education, 17(3), 565–589. https://doi.org/10.1007/s10763-018-9883-1 [accessed June 20, 2026].

Risdiyanti, I., Zulkardi, & Putri, R. I. I. (2024). Ratio and proportion through realistic mathematics education and Pendidikan Matematika Realistik Indonesia approach: A systematic literature review. Jurnal Elemen, 10(1), 158–180. https://doi.org/10.1007/s11858-008-0125-9 [accessed June 20, 2026].

Royal Botanic Gardens, Kew. (2026). Ipomoea aquatica Forssk. Plants of the World Online. Retrieved June 14, 2026, from https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:268410-1 [accessed June 20, 2026].

Sembiring, R. K., Hadi, S., & Dolk, M. (2008). Reforming mathematics learning in Indonesian classrooms through RME. ZDM Mathematics Education, 40(6), 927-939. https://doi.org/10.1007/s11858-008-0125-9 [accessed June 20, 2026].

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3–4), 591–611. https://doi.org/10.1093/biomet/52.3-4.591

Strauss, S., Janne, L., Prusinkiewicz, P., Miltos, T., Smith, R. S., & Smith, R. S. (2020). Phyllotaxis: Is the golden angle optimal for light capture? New Phytologist, 499–510. https://doi.org/10.1111/nph.16040

Teles, N., Ribeiro, T., & Vasconcelos, C. (2024). Exploring the golden ratio in nature by using a STEAM approach: A diagnostic and quasi-experimental study. Education Sciences. https://doi.org/10.3390/educsci14070705

Van Den Heuvel-Panhuizen, M., & Drijvers, P. (2020). Realistic mathematics education. In S. Lerman (Ed.), Encyclopedia of mathematics education (2nd ed., pp. 713-717). Springer. https://doi.org/10.1007/978-3-030-15789-0_170 [accessed June 20, 2026].

Wibowo, H. Y., & Sitawati. (2017). Respon tanaman kangkung darat (Ipomoea reptans Poir.) dengan interval penyiraman pada pipa vertikal. Plantropica: Journal of Agricultural Science, 2(2), 148–154. https://jpt.ub.ac.id/index.php/jpt/article/view/142 [accessed June 20, 2026].

Yin, X., & Tsukaya, H. (2022). Fibonacci spirals may not need the golden angle. Quantitative Plant Biology, 3, Article e13. https://doi.org/10.1017/qpb.2022.10 [accessed June 20, 2026].