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Zoological Evidence for Pythagorean Theorem in Animal Morphological Design

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Abstract: The Pythagorean Theorem, a foundational principle in mathematics, asserts that in a right-angled triangle, the square of the hypotenuse is equal to the combined squares of the two shorter sides. Over 350 proofs exist for this theorem, with notable contributions from Euclid, Albert Einstein, and U.S. President James Garfield. An Indian mathematician Bhaskaracharya provided an early visual proof of the Pythagorean Theorem through the rearrangement of triangles and squares. However, to the best of our knowledge, there has been no previously reported biological evidence supporting the Pythagorean Theorem. This study is the first of its kind to explore, experiment, and demonstrate the inherent presence of the Pythagorean principle in biological systems through their morphological and anatomical features. We examined two invertebrate and two vertebrate specimens for patterns consistent with right-angled triangles. Morphometric measurements of anatomical landmarks revealed configurations that satisfy the Pythagorean relationship, where the square of the hypotenuse closely matches the sum of the squares of the other two sides. This study may thus provide the first direct biological evidence supporting the Pythagorean Theorem.

Keywords: Pythagoras theorem, Biological evidence, *Scylla serrata, Calotes verscicolor,* Asian toad, *Duttaphrynus melanostictus,* Crucifix crab*, Charybdis feriata*

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Introduction

Pythagoras theorem is a core geometric principle in mathematics. It was given by a Greek mathematician Pythagoras (ca. 570 BC–ca. 495 BC) (Saikia, 2013). There are evidences that this concept was given prior to Pythagoras by other mathematician such as Bhaudanya, an Indian mathematician, and also was explored and used by Egyptians, Babylonians, and also by Chinese (Gupta, 2021). However, for unknown reasons, it was credited and named after this Greek mathematician, Pythagoras. According to this theorem, the square of the hypotenuse of a right-angled triangle is equal to the sum of the squares of its two legs, mathematically represented as $\boldsymbol{a^2 + b^2 = c^2}$**.** In ancient Egypt, surveyors referred as "rope stretchers" employed the 3:4:5 triangle ratio to form right angles while measuring land or erecting structures, using ropes with evenly spaced knots (Robert, 2003). There are approximately 370 proofs which were collected and preserved in a book by Loomis (1968). Among these, the first, pictorial or graphical proof of Pythagorean Theorem was presented by Indian mathematician Bhaskaracharya. His method involves arrangement of 4 right angled triangles around a small square, which is closely represented in the sacred Sri Chakram, one of the most divine symbols of Hindu religion, which has 43 interlocking triangles (Kavi, 2023). Apart from this, there are several evidences provided by different authors of which Euclidian proof, Albert Einstein proof, and James Garfield proof, who was the 20th US president are the famous ones (Nurul *et al.*, 2017). Although there are approximately close to 400 proofs for Pythagoras theorem, so far there has not been a single direct biological evidence to prove Pythagoras theorem. In this regard the present study has been attempted to study, learn and prove if this theorem in real time, can be applied to diverse living systems, either in their morphological or anatomical features.

Materials and Methods

To explore this well-known mathematical concept, various live animal models were studied. Invertebrates were obtained from a local animal market, while the vertebrate specimens, a toad and a calotes, were deceased and collected from the university campus. This study involved no harm to any living animals. Only naturally deceased or market-sourced specimens were examined. The species studied included invertebrates -- crabs (mud crab-- *Scylla serrata* and crucifix crab-- *Charybdis feriata*), as well as vertebrates-- the common Asian toad (*Duttaphrynus melanostictus*) and the garden lizard (*Calotes versicolor*). The animals were carefully positioned on a dissection tray, and morphometric measurements were taken using a metric ruler. Measurement sites varied by species: in the toad, the distance from the tip of the head to the origin of the forelimb was recorded; in the crabs, measurements were taken from the origin to the tip of the first appendage; and in *Calotes*, the distance between the forelimb and hind limb was measured. Imaginary lines were drawn to form right-angled triangles, and the side lengths were measured.

Results

In the present study, both invertebrate and vertebrate animals were chosen to demonstrate the presence and existence of right-angled triangles in their morphological and anatomical body design. Imaginary lines were drawn from the origin of first appendage, extending diagonally till the end of the first appendage. These lines clearly formed a right-angled triangle, indicating the presence of a consistent morphological pattern that appears to comply with the measurements described by the Pythagorean Theorem. An online square root calculator was used for calculating the square roots (http://www.math.com/students/calculators/source/square-root.htm).

In Figure 1, three points have been identified as forming the right angled triangle. AB represents one leg, BC denotes the base, and AC is the hypotenuse of the triangle. Point A joining the point C i.e. origin of the base of the appendage known as the merus forming a L shaped structure with merus and propodus, at the point A. The measurements were taken from the ventral side are as follows:

AB= a= 5.5 cm, BC= b=3.5 cm and AC=c =6.5 cm

According to Pythagoras theorem, $a^2+b^2=c^2 = (5.5)^2 + (3.5)^2 = (6.5)^2$

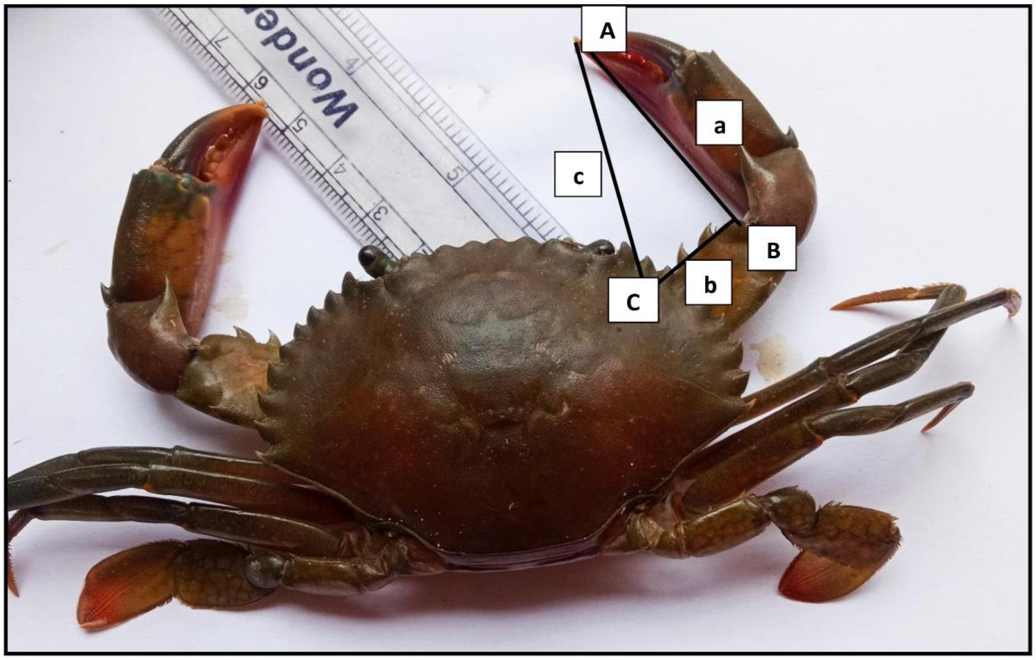

Fig. 1: *Scylla serrata.*

30.25+ 12.25= $(6.5)^2$ or can also be represented as $c = \sqrt{a^2 + b^2}$

$6.5 = \sqrt{42.5}$

$42.5 = (6.5)^2$

This $(6.5)^2$ if we bring the squaring to the left hand side, it will be becoming square root of 42.5, square root of 42.5 = 6.51

$\sqrt{42.5} = 6.5$

6.5 cm= 6.5 cm

Therefore the square of the other two sides = square of the hypotenuse

Hence proves Pythagoras theorem.

It has been calculated in the same way for all the examples.

Similarly in Figure 2, the sides were measured where a right angled triangle is formed in the arrangement of first appendage.

The Side AB=a= 9.5cm, BC=b= 6.5cm and AC=c= 12 cm

According to Pythagoras theorem, $a^2+b^2=c^2$

$= (9.5)^2 + (6.5)^2 = (12)^2$

$90.25 + 42.25 = (12)^2$

$\sqrt{132.5} = 12$

11.51 cm=12 cm

This is very close to the hypotenuse value. Therefore Pythagoras theorem proved.

In Figure 3, the measurements were taken on the toad, from the tip of the head to the origin of forelimb. These are as follows:

AB=a= 4.5 cm, BC= b=2.5 cm and AC=c= 5 cm

$=(4.5)^2 + (2.5)^2 = (5)^2$

$\sqrt{20.25+6.25} = 5$

5.1 cm= 5 cm

As the square of the two sides are equal to the hypotenuse, Pythagoras theorem is proved.

In Figure 4, the measurement between the points of origin of the forelimb and hind limb were

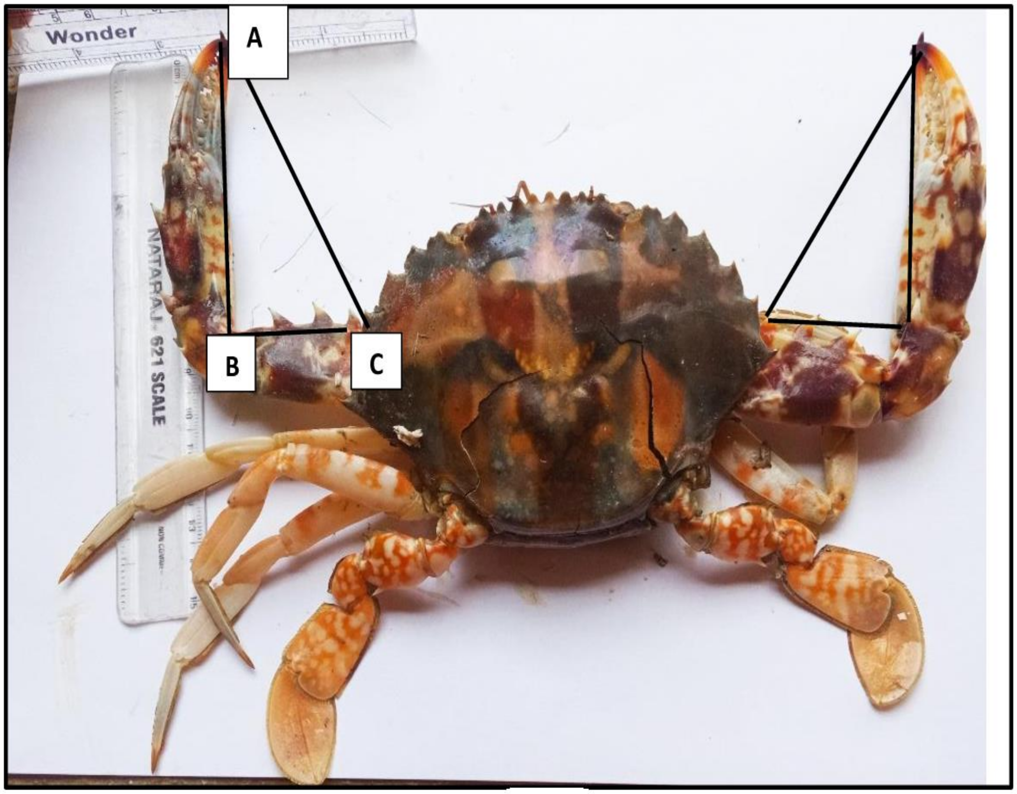

Fig. 2: *Charybdis feriata* (crucifix crab).

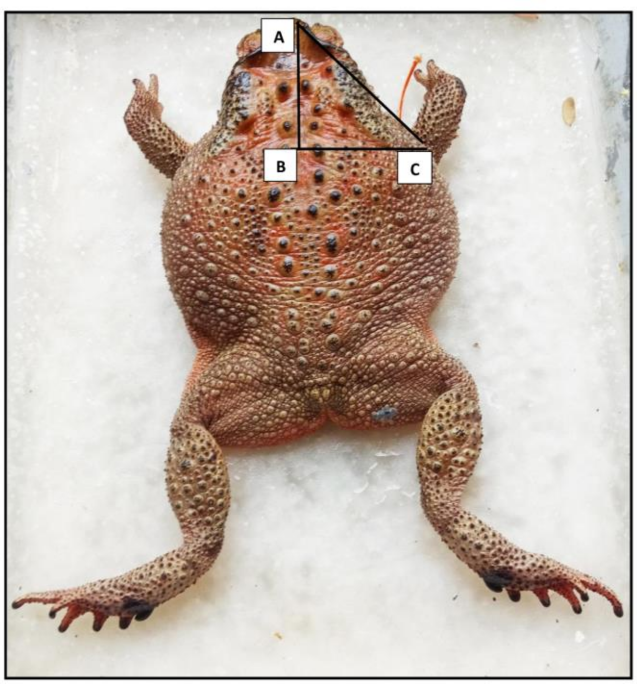

Fig. 3: *Duttaphrynus melanostictus.*

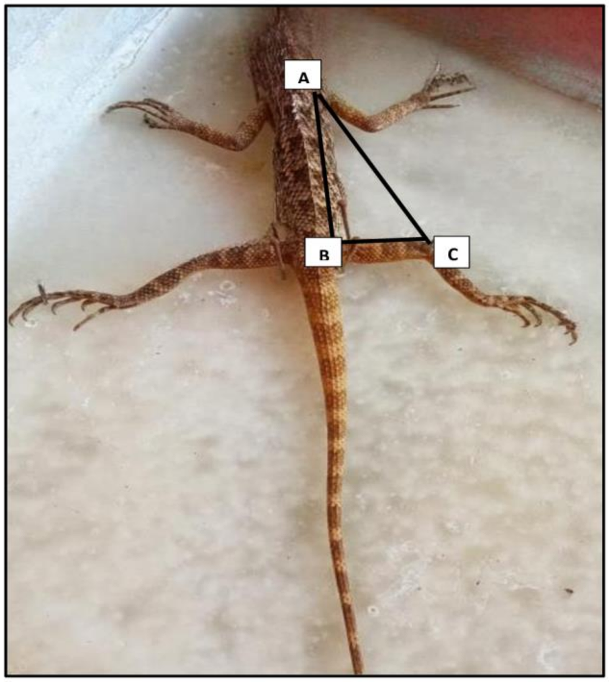

Fig. 4: *Calotes versicolor.*

examined, A right angled triangle be easily envisioned between these two limbs. The measurements are as follows:

AB= a= 2.5 cm, BC=b= 2 cm and AC= c= 3.2 cm

According to Pythagoras Theorem, $a^2+b^2= c^2$

$= (2.5)^2+ (2)^2 = (3.2)^2$

$6.25+ 4 \quad = (3.2)^2$

$\sqrt{10.25} =3.2$

3.2 cm=3.2 cm

Since the hypotenuse is equal the square of other two sides, hence proves the Pythagoras theorem.

Discussion

In the present study, some selected invertebrate and vertebrate animal models were used to illustrate the presence of Pythagorean principles in the construction of body design. As illustrated in the results, section, it was quite clear of the presence of right angled triangle in the construction of anatomical body parts. The values which were calculated are coherent with the Pythagorean Theorem, validating that the hypotenuse squared equals the sum of the squares of the two sides (Figs. 1, 2, 3,4). To the best of our knowledge, this is the first report providing direct biological evidence supporting the presence of Pythagorean principles in natural anatomical structures. Although direct evidence is limited, the construction of anatomical structures in animals appear to conform to the principles of the Pythagorean Theorem. In hydrostatic skeletons, muscles arranged at right angles to each other provide structural support and facilitate movement. This arrangement allows for efficient locomotion and stability in various animal species (Yekutieli *et al*., 2009). The other advantages of having a right-angled position of head versus fore limbs and forelimbs versus hind limbs may be attributed to ensures the body's weight is transmitted vertically through the bones to the ground, reducing stress on joints, and this positioning helps support the heavy head and trunk during locomotion (McNeill, 2003). Additionally this positioning seems to minimize lateral movements that waste energy, and also provides a mechanical advantage by allowing muscle force to act in straight lines, conserving energy during repetitive movements (Taylor *et al.*, 1982).Therefore, the origin and evolution of these anatomical positions may offer significant advantages to animals, particularly in reducing mechanical stress and conserving energy during movement. This functional design has also inspired advancements in robotics, where right-angled limb configurations simplify joint construction, enhance manufacturability, and enable modularity making robotic limbs easier to assemble, repair, and upgrade (Siciliano and Khatib, 2016). Based on these observations, it is evident that the spatial arrangement of the forelimbs relative to the head, the distance between forelimbs and hind limbs, and the development of appendages especially in arthropods often align along right-angled paths. Therefore it may be said that, there seems to be an inherent structural design which seems to adhere to the principle of Pythagoras theorem, but may not be quite obvious, but when observed closely it reveals these unique right-angled patterns, in nature. We concluded that this may be the first instance of biological or zoological evidence supporting the Pythagorean Theorem demons-trated in animal systems.

Conclusion

In the present study, selected invertebrate and vertebrate animal models were examined to demonstrate the natural occurrence of the Pythagorean principle in their anatomical structures. By drawing and measuring imaginary lines corresponding to right-angled triangles within the body design, it was observed that the square of the hypotenuse was equal to the sum of the squares of the other two sides. This finding confirms the presence of the Pythagorean Theorem in animal morphology. Although only a few examples were explored in this study, future research will aim to extend the investigation to internal anatomical structures and a broader range of animal models.

Ethical Statement

Authors declare that no animal was harmed in this study. The animals which were used for the present study were dead ones found in the university campus. No animal was intentionally euthanized for the study.

Author Contributions

Each author has contributed equally to the study's planning, analysis, writing, and editing. They collaborated in designing the research, conducting thorough analysis, drafting the manuscript, and refining its content. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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