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From Algorithms to Inquiry: Reintroducing Geometric Constructions through Indian Knowledge Systems

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ABSTRACT

Until the year 2023, geometric constructions were part of the mathematics textbooks published by National Council of Educational Research and Training (NCERT). In order to cut down the breadth of the curriculum this segment was completely removed in 2023 from the NCERT Mathematics textbooks. In this paper, we will share a decade-long experience of integrating ideas from the history of mathematics from Indian Knowledge Systems using inquiry, higher order thinking skills and hands-on learning. We also highlight how the topic can be re-introduced under the light of using ideas from Indian Knowledge Systems and incorporating guiding principles by National Education Policy (NEP) 2020.

Introduction:

"I am interested in Mathematics only as a creative art."

~ A Mathematician's Apology, G. H. Hardy

The importance of having good foundations of Mathematics from early years in school is already established in the mathematics education research. Yet, it remains as one of the subjects that many students find it difficult to grapple with. One of the most challenging aspects in Mathematics education is

to make the subject more meaningful, relatable and exciting for the students. Mathematics learning in the school is often restricted to learning procedures and assessments tests often check the understanding of procedural skills of the students. While procedures are necessary for us to use Mathematics in everyday life, teaching mere procedures does not help in developing Mathematical thinking in students. Moreso, it creates a boredom in students to pursue tasks that doesn't seem to be meaningful for them in real-life (Gainsburg, 2008). It is here that Mathematics educators, curriculum developers and teachers have to bring in activities that students will not only enjoy but will also find some motivation and meaning to pursue. If they understand why they are doing and what they are doing in Mathematics, the subject can become more appealing to them.

In this paper, we focus on the topic of geometric construction – a topic that is often being neglected and was completely removed from the National Council of Educational Research and Training (NCERT) textbooks in 2023 – and how ideas from Indian Knowledge Systems on geometric constructions can help students love the topic through inquiry and experiential learning. We will share teaching-learning experiences of integrating history of Indian Mathematics into the classroom through hands-on activities in geometric constructions. These experiences and pedagogy can be useful for textbook writers as well as mathematics teachers in making mathematics more engaging and experiential.

Geometric Construction in NCERT Mathematics textbooks:

In the National Council of Educational Research & Training (NCERT) textbooks, geometry is taught from primary classes from introduction to circles, shapes, angles and so on all the way up to Euclidean geometry and proofs in grades 9 and 10. Until 2023, students in the middle school were learning how to use instruments like the compass, set square, protractor, etc. to do geometric constructions. However, most of the activities directly jumped into the task in hand without providing any motivation to perform the activity (Grade8, 2007). For instance, the process of constructing a perpendicular bisector was focused but the lesson never focused on the purpose to learn or the rationale behind the construction procedure of a perpendicular bisector (Grade6, 2007). Like most of the parts in Mathematics curriculum, the construction activities focused on procedures and not the need to know the procedures or how did people come up with these geometric constructions.

Ideas for Geometric Constructions from Indian Knowledge Systems (IKS)

One of the commonly asked questions by students when they learn concepts in Mathematics is – Why do they have to learn it? Where do we apply this in real-life? In simple words, they are looking for a purpose

or a motivation to learn something. When students are unable to find it, they feel learning Mathematics as a pointless pursuit. Thus, it is extremely important to convert the content in such a way that students find either an application, a purpose or a motivation to pursue the learning. It is here that one can find ideas from IKS that can be brought into modern day classrooms to give a purpose and a motivation to learn various topics in mathematics, and in the context of this paper, in geometric constructions.

Some of the oldest available texts on geometric constructions from ancient India are the Sulba Sutras (Datta, 1932). There are seven known Sulba Sutras written across different periods of time starting from Baudhayana Sulba Sutra, written by Bodhayana, which is estimated to be during 800 BCE or earlier (A. K. Dutta, 2016). The Sulba Sutras come under a broader treatise called Kalpam which is one of the six Vedangas. Kalpam dealt with rituals, laws and duties. Some of the rituals involved construction of fire altars which were made up of geometric shapes. Back in those days, people from the Indian subcontinent had come up with an ingenious multipurpose instrument for geometric constructions – a rope! To draw a circle, a rope was used. Using circles, a square was constructed. They also came up with ways to construct a regular hexagram, cut a circle into six, eight, twelve and sixteen equal parts just using circles and arcs. They also discussed about constructing a square whose area is the sum/difference of two unequal squares, transforming a rectangle into a square of the same area and geometrically finding the value of square root of 2. All these geometric constructions were motivated by a real-life application which was the construction of fire altars.

Apart from Sulba Sutras, there were many treatises on Yantras which contained mystic diagrams of geometric shapes which had mystic symbols, mantras, letters and numbers and were used for worship, meditation and rituals. Some of the geometric constructions in Yantras also form good source for content to be taken to the classroom from a mathematical perspective.

Coming to textbooks until 2023, when geometric constructions were discussed in the NCERT textbooks of grades 6 to 10, it directly started with procedures for doing geometric constructions and completely lacks the motivation to do it. It is but natural if students found this process very dry and many would lose interest in the topic. However, if we can leverage on the opportunities that lie in topic of geometric constructions like inquiry, hands-on activities, etc., and create excitement by giving students a purpose of doing these constructions, then we have an opportunity to getting students develop a liking towards the subject. This is where we can draw ideas from IKS.

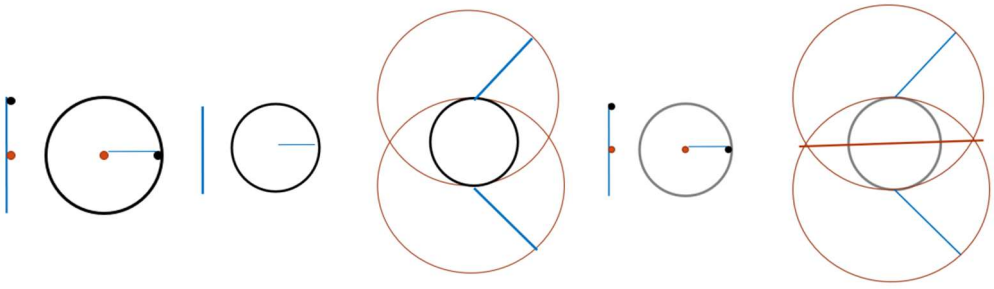
During 2012 to 2024, the principal investigator of this paper has tried using those ideas during Math camps where students were asked to try doing various geometric constructions using a rope on an open ground. Initially, the students are asked to put themselves in the shoes of their ancestors who lived more than 2500 years ago and who did not have access to modern day instruments for geometric constructions, not even a scaled ruler. In such a scenario, how do you (the students) think they would have constructed a circle? Multiple answers come up in the class such as, using a stick and turn it around, two people holding hands where one person is at the centre and the other person going around that person and some would say, use a rope as radius to go around a fixed point. When asked which is the next common shape that could have been commonly used, they come up with multiple answers one of which being a square. In the following paragraphs, we show the pedagogy used in the class to let students explore and learn the construction procedures from the Sulba Sutras and other texts from Indian Knowledge Systems.

Activity 1: Constructing a Square

The students are asked how to construct a square with a rope. Most of them struggle and rarely do they succeed in doing a proper geometric construction using a rope. They are then introduced to the below method of constructing a square using intersecting circles as explained in the Baudhayana Sulba Sutra.

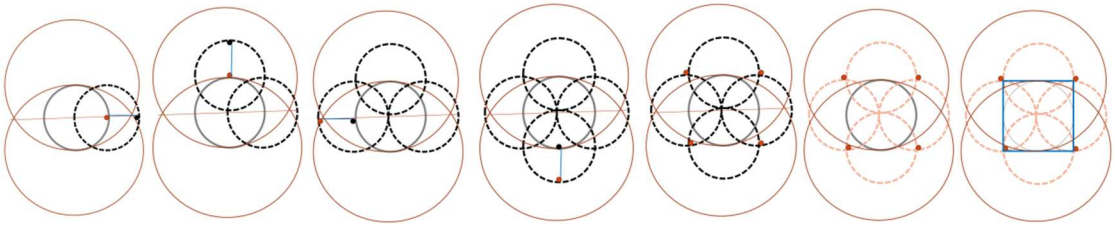
After having tried and failed to construct a perfect square with a rope and no other instrument, they truly appreciate the genius construction method by Bodhayana. However, they are clueless why the method is so complex. The teacher then takes it step-by-step and asks the students what Bodhayana might be doing at each step:

Figure 1: **Procedure to construct a square in Baudhayana Sulba Sutra**



They slowly start seeing how an extended diameter (the horizontal line) is being constructed using circles.

Figure 2: **Continuation of the procedure to construct a square**



By the end of the construction, they have analysed the procedure, evaluated if there are inconsistencies, placed their arguments and integrate the steps to create the square. Thus, they end of using higher order thinking skills – Analyse, Evaluate and Create (Krathwohl, 2002) – explained in the revised Bloom's taxonomy. how drawing multiple circles has led to identifying four points in four directions (north east, north west, south west and south east) from the center that become the vertices of a square. After they try it out in their notebook, they are taken to an open ground to perform the construction just as Bodhayana or people of his time would have done – using a rope. The students are then split into small groups and they get to do the geometric constructions on a bigger canvas – the open ground.

Picture 1: **Students constructing a square using a rope during a workshop**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Picture 2: **Students constructing a square using a rope during a workshop**

Activity 2: Constructing a Hexagram (R.C.Gupta, 2007)

Figure 3: **Hexagram**

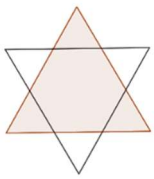
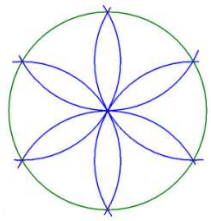


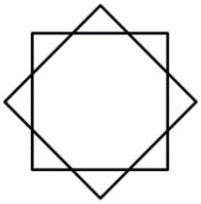
Figure 4: **6-petalled flower**



Initially, the students start by trying to draw an equilateral triangle using estimation. After some handholding, some students figure out a way to construct an equilateral triangle using arcs. But the challenge they encounter is to draw the second equilateral triangle which will align with the first one to make a perfect hexagram. Through peer group discussions, the students understand that if they can get the six vertices of the hexagram, then they can draw the hexagram. An activity of drawing a 6-petalled flower-like design gives them an understanding of how circumference of a circle can be cut in 6 points equidistant from its neighboring points. The 6-petalled flower thus leads to the construction of a hexagram. The students who would have fiddled with a compass earlier and drawn a 6-petalled flower-like design intuitively come up with the idea. Here, they are connecting the activity to a previous activity where they use the higher order thinking skill like analysis.

Activity 3: Constructing a Octagram (R.C.Gupta, 2007)

Figure 5: Octagram



Rotating squares or constructing octagrams enable students learn properties in circles, angles measuring 45 and 90 degrees, squares inscribed in a circle. When they are shown the figure and asked to construct, they come up with more than one way of constructing this image.

Picture 3: **Students constructing an Octagram during a workshop**

More Activities:

After the initial tasks of constructing geometric shapes, they are given activities from Sulba Sutras that also lead to geometric representation of Pythagorean Theorem using constructions like constructing a square whose area is sum/difference of two unequal squares.

Picture 4: **Students constructing a square whose area is difference of areas of two unequal squares**

While the hexagram and octagram were more intuitive, the abovesaid construction is not intuitive. But the activity leads them to analyse and connect the dots with something that they have already learnt – the Pythagorean Theorem – and their understanding becomes better when they have to perform the construction on the ground and explain why they did each of the steps. The students enjoy doing this activity on the ground and are fully engaged in discussions and debates while performing these constructions. Their understanding also is deepened because they are not only doing the activity hands-on but also minds-on. After the activity, the teacher can also explain the proof behind the construction method.

In one of the sessions, the students were asked to prepare clocks based on their understanding of geometric constructions. While engaging in the activity, they had to practically implement their learning especially for constructing angles of 30, 60, 90 degrees, construction of equilateral triangles, hexagram, etc. Not only were they able to do it successfully, they thoroughly enjoyed doing the activity and kept asking for more such activities.

Picture 5: **Clocks constructed by the students using a rope and a pen**

Findings:

1. Generally, when students learn methods of construction, they learn it as a process without understanding the rationale behind it. Using the above constructions from IKS and the pedagogy involving hands-on learning, students feel more confident of the concepts and their understanding is better.
2. Generally, to show the Pythagorean Theorem using a figure, students are shown three squares formed on the sides of a right angled triangle (typically of sides 3,4,5). Construction methods in Sulba Sutras of creating a square that has area of sum/difference of two unequal squares reinforces the idea and application of Pythagorean Theorem through a different image.
3. Students find a motivation, purpose to learn geometric constructions along with the rationale for all the rules and thereby finding mathematics more meaningful.

Conclusion:

While there could be constraints for covering the topic of geometric constructions in limited timeframe of discussing mathematics in school, we cannot overlook the advantages of teaching and learning geometric constructions using ideas and topics from IKS.

1. The activity of geometric constructions using ideas from IKS also brings in inquiry and higher order thinking to the classroom.
2. IKS is a rich repository of knowledge that existed in India and transmitted to the rest of the world in the past thousands of years and it is extremely important that the students of today are aware of it (NEP, 2020) (NCF, 2005). These activities help students appreciate the origin of geometric constructions through humble means and the ingenuity behind all the procedures. It also helps them appreciate the genius minds who came up with the algorithms thousands of years ago.

3. Geometric constructions offer a lot of scope to get students actively engage in an activity which is far from abstraction. Thus, it is a topic that can build confidence in a student in Mathematics.
4. The ideas from IKS can be used to fit into modern day contexts like the activity of constructing clocks or creating a geometric rangoli or kolam on the ground which the students will find joy in.
5. Students get a geometric approach to understand algebraic identities and Pythagorean Theorem in ways that are different from what they have been introduced in the school.

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