PROJECT AAKAAR

Education aids for visually impaired students to study geometry

National Institute of Technology, Warangal

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1 INTRODUCTION

Project Aakaar is an attempt to help visually impaired (VI) students gain a fundamental understanding of geometry and inspire them to practice the subject.

We have carefully designed a set of puzzles called Tactile Tangrams where standard shapes like triangles, rectangles, and semi-circles are to be combined to give a 2D representation of compound shapes. These puzzles connect simple shapes with complex structures of famous monuments. Aimed for VI students at the elementary school level, Tactile Tangrams are a fun way to infuse an intuition for geometry at a tender age. Further, we have designed a construction tool called Hexacompass, which is a VI-friendly tool for angle measurement and construction.

All these tools are 3D printable, which makes them easily accessible and self-manufacturable, with the use of desktop 3D printing, a technology that is becoming more commonplace every day. In this document, we have described our motivation and design process so that people with similar interests can not only use these tools but also contribute to the project with hopes to expand the toolkit to make geometry a more VI-friendly class.

2 ABOUT THE TEAM

Project Aakaar began as an *Engineering Project in Community Service* (EPICS) at NIT Warangal, India, when three junior engineering undergrads, Sarthak Kapoor (Materials Engineering), Shantanu Landore (Mechanical Engineering) and Daksh Parmar (Biotechnology), came together with an objective to improve education in geometry for the visually impaired (VI) students. The team has been mentored by Dr. Kyle Keane[2] since the very beginning in February 2019.

With a vision to transform education in geometry for the VI by designing appropriate educational aids, Aakaar aims to increase the participation of VI students in the field of STEM.

3 MOTIVATION

Vision is the most dominant among all our senses. According to an article[3], up to eighty percent of our perception and learning has some link with vision. Vision plays an important role in self-learning as we grow up and observe the environment[4]. Much of this self-learning forms the basis of understanding the subjects we encounter in schools. For example, as students with typical sight, we were not explicitly told that a cylindrical pillar appears like a rectangle when seen from a certain

[2] Dr. Kyle Keane is a lecturer at MIT in EECS Department. He has years of experience in assistive technology and also teaches a transdisciplinary course called 'Principles and Practices of Assistive Technology'.
[3] 'Vision Disturbance after Traumatic Brain Injury' by D. Ripley and T. Politzer (2010)
[4] 'Effects of early experience on children's recognition of facial displays of emotion' by SD Pollak and P. Sinha (2002)

distance, or that the projection of a spherical ball is nothing but a circle, something that we understood intrinsically.

On the other hand, for children with visual impairment, this natural perception that is triggered by the visual system becomes a luxury they do not have. As a result, many of them need more time and effort to understand concepts like geometry, where just chalk-and-talk pedagogy is inadequate.

According to Kartik Sawhney[5], who is a disability advocate and technologist, one of the five problems that keep VI students away from STEM subjects is the scarcity of resources providing for a solid conceptual understanding of STEM for the blind. We found this problem substantiated by our experience at the schools for the blind in case of geometry, a subject that became our point of focus for the project.

During our interview with one of the Teachers for Visually Impaired (TVIs) at Devnar School for the Blind in Hyderabad, India, we understood that not only it was difficult for the VI students to grasp the concepts of geometry, but it was also challenging to teach the same (read the whole conversation in Appendix A). While the students in the school used tactile templates to touch and register shapes, there was a lack of tools that established a relationship between different shapes and connected geometry with the observable world. Thus, there was no means to bring a natural intuition for the subject that could form the basis of a formal course in geometry.

The problem is further compounded in schools where teaching aids and appropriate infrastructure are at a bare minimum. During our visit to Louis Adarsh Blind School in Warangal, India, which is a charity-run school in a dilapidated condition, we couldn't find tactile teaching aids or even sufficient amounts of braille-printed books. This is the case with many of the schools for the blind in developing countries like India which have large populations of VI students (at least 200,000 in India alone[6]).

We realized a need for easy-to-procure educational aids to help understand relationships among/between geometric shapes and the environment, and have the potential to be used for practicing geometry. We set the following parameters necessary for the designs to accomplish the objective:

1. The designs should be easily 3D printable so that anyone with the CAD (Computer Aided Designs) files and access to even a low-quality 3D printer can print them.
2. These aids should not go beyond the scope of the curriculum, rather supplement the topics in the curriculum.
3. The designs should be easy to understand and tickle curiosity and imagination in the user.

[5] 'STEM Access for the Blind and Visually Impaired' by Kartik Sawhney. https://stanford.edu/~kartiks2/stem-access.pdf

[6] 'Childhood blindness in India: causes in 1318 blind school students in nine states' by J.S. Rahi, S. Sripathi, C.E. Gilbert, A. Foster. https://doi.org/10.1038/eye.1995.137

4 CURRENT TECHNOLOGY

Before we initiated our designing process, we surveyed existing tools and technology to identify helpful techniques in bringing viable solutions to teach geometry. Many of these technologies are being successfully implemented in resource-rich developed countries, but are either too expensive to be used in developing countries like India, or still in the prototyping stage (eg. refreshable tactile displays).

We realized that the identified challenge required designing and fabrication from scratch as none of the tools we came across could be directly used for the given purpose in the given setting of classrooms. Nonetheless, we thought it would be helpful to present here a list of the same for future reference.

4.1 GRAPHICAL TACTILE DISPLAYS FOR VISUALLY-IMPAIRED PEOPLE

1. Non-refreshable Graphics: These are tactile displays that permanently portray a specific design. For example, tactile maps.
2. Refreshable Displays: These are screens filled with actuators that change as in/out according to computer input. The arrangement of the actuators states can be changed to display new tactile images.
3. Virtual Screens or Dynamic Displays: These are refreshable displays with a smaller size of the actuators that are controlled using vibrations.

4.2 GEOMETRY TOOLS FROM AMERICAN PRINTING HOUSE[7]

1. Geometro (set of manipulative)
2. inTact sketch pads and Draftsman (tactile drawing boards)
3. Braille Large Print Protractor
4. Geometric Forms

4.3 GAMES USED IN EDUCATION

1. Fisher Price Matchin Middles Oreo game
2. Fittle (created by LV Prasad Eye Institute)

[7] Link for the website: https://www.aph.org/educational-resources/tactile-literacy-tools/

5 OUR TAKE ON DESIGNING TEACHING AIDS FOR GEOMETRY

From our experience at the school for the blind, we identified a need for tools that explained concepts of basic geometry in an attention-grabbing manner (concept building), and gave independence to the students to practice geometry (construction). As we brainstormed around these two ideas, we realized that not only they called for two different types of tools, but also applied to two different age groups of students. Therefore, we worked on the ideas exclusively and designed concept building tools for the VI students of classes 3-5, and construction tools for students of classes 5-8.

5.1 CONCEPT-BUILDING TOOL: TACTILE TANGRAM PUZZLES

In the initial few months, our primary focus was on designing concept building tools and began exploring various ways to explain abstract concepts of geometric orientations and features. We were fascinated by and eventually sold on the idea of using games as a fun way of learning geometry. Games are known to make significant contributions to learning. Not only they open our minds to new possibilities, but they also lead to better retention of knowledge explicitly or implicitly imparted by them[8].

Computer and mobile games have shown immense promise at improving the cognitive abilities of students and supplement formal education. While this concept has an immense outreach in today's time of technology, it is rather less appropriate for the students who rely greatly on touch to gather information. For our educational aids to teach geometry, we needed something tangible and fun to work with, and at the same time with scalable outreach in a developing country like India.

Tactile puzzles have been used in the past to make educational tools for VI students. Fittle[9] puzzles designed by LV Prasad Eye Institute in Hyderabad is a fine example. We settled on designing tactile puzzle games for concept building tools as they gave us the space to experiment and find a balance between ease of use and the amount-cum-complexity of knowledge imparted using them. Throughout the design process, an unspoken rule of keeping the designs minimal and easy to 3D print was always followed. This was to ensure that they could be printed with a low-quality 3D printer without an expert operator.

Our initial idea was heavily inspired by Tangrams, which are old Chinese puzzles where seven different standard shapes are put together to form shapes of various common objects. We implemented something similar where few standard shapes would come together and fix together using pins to form common objects. The thought was to elucidate how simple shapes can be

[8] 'The Effect of Using Educational Games in Teaching Kingdoms of Living Things' by M. Selvi and A.O. Cosan
[9] Link to the website: http://fittle-project.com/

combined to represent a simplified version of real-world objects. In our particular puzzle, part of a boat like sail and deck are represented using triangles (see Figure 1).

Figure 1. Boat puzzle with simple shapes as joining pieces

But as we printed the boat puzzle, we realized a few issues with the design. One, using pins to join the pieces didn't give reliable joining. This was because the printing of the complementary grooves used supports which, when removed after the print, resulted in dimensionally inaccurate grooves with rough internal surfaces. Another problem was from a usability point of view. Since there was nothing like a physical template that explained what the final result should look like, it could be rather confusing for a VI person to arrange the pieces correctly.

To overcome these two issues, we modified the design and added a base plate that has the required final shape engraved on it (see Figure 2). It provided a more convenient way of completing the puzzle where the final goal could be touched and felt, and the pieces could be put accordingly into the groove. Moreover, the use of grooved templates eliminated the need for pins to join the pieces together. As the thickness of the pieces exceeded the depth of the groove, the resulting figure after populating the grooves correctly would be raised, giving good tactile feedback of the final result.

With our idea ready for designing the concept building tools, we moved forward to make various sets of puzzles that have some connection and fall under a common category. Eventually, we designed what we now call the **Geometric Theme** and **Monument Theme**, each having four puzzles.

For each theme set, we have designed a 3D printable box that holds together the base plates and the fitting pieces. Read more about the box in Section 6.3.

5.1.1 Geometric Theme

Under this theme, each of the four base plates is engraved with a rectangle, an isosceles triangle, an equilateral triangle, and a parallelogram respectively. Here the fitting pieces are two equal right-angled triangles. The final goal is to orient the pieces such that they fit into the given base plate. For example, for completing the 'rectangle' puzzle, the triangles are to be oriented such that their hypotenuse touch.

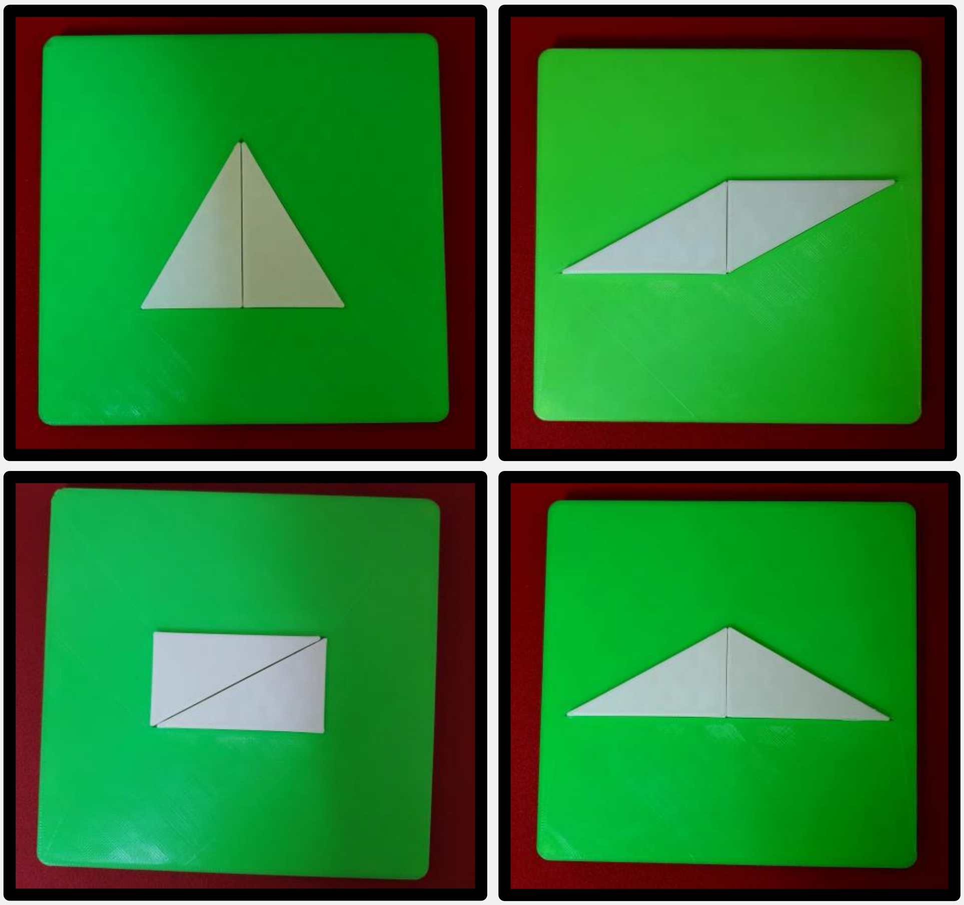

Figure 2. Set of puzzles in Geometric Theme; two equal right-angled triangles are used to complete all the puzzles.

Geometric theme of puzzles aims to work on the following objectives:

1. To understand the difference between different sides of the right-angled triangle
2. To create an intuition for how orientation plays a vital role in making meaningful relationships between shapes.

The exercise turned out to be fun and somewhat challenging for the VI students from class 5 who played with these puzzles. The fact that they could and must flip the fitting pieces when going from one shape (base plate) to another was challenging for them to come by.

5.1.2 Monument Theme

The monument theme includes four base plates each containing tactile images of the Taj Mahal, Leaning Tower of Pisa, the Pyramids of Giza, and Eiffel Tower respectively (see Figure 3). These tactile images have certain hollow features where the fitting pieces would go in. For example, the minarets of the Taj Mahal in the puzzle are to be completed using rectangular pieces. We have used features at multiple heights from the base plate to represent the distance of the feature from the point of view and also to bring out architectural features.

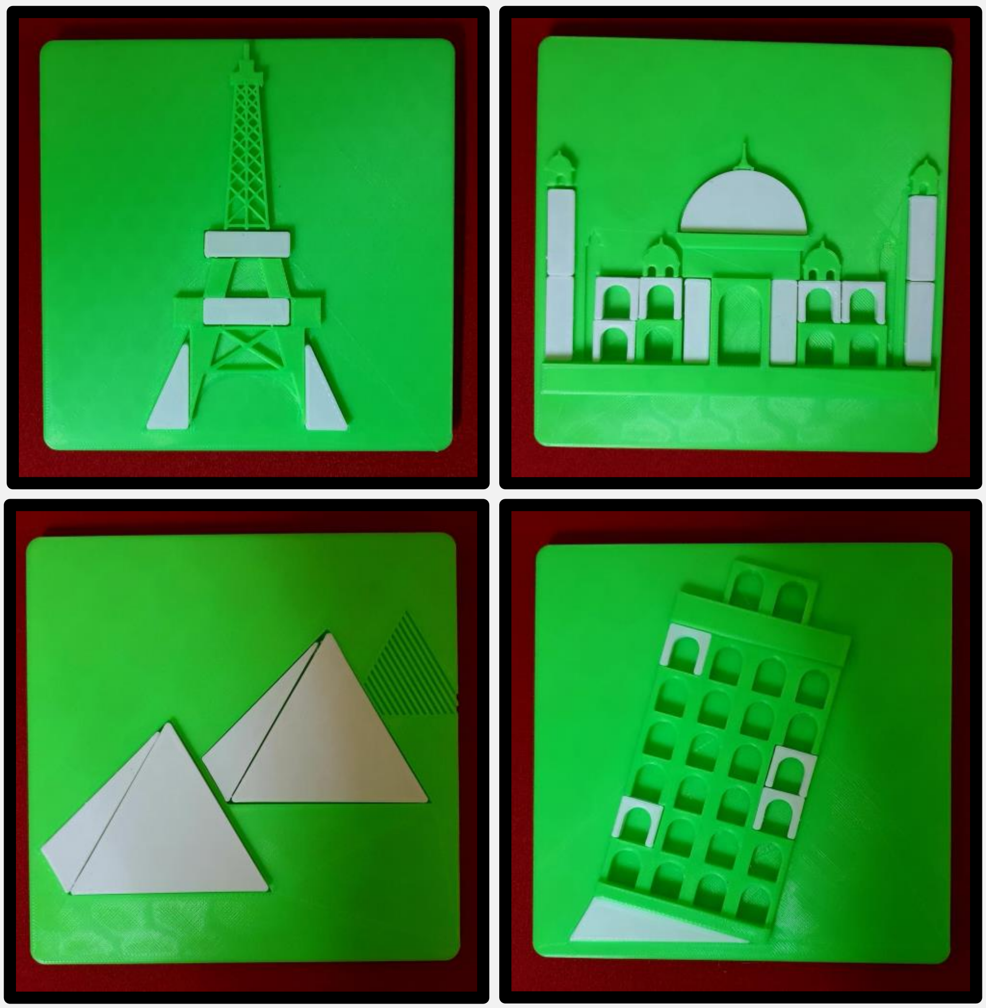

Figure 3. Set of puzzles in Monument theme (white ones are the fitting pieces)

Monument theme of puzzles aims to work on the following objectives:

1. To know through touch the shape of important monuments and identify parts of them as simplified representations using geometric shapes. For example, the use of triangles for representing pyramids.

2. To understand the concept of projection of 3D shapes. For example, the dome and minarets in the Taj Mahal, which are hemispherical and cylindrical in shape, are represented using semi-circle and rectangles.

3. To understand the employment of geometric shapes for representing factual information, like using a wedge to depict the incline in the Leaning Tower of Pisa.

4. To understand the connection between architectural features of different monuments. For example, we have used the same window piece for completing the windows in the Taj Mahal and the Leaning Tower of Pisa puzzles, as both the monuments have almost similar looking windows.

From our conversations with VI students about the monument theme, we realized that such a tool proves to be very helpful for VI students to understand the architectural features by the means of touch, rather than words during verbal teaching.

One of the VI students at Louis Adarsh Blind School in Warangal who completed the Taj Mahal puzzle gave a really encouraging comment:

"Until now, I only heard about the Taj Mahal, but from your puzzles, I have actually seen it".

5.2 CONSTRUCTION TOOL: HEXACOMPASS

During our second visit to Devnar School for the Blind in Hyderabad in December 2019, the TVIs gave us ideas for relevant teaching aids. One idea was to make a tool that explained complementary and supplementary angles. Another idea was to design an angle measurement and construction tool. We thought of combining the two ideas into one comprehensive tool and the result was the Hexacompass. It is based on our puzzle design and contains a base plate and fitting pieces, along with a detachable compass. The tool has two major functions:

1. To illustrate the concepts of complementary and supplementary angles using triangles of standard angles i.e. 30° and 60° measure;

2. To aid in practical geometry with its VI-friendly detachable compass that can be used to measure angles of given objects as well as be fixed at a particular angle for construction.

The tool features a base plate engraved with a hexagon containing sections that correspond to four 30° triangles followed by four 60° triangles (see Figure 4). As the user fits the triangles in order, the cumulative angles turn out to be 30°, 60°, 90°, 120° using the 30° triangles followed by the 180° mark, 240°, 300° and 360° marks using 60° triangles to complete the hexagon.

Also, a semicircular ring is projected outwards for 180° along the periphery of the hexagon. Next to the ring, up-raised dots at 10° intervals are present, along with an extra dot at 45° and 135°. When these dots are counted in clockwise or counterclockwise order, the tool effectively acts as a protractor.

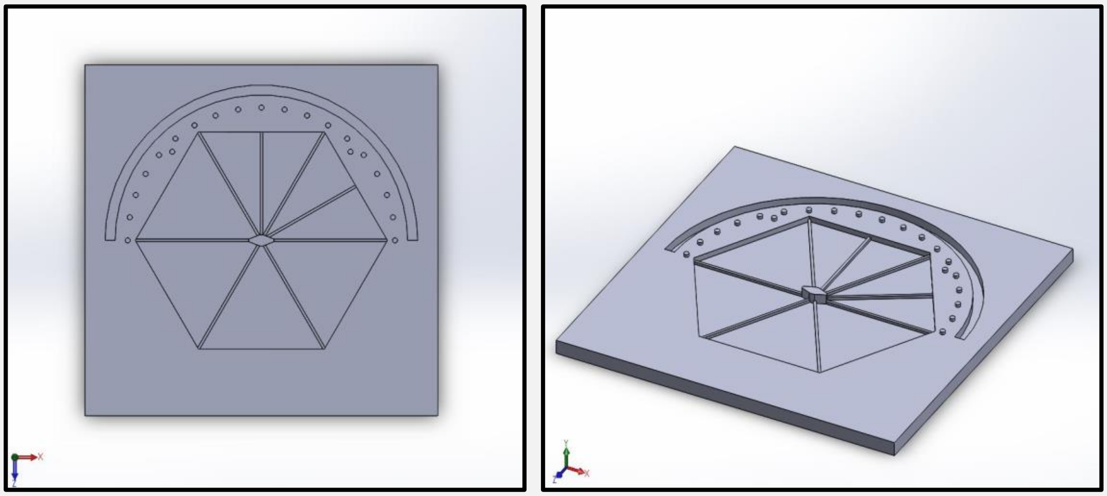

Figure 4. Base plate of the Hexacompass containing a diamond key in the center to fit the detachable compass during angle measurement

5.2.1 Concept of complementary angles

The user starts by placing the first 30° triangular piece. Then they need to insert two more 30° triangular pieces into the slots to get a cumulative angle of 90°. This implies that the complement of a 30° angle is in fact 30°+30°=60°. A similar exercise can be performed for a 60° angle as well to determine that its complementary angle is in fact 30°.

5.2.2 Concept of supplementary angles

The user can start off by inserting one 30° triangular piece. Now, three 30°, as well as one 60° triangular piece, also need to be fit in order to achieve a cumulative angle of 30°+30°+30°+30°+60°= 180°. Multiple permutations and combinations can be used in this case and VI students can have a fun experience in trying out various such combinations.

5.2.3 Detachable compass

The detachable compass includes two arms, a reference arm, and a rotating arm, with a screw-type pivot through the shoulder of both arms that can be tightened to fix the orientation of the arms and loosened during angle measurement (see Figure 5). The reference arm, on which the rotating arm lies, has a diamond-shaped groove in the bottom of its shoulder. When the compass is placed on the base plate, a similar-shaped extrusion present in the center of the hexagon locks the compass by filling the groove.

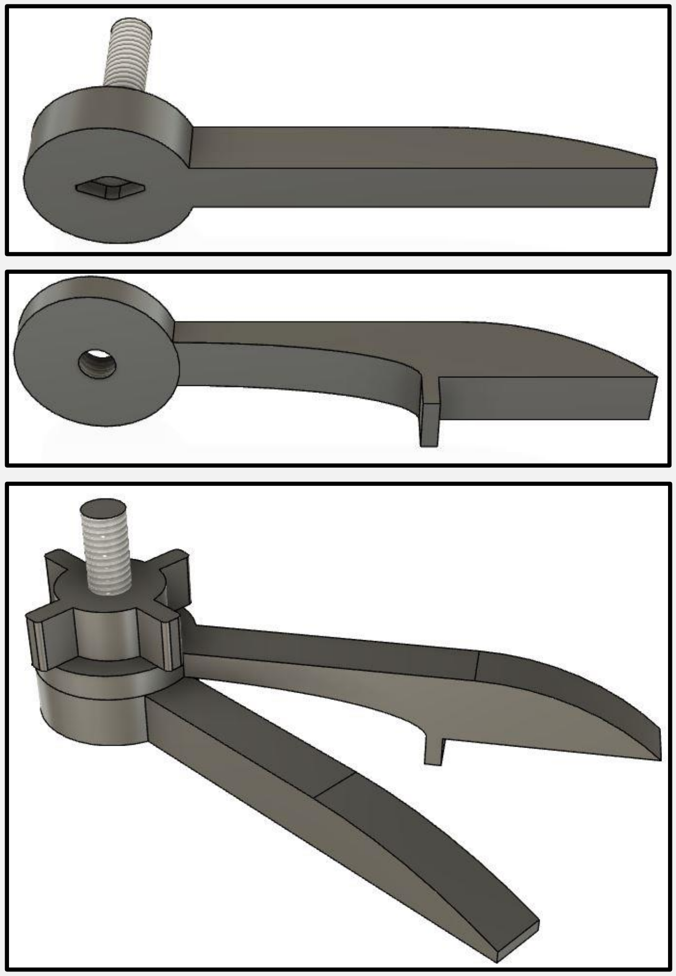

Figure 5. (Top to bottom): Reference arm that fits on the diamond key of base plate; rotating arm that rotates about the bolt on the reference arm; assembly of the two arms tightened using a nut.

5.2.4 Key features

1. The shape of the extrusion-slot ensures that there is no movement of the reference arm about the center.
2. The swinging arm also has a downward-facing fin-like extrusion that fits into the groove in the base plate which goes around the periphery of the hexagon for 180°. This provision is to give structural support to the swinging arm.
3. The shapes of both the arms are to minimize material usage while maintaining sufficient strength.
4. The dots on the hexagon plate can be used to determine the angle to the nearest multiple of 10°.

5. The detachable compass can be lifted vertically from the diamond extrusion in the base plate and can be physically taken elsewhere to compare or replicate the measured angle.

6 DESIGNING

This section explains the process we followed and points we kept in mind during the designing of the educational aids. It also includes a few of our observations which might come handy for someone who would like to carry forward this work.

We didn't start with a fixed work plan in the beginning, but in retrospect, we happened to have a certain flow during the designing (see Figure 6). Paper sketching proved to be an efficient and time-effective way of exploring ideas. Once we had a certain concept on paper, we used to implement it in either SolidWorks or Fusion360 which are two popular CAD modeling software. Finally, we would print it and look for areas of improvement.

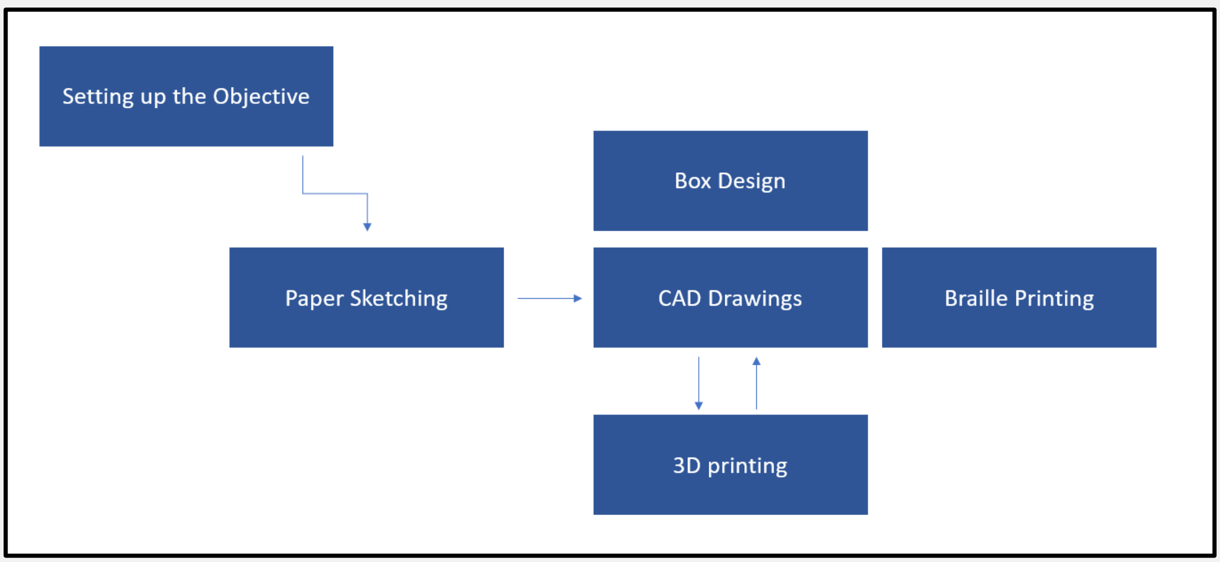

Figure 6. Work flow during designing.

6.1 CAD MODELING

During CAD modeling, we kept the following points in mind to ensure smooth 3D printing, a durable structure (as it is to be used by children), and above all, to make sure that all the features are legible and useful to VI students.

1. Base plates must have a thickness >= 5mm for ease of handling and structural integrity.

2. Designs should have minimal use of support structures[10] during desktop 3D printing. Since our tools are touch-based, we wanted to avoid the risk of unwanted surface roughness resulting from the removal of support structures after printing.

3. *Smaller the dimension, the higher the tolerance for good fitting*. In our puzzles, the scale factor of a piece was approximately from 0.87 to 0.98 times the dimension of its groove. For instance, the dimensions[11] of rectangular grooves in the Eiffel Tower and the Taj Mahal puzzle were 10x30mm, but that of the pieces turned out to be 8.75x29.5mm for good fit (scale factor of 0.875 for 10mm side and 0.98 for 30mm side). Similarly, the right-angled triangles used for the Pyramid puzzle required lower tolerance with a scale factor of 0.975 times the size of the grooves (see Figure 7).

Figure 7. (Left to right): High tolerance required for smaller pieces in Taj Mahal puzzle; Lower tolerance required for larger triangular pieces in Pyramid puzzle.

4. To feel a certain feature properly, all of its dimensions should be at least equal to 2.5mm. We understood this the hard way. The truss features printed on the Eiffel Towers were too

[10] Support structures are 3D structures/scaffoldings that are required to print overhanging sections of the CAD model. They are designed to be easily removable from the 3D print, but in some cases they leave aberrations and projections on the print surface after removal.

[11] These are the dimension in the CAD model and not that of the 3D printed parts.

detailed/small for the VI students to interpret (see Figure 8). We did not anticipate this during the design phase and could only be known after printing. Thereafter, we estimated a threshold for the dimensions beyond which they are interpretable. This was done by evaluating the smallest interpretable feature in our puzzles, which was the top of the minarets (2.5mm) in the Taj Mahal puzzle.

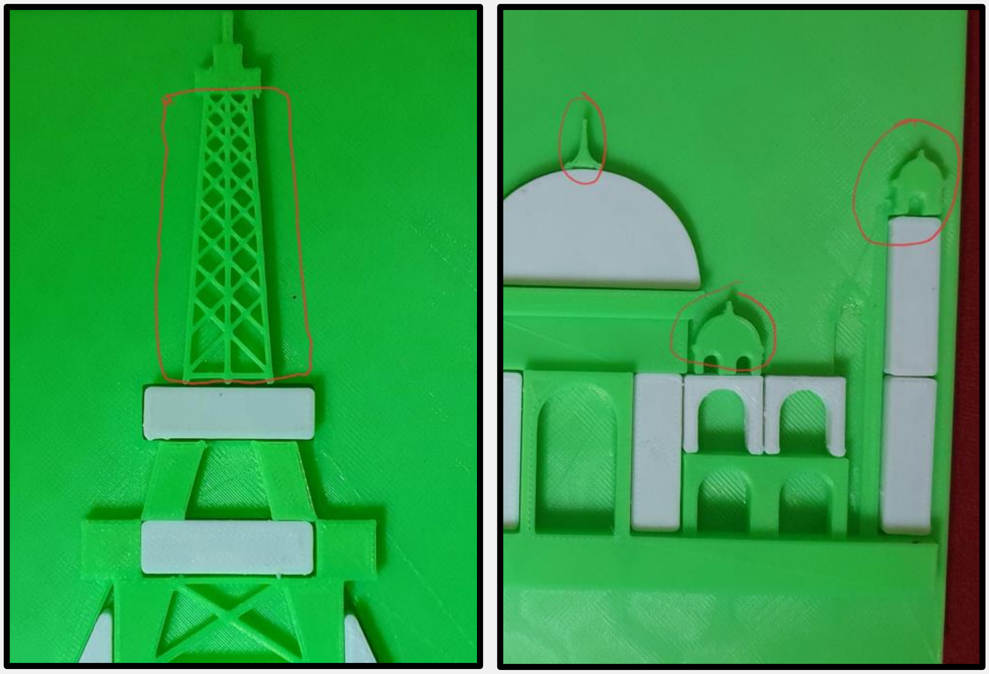

Figure 8. (Left to right): Trusses on Eiffel Tower that were difficult to interpret; top of the minarets were the smallest features that were properly interpretable.

5. Include fillets[12] wherever possible (see Figure10). This serves two purposes:
    a. It reduces the stress concentration at the given edges, thereby increasing the strength and life of the component.
    b. It reduces the possibility of a sharp edge possibly hurting the user.

6.2 Box Design

The box was designed to hold the puzzle pieces as well as one puzzle theme consisting of four puzzle plates. The design process of the box was as follows:

1. The box has a minimum number (two) of joining parts to decrease the chances of fracture at joints.

[12] Fillets are used to avoid sharp edges by rounding them.

2. The two components were: (i) base of the box (ii) walls of the box (see Figure 9). For joining the components, we used superglue along with deliberate projections at gluing surface to increase the surface area. The superglue Feviquick (widely available in India) is an ideal superglue for the purpose. In fact, it is so strong that in joints of pieces of small dimensions, the strength of the bonded area seemed to be greater than the strength of the bulk of the PLA.

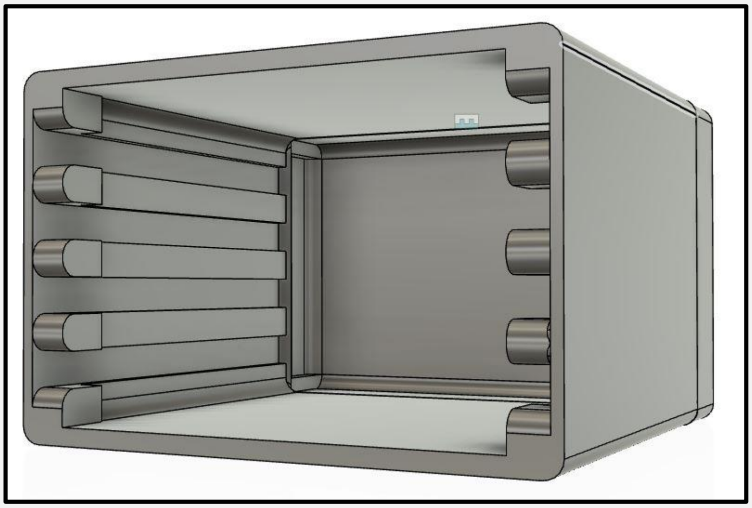

Figure 9. Top view (at an angle) of the box.

3. We rounded the edges for minimum stress concentration using fillets. A stress concentration is a location in an object where the stress is significantly greater than the surrounding region. It occurs when there are irregularities in the geometry (mainly at edges) or material of a structural component that cause an interruption to the flow of stress.

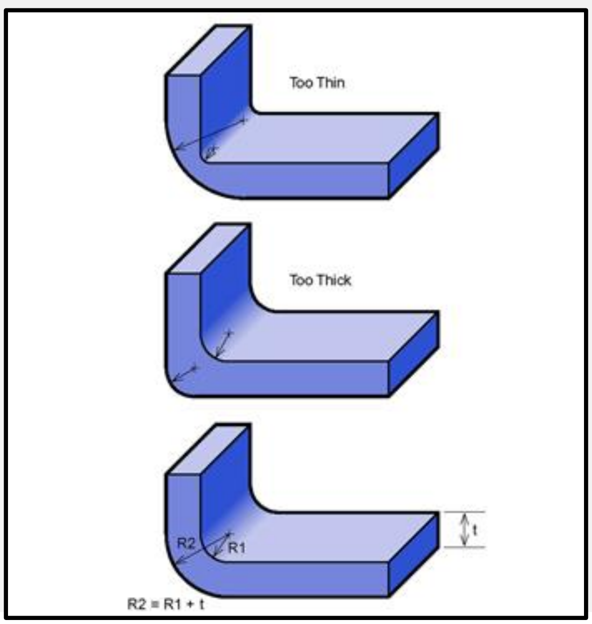

Figure 10. Fillets given at inner and outer edges yields best flow of stresses[13]

4. The number of overhanging components was kept minimum to avoid support structures during printing.
5. We ensured that the box was user friendly, especially for VI users with the following features (see Figure 11):
   a. Easy insertion of puzzle plates with rounded guides.
   b. Puzzle plates cannot enter diagonally into more than one rack by simply extending the rounded guides towards the opposite face.
   c. The racks have enough spacing between them for easy removal of the plates.

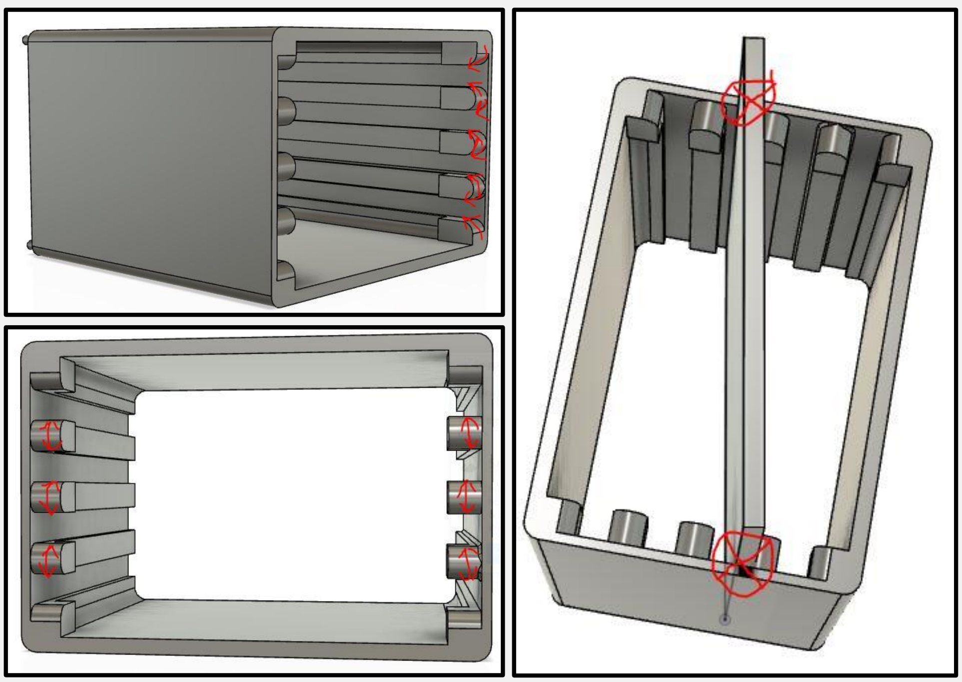

Figure 11. (Clockwise from top left) rounded guides for easy insertion; extended guides avoid diagonal entry of plates; good spacing between the racks for easy removal.

[13] Link to the reference website: http://www.bingmold.com/article/en/Plastic-Injection-Molding-Part-Design-Guidelines.html

7 BRAILLE PRINTING (FUTURE SCOPE)

Braille printing on the puzzles can make them richer in information. For example, in the Monument theme, historical facts and information regarding the geometric features can be printed at the back of the plate. But braille printing introduces an additional constraint on the CAD designs because one must model the design such that braille can be printed vertically.

It has been observed that vertical braille printing gives far better results than horizontal printing. The braille dots are more spherical and smooth in the former which score better in readability. During our testing of the puzzles, we printed a small plate in the vertical and horizontal orientation. When given to a VI student, the vertically printed braille turned out to be more comfortable to read due to the smoothness of the dots.

While we haven't incorporated braille in our designs, one can explore the possibility of keeping in mind the constraints. Also, one can bypass the constraint of vertical printing by separately printing a braille plate (in vertical orientation) and pasting it on the design using superglue (works for PLA material).

Following links might be helpful:

1. OpenSCAD code for Braille dots

   https://github.com/KitWallace/openscad/blob/master/braille.scad

8 APPENDIX A

The document contains a record of conversations that happened on March 8, 2019, at Devnar School for the Blind, Hyderabad. Although the language has been edited as and when required to fit the flow of the document, the content has been kept as pure as possible.

Introduction:

The Devnar School for the Blind was established by Dr. Saibaba Gowd, an Ophthalmologist and a Padma Shree awardee. Having worked in camps and treated VI children before, Mr. Gowd connected with the woes of the VI children as well as their parents regarding their education and survival in the society. Although their vision could not be restored, he established the schools in the hopes of giving them the means to make a living in the society, and the school has managed to achieve all that and much more with many of its alumni working in banks, government offices and even studying abroad. This school is the first English medium school for the blind in Andhra Pradesh and Telangana states, with classes till Class X and a high school in another campus till Class XII. The school is a hostel-based institute with few day scholars and has a solar-powered kitchen.

Questionnaire for Teachers for Visually Impaired (TVIs):

The following questions were collectively answered by Mr. Yadgiri Reddy and Mr. Naresh, who teach mathematics to the VI students, and Mrs. Hasina, who takes care of the school's computer lab.

1. **How long have you been TVI?**

   We generally have an experience of over 5-7 years.

2. **Have you also taught sighted students?**

   No. We were given training specifically to teach VI students and were subsequently recruited by Devnar School for the Blind.

3. **Which subjects to what age groups do you teach?**

   The subjects taught are according to the *Telangana State Board Curriculum*, so it's the same as for any other teacher or school for the sighted. The only difference is that VI students are exempted from any question that involves figures or requires the student to perform geometric construction. So during teaching, subjects like geometry are taught theoretically only, no measured construction is taught. The age-class relation for the students is the same as that for sighted students.

4. **What is the size and strength of the classrooms?**

   Classrooms are fairly small, having around 15 students sitting around the teacher like a square table with the teacher in the middle. However, ideally the teacher-student ratio should be 1:8 but due to lack of TVIs, some classes have around 20-25 students at a time (like the Class 9 classroom we visited).

5. **Out of the total students, what proportion are partially VI and fully VI?**

   More than around 70% of students are fully VI, remaining are partially VI. We also admit a limited number of students who are both VI and have some form of mental issues. These students are not taught the usual curriculum, but basic lifestyle measures like taking baths, going to the washroom and so on.

6. **Do they understand Braille?**

   Yes, they understand Braille and are taught Braille from Class 1 onwards.

7. **What basics are taught initially and how does the teaching mature over time?**

   They are taught English alphabets in Kindergarten verbally, such that once they get to Grade 1, they are comfortable with English and then can proceed to learn English Braille.

8. **How are they introduced to the most basic math/geometric concepts like lines and shapes?**

   They are introduced to lines and shapes through tactile graphics and 3D printed models of various shapes like spheres, cones, cubes, pyramids etcetera. Tactile graphics are also used to explain some concepts like transversals, triangles, tangents to circles, circumscribing and inscribing figures, heights and lengths of triangles, radii of circles, properties like refraction, concepts of parallelograms, intersecting lines and so on. For explaining concepts like parallelograms, we use these tactile graphics and by touch as well as using Braille scale, we qualitatively as well as quantitatively explain the concepts. They cannot construct shapes using rulers like sighted students. Instead, they make the shapes on Taylor Frame itself.

9. **Can you help us understand how Taylor Frame is used?**

   Taylor frame consists of a board with a grid of ‘octagonal holes’ in which metal pieces called tabs can be inserted in 8 different orientations. Each tab is used in one of its two vertical orientations which makes it possible to denote 16 different characters using a tab. These include numbers, arithmetic operators, decimal points, even brackets, radical signs and special numbers like pi and a given set of alphabets for the remaining orientations which can be used by TVIs to denote a variable or a constant. Using this system, students can also represent exponents, subscripts, fractions by placing the tabs at the grid position along the direction in which we usually would represent on paper.

10. What subjects the students like the most?

Generally, students have a broad and varying interest in the subjects taught to them, similar to what can be expected from a group of sighted students.

11. What assistive tools/tech are used in teaching specific concepts?

For teaching math, Taylor Frame is used extensively for arithmetic operations as well as algebra. For teaching Physics, Chemistry and Biology, 3D models are used to give them a feel of chemical reactions, shapes of molecules, the formation of orbitals while they are given tactile models to explain phenomena like reflection, refraction, mirrors and lenses. We even have human-sized models of the anatomy of the human body.

12. Do you also have a Computer Lab and what do you teach them there?

Yes, we have three computer labs and students from Class 6 through 10 have the lab thrice a week. Each computer has a screen reading software called JAWS installed on it. JAWS talks back each alphabet that the student types. The students can use the software to surf the internet, send and receive emails and use tools like Microsoft Office.

They have also started to teach C# in higher classes. There is also a new Indian software called Anupama which uses a regular scanner to scan pages of books and once done, it can read back to the user the entire book in audio.

13. Are there devices in the lab for low vision children?

Yes, there is a device called Optelec which zooms in portions of the paper/book that is presented onto the device.

14. Does the school have a Library or something equivalent?

Yes, the school does have a library. It is filled with books reprinted in Braille using their Braille printer. The books are of a pretty wide range of genre from sci-fi to novels, biographies, again, similar to what one might expect in a regular school.

15. What is the most expensive and cheapest tech/tool used in the school?

Braille scribes are the cheapest ones. They are used by all the students from Grade 1 through to Grade 10. The most expensive ones are the Optelec device in the computer lab for low vision students costing around INR 100,000 (USD 1,400) and the Braille Printer for printing books for the library costing around INR 300,000 (USD 4,200).

16. What training was required to make use of the tools in order to teach?

Training included having a good command over the Braille code but more importantly focused on the methodology that must be followed by TVIs for teaching VI students.

17. **How proficient are these kids compared to sighted ones? Biggest advantage/disadvantage?**

    They have pretty sharp minds and at no point do they feel inferior to the sighted students in any way, especially when given appropriate care and assistance. Sighted students are obviously blessed with vision, but other senses in VI students are much heightened. In fact, none of them even needs a walking stick to get around in the campus, they only need to be guided around any given place once or at most twice and then they essentially navigate on their own without any assistance.

18. **Are they given projects or something similar? If yes, how many of them do it?**

    Project work is given to a lot of students from various classes. But a few students from Class 10, who are old enough with a certain level of maturity and have a grasp of basic scientific concepts, are given the opportunity to work on science projects that are taken to state and national level competitions. One of their projects was even selected among the top 30 nationally, competing with ones made by sighted students.

19. **What is the process of conducting exams (the medium in which questions are asked and answered) and how are they evaluated?**

    <u>For Math</u>: The questions are read out one or two times until the students have understood them. They then solve them on Taylor Frame and the answers are evaluated subsequently by the teacher just after they solve.

    <u>For other subjects</u>: The questions are given on Braille paper and the students are also asked to solve them using Braille. For evaluation, the teachers usually discuss the solutions with four or five meritorious students and along with them evaluate the other answer scripts to save time and divide effort.

20. **What all extra-curricular activities or sports are introduced to the students?**

    The students are introduced to cricket and it's their favorite sport as well, pretty much like a majority of the standard Indian population.

21. **Are you aware of Fittle (educational tool developed at LVPEI Hyderabad)?**

    Yes. In fact, Srinath (lead designer) had been to Devnar School for the Blind to study Braille and implement it for Fittle.

The following questions were answered by Mr. Parmeshwaram who teaches Physics and Chemistry at Devnar School for the Blinds.

1. **How long have you been TVI?**

   I have been teaching at this school for more than 8 years.

2. **Have you also taught sighted students?**

   No, only the visually impaired students. I was an engineer in Emirates airlines, after which I took voluntary retirement and came here to teach. I have been associated with this school since its beginning though.

3. **Which subjects do you teach to what age groups for the VI students?**

   Physics and Chemistry of high school level.

4. **What basics are taught prior to you teaching them?**

   They are taught Braille and nuances of reading and writing. Since I teach only 9th and 10th graders, they have already studied middle school physics and chemistry.

5. **How are they introduced to the most basic math/geometric concepts like lines and shapes?**

   We use tactile tools for most of our teaching along with verbal explanations. Everything from orbital shapes in chemistry to formation of images in optics is taught via tactical models.

6. **If possible, can you give us a copy of the syllabus sheet or at least corresponding oral citation?**

   The syllabus is same as that of SSC (Telangana State Board) for sighted students and no changes are made for the VI students other than a few exceptions including geometry.

7. **What are the assistive tools/tech used?**

   We use computer software like JAWS to teach them basic computer operations, and even other stuff like sending emails, listening to audiobooks etc.

8. **How proficient are these kids compared to sighted ones?**

   They are all equally proficient, maybe more in some areas. It's the same as a normal school, some of them are better at grasping concepts than others. They are definitely better at remembering concepts as compared to sighted students. Once they understand something, they can do it by themselves.

9. **Do you give them Homework? If yes, what kind of homework?**

Yes, of course, they are given homework but not very frequently, and not new topics. We give them projects as well. In fact, their assessment requires them to finish a project in their academic year.

10. What percentage of them are able to solve on their own? How well do they solve?

They can solve similar problems themselves, for the most part. Some require assistance. Again, it is the same as for sighted children.

11. Are they given projects or something similar?

Yes, they are. As I said, it is part of their assessment. Some of them take it to the next level also, of their own accord. For instance, a team from our school participated in the National Telangana Science Congress and went on to the National level (after clearing district and state level) and won a gold medal. Their project was a portable solar mobile charger for farmers. And there's another team this year, they are working on making education involving electrical circuits safer for VI students by use of a Raspberry CPU and buzzers.

12. What is the best (and maybe the worst as well) part about teaching VI students?

There's no bad part, at least I don't think so. As for the best part, they are very attentive and focused. I believe sighted students can learn from them as much as these students can learn from sighted students. In fact, I am always learning something new from them myself while teaching. After all, learning is a never-ending process, isn't it?

After answering the questions, Mr. Naresh and Mr. Yadgiri Reddy showed us the 3D shapes and tactile tiles that they use for teaching mathematics. Then we explained to them our ideas to get their feedback and suggestions. We showed them what Sarthak and team had come up with at LVPEI in January for measuring angles and constructing triangles of various dimensions. According to them, the idea does have potential because geometry is a difficult subject for VI and intuition for it doesn't come naturally to them. They would certainly like to see the prototypes and emphasized on getting regular feedback from VI students and TVIs.

<u>Questionnaire for VI students:</u>

The following questions were answered by students of Class IX at Devnar School for the Blinds, Hyderabad, on March 8, 2019. Around 20 students were present with 60:40 boy to girl ratio. Pravallika, Praveen and Sai Teja were few of them who actively participated.

1. **What are the subjects that you study?**

   We are taught the same subjects as sighted students studying in the Telangana State Board. This includes Mathematics, Science, Social Studies, Computers, English, Hindi, and Telugu. Also, we have computers and science labs. The tactile and 3D models in science labs are incredibly helpful in understanding the subject. (Justifies our plan for making tactile tools for geometric properties)

2. **What are your favorite subjects? Why?**

   Mixed replies by students.

   We love Mathematics and Science. Our teachers are polite and they take time to explain the concepts. The best part about science is that we get to touch the tactile models in the lab which boosts our imagination. Also, we get to do science cool projects.

   We love History and languages too.

3. **How comfortable are you with braille?**

   Very. Comfort level increases with practice and we have been using braille rigorously since Class I (Pravallika wrote all the English alphabets in under 20 seconds. Their school starts with Kindergarten, but braille education starts in Class I).

4. **What languages can you read and write?**

   Hindi, Telugu, and English. We are more comfortable with using braille for English than for local languages. (Braille for local languages is an issue)

5. **What is your favorite assistive tools/tech, and why?**

   We love using the computer lab equipped with JAWS screen reader as it brings us closer to today's technology, i.e., the internet and computers. Also, we find Taylor Frame really helpful for mathematics.

6. **Do you know about Talking Calculators?**

   <u>Praveen</u>: *Yes! I know about it. But we don't use it here. Also, we have brains and can do the calculations on our own.*

7. **Do you get homework? If yes, do you like doing it, or do you take help?**

We get homework regularly and as most of us live in the hostels of the school, we do it independently without any help from our parents. Moreover, we love doing homework as practice makes us more comfortable to understand the concepts and visualize them better (Although a few of the students were not so agreeable, that is only natural for students of Class IX).

8. Are you given projects or something similar?

Yes. We have a science exhibition every year where students from all classes present their projects. Moreover, in Class X, a few students are selected to take part in project work that they present at state and national level.

9. Do you need help from sighted people or parents/guardians?

At school, we don't need any help other than our friends. Together we are interdependent and independent at the same time. Here we walk without any walking stick as they might hinder other VI students' movement, and also we don't feel the need to use them as we know the place quite well.

10. What kind of games/puzzles do you play?

We play cricket a lot here in the school's courtyard.

Praveen: I love solving math's puzzles (He asked us if we had any, but we didn't anticipate this and couldn't give him one. Although, he did tell us square roots of a few perfect squares).

We had a few more questions but couldn't ask as the students were running late for their lunch break. Also, during our conversations with Praveen and Sai Teja, we told them about Mars and space exploration and they looked pretty interested in the same. In fact, Sai Teja had some questions about how to send satellites to space. Honestly, we felt that these students are not much different from sighted students and have creative dreams and ambitions, only that their world is a bit different.