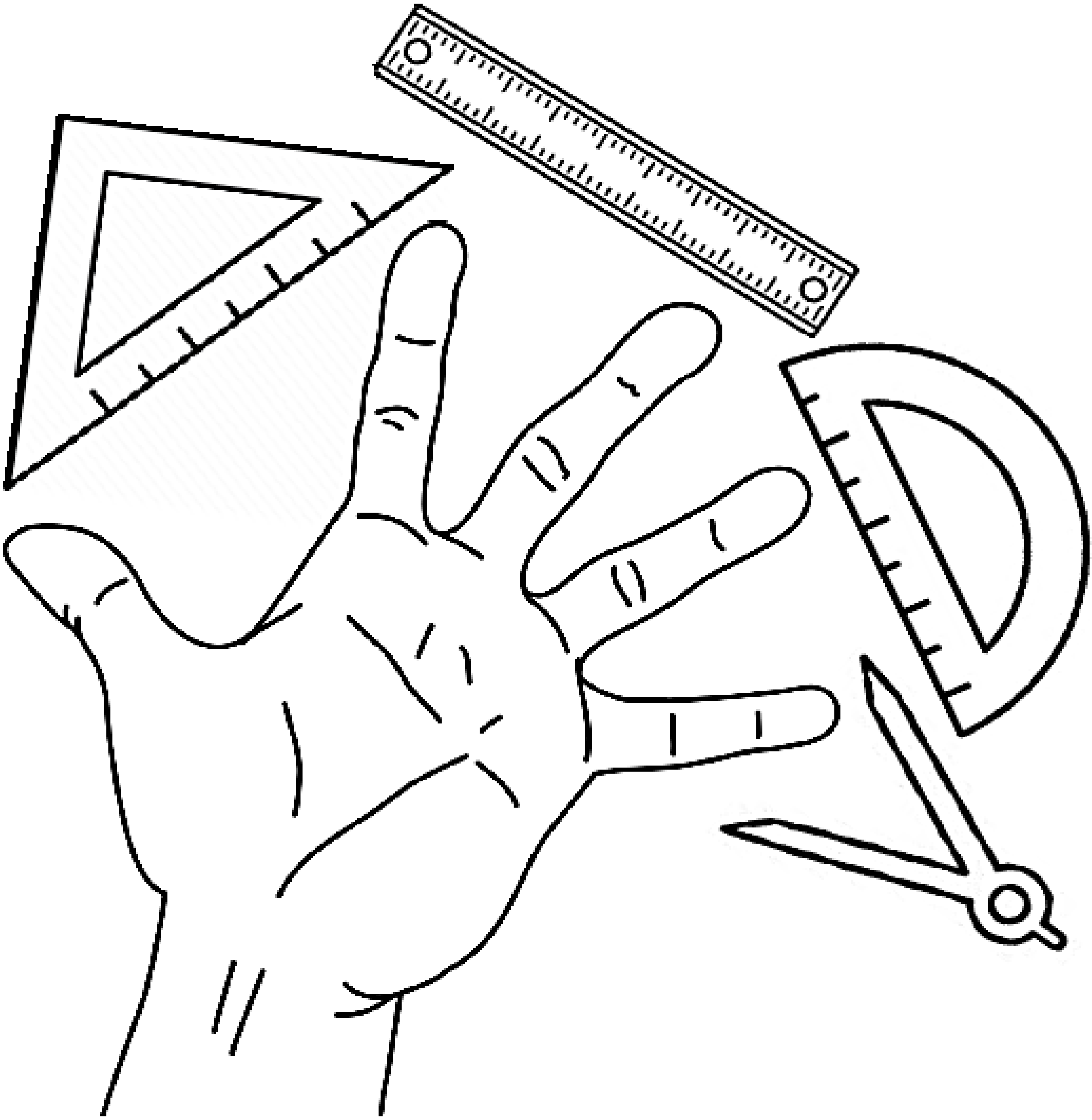
Degrees of Accessibility

A 360° User Perspective Report on existing accessible Geometry Construction Kits for students with blindness

by

Xavier's Resource Centre for the Visually Challenged (XRCVC)



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A 360° User Perspective Report on Existing Accessible Geometry Construction Kits
for students with blindness

Based on the research conducted by:
Xavier's Resource Centre for the Visually Challenged (XRCVC)
As part of the **Great Eastern CSR Foundation's**
Inclusive Education Project

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“Blind students can do this when this topic comes in class!”
- *Research Participant*

“Oh this is what is a compass…I have seen it before in a pencil box, but never knew what it is used for or how it is used”
- *Research Participant*

Come join us on our journey of learning from our students!

PREFACE

Education, in its formalised *avatar,* has built an extensive system of curriculum delivery mechanism through the school system. Each subject is taught to the student in their respective classes, practised at home, and mastered through the course of the student's participation in school. A successful completion of all subject curriculums, curated by educationists, aims to give the student a step forward in building careers post their schooling years.

Have we wondered then, for students with disabilities, and here we are discussing for students with blindness and low vision in particular, by telling them that they 'cannot' study some of these well-curated curriculums and opt for alternative subjects, are we giving them the same career opportunities? Or are we flexible in our curriculums which we otherwise so vehemently insist on all school students to undergo? Given that the latter is not true, the XRCVC has been actively working to understand the reasons for the former so that the gaps can be bridged.

Our work on making mathematics and science accessible for students with blindness and low vision started with our research report ***Numbers and Reactions (2013),*** which highlighted for us the reasons for lack of access to Science, Technology, Engineering, and Mathematics (STEM) subjects for students with blindness and low vision. Since then, our work has expanded to spreading awareness, conducting training programmes, and building up resources for accessible STEM study.

The current research resulted from a strong need in the field of accessible STEM study. Geometry, as a subject inherent to high school mathematics, is often considered out of reach for students with blindness and low vision. It is assumed to be a purely visual subject. This, however, is far from the truth. What our eyes study in shapes is accessible to touch as well. Both 2D and 3D shapes are tactually accessible. However, this means that geometry study kits and construction tools, designed so far only for the eyes, have to be designed keeping in mind the sense of touch.

The world over, several tactile accessible geometry construction tools have been developed and used over the years. When we interacted with students and teachers, what we found was that most tools were being adapted in their usage by teachers locally, in the absence of a clear-cut methodology shared by developers of the tools. Further, all tool sets could not do all tasks and a complete geometry construction kit including all parts was, oftentimes, missing. This made it nearly impossible for the student to perform all elements of geometry construction.

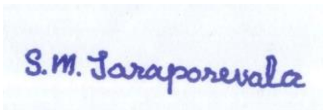
This motivated the XRCVC team to carry out a systematic investigation of the subject. The aim was to collate most widely used national and international geometry construction sets, test them with a wide user base and be able to identify features to develop a comprehensive geometry construction kit that will make teaching and learning of geometry accessible and effective. The current report is a culmination of this ambitious idea that took seed two years ago.

We have tried our best to put together a report that accounts for maximum number of learning variations. The report however does not claim to be a complete account of every tool that might exist. Further, the methods used to teach these tools have been adapted based on what was used locally and based on the XRCVC's work experience. The same may not match the methods as envisaged by the tool designers. We would also like to affirm that the XRCVC has conducted this study for applied research purposes only and we do not hold any commercial interest in any of the tools studied. The XRCVC presents this work as a start point to documentation in this area, which it will look forward to building with collaborators in the future.

The XRCVC would like to extend heartfelt gratitude and thanks to the **Great Eastern CSR Foundation** for funding support extended under our Inclusive Education Project that made this research possible. Without this, the research would never have taken off. We also acknowledge and thank other organisations and individuals whose involvement has helped ensure the success of this research. We would like to acknowledge the key role played by the Tech Mahindra Foundation in partnership with whom XRCVC was able to launch its focus on accessible STEM education. We also thank the Dhun Pestonji Parakh Discretionary Trust whose ongoing support through the years has enabled us to investigate and work on diverse accessibility issues for persons with blindness and low vision.

Special mention needs to be made of Smt. Kamla Mehta Dadar School for the Blind, Mumbai; Kanu Bhai Andh Vidyalay Malkapur, Akola; N.A.B. School for the Blind, Junagadh; Saksham Resource centre for visually impaired, multipally handicapped & deafblind children, New Delhi; The Victoria Memorial School for the Blind (VMSB), Mumbai, students of St. Xavier's College, Mumbai, and students who came independently to us from other colleges in Mumbai. These institutes and individuals helped us to facilitate research at their respective locations and with their students. Without their support, the research vision would have remained on paper. We are tremendously grateful to each and every one of our students and their parents for taking time out from their already packed study schedules and their much illusive play time to be patient in learning all our tools and testing them for us. In helping us learn how they learn, the students' invaluable time, efforts and inputs are what make this research report relevant and valuable.

We hope that this report will prove to be useful reading to anyone interested in working with or designing universally accessible geometry construction kits for all students including students with blindness and low vision. And we look forward to someone being inspired by this and creating the next generation of accessible Geometry Construction Kits making all the time invested by our students in giving valuable inputs lead to something useful for the community at large.



Dr. Sam Taraporevala
Research Director
December 2019

PROJECT IMPLEMENTER

Xavier's Resource Centre for the Visually Challenged (XRCVC), St. Xavier's College, Mumbai (www.xrcvc.org)
The XRCVC is a state-of-the-art support and advocacy centre for persons with disabilities in general and persons with blindness and low vision in particular. It is a department of St. Xavier's College, Mumbai, India, and works actively in providing inclusive education services to students with disabilities on campus. It also does active work in providing Support and Training Services to persons with blindness and low vision, Awareness Generation and Advocacy Initiatives. The XRCVC works actively towards building access and inclusion both at the micro and the macro levels.

One key area of work by the XRCVC has been Education Access for persons with disabilities. Our work has aimed at opening up more educational streams for persons with disabilities especially in the traditionally denied STEM fields as also building up resources of training, education content, and teaching learning aids for making STEM education possible. The current research is part of our endeavour to increase access to quality teaching-learning tools in the STEM discipline to persons with blindness and low vision.

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READING GUIDE FOR THE RESEARCH REPORT

The research report has been divided into four main sections. We present below the framework for the same to facilitate an effective reading experience for readers of this report.

Section I: Chapters 1-2: Introduction and Research Framework

This section will enable the reader to understand the context, need and framework used in the research. Since this research was a dual process of teaching respondents followed by testing them, it is critical for the reader to first understand the teaching pedagogy in the research. Further, this report uses a wide range of tools so unless the reader spends time understanding the tools and teaching pedagogy, subsequent reading may pose some challenges. Teaching pedagogy is part of Annexure G and we strongly recommend reading through the same.

Section II: Chapters 3-5: Skill-wise Analysis

This section presents a skill-wise analysis of the research data. This section is useful for readers interested in obtaining an overall idea of features of tools that will be effective for specific skills. Each chapter provides design ideas for tools relevant for the skill analysed in the chapter.

Section III: Chapters 6-9: Tool-wise Analysis

This section presents a tool wise analysis of the research data. It is especially useful for designers of specific tools studied in this research or for readers interested in understanding challenges associated with specific tools. Each chapter provides challenges associated with specific tools along with design suggestions for improving individual tool designs. The chapters also provide cross-tool analysis for accuracy and user feedback for a cross-tool comparison.

Section IV: Chapter 10: Conclusion and Way Forward

The last section of the research provides for a distillation of learning from the research process to provide a design brief for future tool designs. It highlights challenges and sets forth potential work for the future. This section will be of interest to any reader who wishes to design accessible geometry construction kits.

In addition to the above, the report has presented a list of annexures and tables as also abbreviations for easy reference and use for its readers. These can be accessed as part of the Table of Contents section of the report.

LIST OF TABLES

LIST OF ABBREVIATIONS

STEM	Science, Technology, Engineering, and Mathematics
TSBVI	Texas School for the Blind and Visually Impaired
3D	three-dimensional
TLA / TLAs	Teaching-Learning Aids
GCK / GCKs	Geometry Construction Kit(s)
NIEPVD	National Institute for the Empowerment of Persons with Visual Disabilities (Divyangjan)
NIVH	National Institute for the Visually Handicapped
RNIB	Royal National Institute of Blind People
APH	The American Printing House for the Blind
WT	WORTH Trust (Workshop for the Rehabilitation and Training of the Handicapped Trust)
Cm	Centimetre(s)
Mm	Millimetre(s)
°	Degree
TD / TDs	Tactile Diagram(s)

TABLE OF CONTENTS

CHAPTER 1. SETTING THE CONTEXT: AN INTRODUCTION

Mathematics, as a subject, holds a central and significant position within the formal education system. In India, mathematics is compulsory in all primary and secondary schools. Often school curriculums and merit are centred around sound mathematical knowledge. Given its importance, no student can be considered exempt from partaking in the teaching and learning processes of mathematics.

Traditionally, mathematics, and more specifically geometry, is considered beyond the understanding of students with blindness and low vision — given its visual nature, representation and reproduction. However, it is the classical methods of teaching geometry involving the use of visual modalities like graphs, lines, drawings etc. (Rouzier et al., 2004) that make the subject exclusionary.

Douglas Clements writes extensively on geometric thinking as a means of not only learning mathematical concepts but also developing spatial reasoning/awareness (https://files.eric.ed.gov/fulltext/ED436232.pdf). Thus, teaching geometry to students with blindness and low vision is as important for their understanding of mathematical concepts as for their performing everyday tasks.

The development and ready availability of teaching recommendations like the Teacher's Manual for Adapting Science Experiments for Blind and Visually Impaired Students by Dion, Hoffman and Matter (2000) or Teaching Math to Students Who are Blind or Visually Impaired by Osterhaus of the Texas School for the Blind and Visually Impaired (TSBVI) are circumventing the visual limitation to teaching and learning geometry and improving the mathematical content available to students with blindness and low vision. In terms of assistive technologies available to persons with blindness and low vision to learn mathematics, Karshmer and Bledsoe (2007) classify the available technologies as per techniques used: tactile graphics; tonal representations; audio aids; haptic feedback and integrated approaches.

Batista cites that Leon et al., (2016) writes that the best way persons with blindness and low vision receive information about geometric and mathematical concepts is through touch and sound. Therefore, the use of tactile graphics and more concrete materials, i.e. manipulatives, are considered effective mediums for delivering mathematical instructions (Brawand and Johnson, 2016). The use of manipulatives or 'objects designed to represent explicitly and concretely mathematical ideas that are abstract' (Moyer, 2001 p.176) is not a new technique employed for teaching mathematics in schools. Manipulatives have both visual and tactual appeal thereby making them accessible to all students.

The present day technologies that are being created to assist students with blindness in learning and performing geometry are looking to utilize the ability to hear and touch. There is increasing research and development of software that allows for the study and manipulation of geometric figures virtually. 3D printing technology has opened up the scope for converting images into models in real time. Software solutions like MathTrax have enabled graphs to receive audio feedback. However, the problems with availability, cost, effectiveness and integration of these complex assistive technologies into primary and secondary school curriculum have to be looked at critically.

There exists a dearth of information on available geometry tools that make geometry construction possible for students with blindness in schools at simple and cost effective manner. This is not to say that these tools do not exist, but their usability and effectiveness have not been adequately studied.

Robison's (2007) work found that the progressive step method of teaching geometric constructions to students in Chennai was successful. However, the progressive step method involved the depiction of consecutive stages of construction in tactile format. Students did not perform these practical geometry constructions individually or independently. Tanti (N.D.) made use of a tactile ruler, a protractor and a spur wheel to aide practical geometry constructions when teaching geometry in Malta. Her work finds that the students could adequately perform geometric constructions albeit with minor errors, when the students were able to memorise the method and gradually perform all the steps in person.

In terms of availability of geometry tool kits, Pradhan and Samantha (2018) inventoried the assistive technologies – including geometry kits – available in specialised institutes for the blind across two divisions in West Bengal. Their research reiterates the need for increased access, availability and funding for assistive technologies and trained professionals.

The Challenge

As an organisation that has been actively working on building access to STEM education for persons with blindness and low vision, the XRCVC has been encountering the concerns listed above at multiple levels. Our work in accessible STEM for students with blindness and low vision started with our first research in the field published in the report Numbers and Reactions (2013). The report had highlighted the following key areas of intervention needed to make STEM study more accessible and available in India.

- Availability of Teaching-Learning Aids (TLAs)
- Content Creation and TLA manufacturing locally to reduce costs
- Learning services to students and training of trainer services to educators
- Awareness

Our work post the research lead us to start collating and collecting resources and TLAs available in the field both nationally and internationally to start building up a local library. Simultaneously, we also started building our in-house capacities for training students in STEM-related special skills such as Nemeth, LaTeX, ASCIIMath, Geometry Skills, Lab Skills, etc., and started offering these to students directly as also to trainers for subsequent dissemination.

It was during our implementation of Geometry Skills to students with blindness and low vision that we encountered some challenges. These could be highlighted as follows:

- **Variety of tools being used:** Our work with different students led us to a variety of geometry construction kits that were being used by different organisations, parents and special educators.
- **Diversity in operation of similar tools:** Even when students and special educators were using similar tools, the methods for using them varied. Many times, either the tools did not come with "how to use" manuals, or even if they did, the methods were adapted by tutors and students.
- **Lack of usage:** Even though a large number of students owned the locally available tools, they had never used them because they did not know how to.
- **Lack of a Comprehensive Geometry Construction Kit causing difficulty in constructions and eventual loss of interest:** We also found that students were using stand-alone tools to do

scattered geometry work rather than a comprehensive kit, akin to their sighted peers. For e.g., most students with blindness identified only the protractor and ruler in the kit and not a compass. This also meant that the number of geometry constructions were restricted. Moreover, to use many of these instruments, additional side tools – in terms of pins, sheets or drawing boards – were not standardised or readily available. Students would depend on locally available products for the same, and oftentimes, find it challenging to draw with those products not meeting the design requirements for effective drawing. Once ineffective tools made constructions difficult, it would lead to a rapid loss of interest for learning among tutors and students alike.

- **Few solutions for same-side drawing:** Most tools available used reverse-style drawing as a method because earlier the same-side drawing method was not in use. In geometry construction, reverse-side drawing always added complexity and difficulty leading to frustration and loss of interest.

When we encountered these issues, we thought it apt to undertake a comprehensive research on existing Geometry Construction Kits (GCK) to ascertain the real design challenges as also possible solutions. It was also clear to us that the research would need to keep user experience and feedback as the key to investigation. Given that many students did not study geometry to be able to give comprehensive feedback across all tools available in the market, the study had to be envisaged as both a teaching and feedback design.

This report is a compilation of the research undertaken and aims to make data available on the existing GCKs in schools for students with blindness and low vision. The research highlights the usability of these kits and their effectiveness. The report also aims to bring to light the possible design solutions for a comprehensive GCK suitable to the Indian market to make access to geometry easier and fun for students with blindness and low vision.

Subsequent sections of this chapter highlight the research details.

Research Framework

The *Key Research Objective* was the following:

To research and identify the most effective design elements for building a comprehensive accessible Geometry Construction Kit (GCK) for students with blindness and low vision

The **Key Activities** identified for the research included the following:

- To undertake research and identify the list of existing GCKs available for students with blindness and low vision
- To be able to identify and document the pedagogy of using each of the GCKs available in the market
- To teach users how to use the existing GCKs and subsequently test for effectiveness of the kits in constructions, as also obtain user feedback on their usefulness

Expected Outcomes of the research included the following:

- A holistic understanding of the effectiveness and challenges of existing GCKs

- A clear understanding of useful and effective design elements of GCKs that can make geometry construction accessible and efficient for students with blindness and low vision
- To be able to develop a clear design brief for development of a comprehensive accessible GCK.

Scope:

The research aimed to focus on getting a more detailed understanding of use and effectiveness of the GCKs in the Indian scenario. Secondary research and the list of GCKs used for the study were not limited to India but those used across the globe were utilised. User-level testing and data collection was limited to Indian respondents.

Research Method:

The Research used both primary and secondary data. Details of methodologies used for both are listed below.

Primary Data Collection: For this, in-person training of students in the use of GCKs, testing and simulated game environment was created. Data was collected through researcher observations at this stage. In addition, the questionnaire method was used to collect specific feedback data from the students.

Data was collected from a purposive random sample of totally blind boys and girls across urban and semi-urban areas. Data was collected in Mumbai, Delhi, Junagadh and Akola. Further, to keep the group diverse in age, students from Class 4 to 12 were made part of the study. For sample classification, Classes 4-8 were considered as young, and Classes 9-12 as older.

The sample size was 40.

Sample Distribution

Female		Male	
Older	Younger	Older	Younger
10	10	10	10

Percentages have been used to analyse the primary data collected.

The Researchers' Observation sheets and questionnaires used for primary data collection are attached as Annexure C, Annexure D and Annexure F.

The sample does not claim to have statistical confidence; the primary data collection has been an exploratory process to gauge and identify ground level reality in the effectiveness of GCKs in the study of geometry for students with blindness and low vision in India.

Secondary Data Collection: For this, the following was undertaken:

- Literature review of national and international best practices in teaching and learning of geometry among blind and low vision persons
- An extensive compilation and procurement of as many as possible and popularly used GCKs for students with blindness and low vision—both nationally and internationally

Subsequent chapters will highlight the detailed research design for primary data collection for setting the overall framework of the report.

CHAPTER 2. THE RESEARCH PROCESS: THE TEACHING-LEARNING EXCHANGE

As listed in Chapter 1, the purpose of this research study has been to develop a clear understanding on the design of an effective GCK for students with blindness and low vision. As the research team started considering the design of such a study, it soon came to our realisation that in order to get user feedback on all the different GCKs we had to first have students who used all these available kits.

Due to the existing bias at the ground level, it was nearly impossible to find enough number of students who were using all the GCKs that the research was interested in studying. Hence, it was acknowledged that the research would have to follow a different design. It would have to have a teaching phase followed by a feedback phase.

This chapter aims to familiarise the reader of this report with the following:

I. Overall research design (Sample, Framework and Process)
II. The GCKs and tools used and tested in the research
III. Tool combinations across skills
IV. The specific pedagogy of teaching used in the research

I. Research Design

Given that the purpose of the research was to identify the most effective design elements for a comprehensive GCK, efforts were made to design the research process and the sample to ensure that one could elicit the maximum amount of feedback from as diverse a group as possible without any prior learning or exposure interfering with feedback. Presented below are details of the sample and the research process used.

The Research Sample:

The purposive sampling aimed to get inputs of respondents across gender, age and location. Efforts were made to ensure that a diverse sample would reflect design preferences that are as universally applicable as possible to create the design brief that will have high effectiveness for maximum number of users.

The research was conducted in four locations, the two cities of Mumbai and Noida and the two semi-urban cities of Junagadh and Akola to ensure an urban-semi-urban variation. The sample size for the research was 40 participants with an equal number of female and male participants. The participants were grouped according to age, the younger group comprised of students from Class 4 to Class 8 and the older group comprised of students from Class 9 to Class 12. Also, for the purpose of this study, only the method for students with total blindness was used. While we initially wanted the full sample to be comprised of students with total blindness, in some rare cases where we did not find enough totally blind participants, some students with low vision were taken on with only their sense of touch used to work with the tools. The demographic distribution of the sample across age, gender and geographical location is documented in Tables 2.1 and 2.2 below.

Table 2.1: Distribution of Nature of Respondents

Location	Older		Younger		Total
	Male	Female	Male	Female	
City	3	8	6	4	**21**
Non-City	7	2	4	6	**19**
Total	**10**	**10**	**10**	**10**	**40**

Table 2.2: Distribution of Nature of Respondents by Gender

Location	Male	Female	Total
City	9	12	**21**
Non-city	11	8	**19**
Total	**20**	**20**	**40**

As reflected above, while the sample has tried to maintain diversity across age, gender and location, we were not able to get an equally representative sample for each category. Since the research process demanded a long time commitment it was difficult to find the exact number of respondents for each category. Further, the research also faced the challenge of respondents dropping out half way due to medical and logistical reasons, needing the research team to make modifications. However, this has been taken into consideration subsequently where location was not made into a variable of comparison but left only to a variating factor at the time of analysis.

The Research Framework:

For the purpose of being able to receive specific feedback about existing GCKs, it was essential for the research to develop a sound framework against which data could be collected.

This framework was developed in conjunction with the nuances of pedagogy of geometry as a field of study. Since the purpose of the study was to identify design elements related to GCKs, it was important to keep in mind the specific purpose of each tool and understand whether the design elements of the tool fostered or hindered the performance of the said task by the specific tool.

In order to streamline and structure the same, the research has used a **Skill Framework** for the data collection and analysis. Geometry studying can be broadly divided into **six core skills**. These skills are used for geometry constructions across years of studying. The research has, therefore, used these skills as the bedrock to devise the research design and, subsequently, the data collection and analysis. The table 2.3 below presents the details of the skill framework.

Table 2.3: The Skill Framework of the Research

Sr. No.	Skill Name	Tools in the GCK that will be used
1	Constructing a Line Segment	Drawing Boards, Sheets to draw on, Pins, Styluses, Rulers
2	Measuring a Line Segment	Drawing Boards, Tactile Diagrams, Pins, Rulers
3	Constructing an Angle	Drawing Boards, Sheets to draw on, Pins, Styluses, Rulers, Protractors
4	Measuring an Angle	Drawing Boards, Tactile Diagrams, Pins, Styluses, Rulers, Protractors
5	Drawing/Constructing a Circle	Drawing Boards, Sheets to draw on, Pins, Styluses, Rulers, Compasses
6	Constructing /Cutting Arcs	Drawing Boards, Sheets to draw on, Pins, Styluses, Protractors, Compasses

The research used a large number of tools, all of which are listed in the subsequent tools sections. Each of these tools was tested for their effectiveness for the skills that they apply to. The pedagogy used in teaching students each of the six skills listed above with all the tools being tested is explained in the subsequent section on pedagogy. But it is important to state that the research followed the teaching-testing and analysis of data within this skill framework.

The Research Process:
The ground level reality was that not too many students with blindness had had exposure to geometry kits, and those who had, had primarily used the reverse-side drawing method of learning. Therefore, the research was designed such, that all respondents were first taught the abovementioned skills through usage of the tools selected for testing. Subsequently, they were tested and also observed under a neutralised game environment. In the end, user feedback was also procured through a questionnaire.

The Process can be detailed out as below:

Stage 1: Participant Registrations: Participants were made to sign a Consent Form and their details were recorded. While signing the consent form (or getting the form signed by their supervisors for minors), the students were informed about the entire study procedure listed here as well as the terms and conditions for participating in the research. The Consent Forms can be found in Annexure A and Annexure B.

Stage 2: Training: The participants were trained in each of the abovementioned skills using the geometry tools selected in the research. Students were asked to continue to practise till they learnt the skill thoroughly. Observations were made and noted during this time. A video recording of the same was also taken. The researcher's observation formats can be found in Annexure C.

Stage 3: Test: At this stage, the participants were asked to perform one construction for each of the skills independently — for each tool combination presented by the researcher. Observations were made and noted during this time. A video recording of the same was also taken. The researcher's observation formats can be found in Annexure D.

Stage 4: Game Simulation: At this stage, the participants were given all the tool combinations taught and they were asked to select any one that they preferred to work with and perform one construction per skill based on the selected tool combination. Their tool selection was noted down for each skill. The researcher's observation formats can be found in Annexure E.

Stage 5: Feedback Questionnaire: The participants were made to answer a detailed questionnaire related to the tools used for each skill at the end of training, test and game simulation for each skill. On completion of all six skills, the participants were made to answer a detailed questionnaire about all the geometry tools used for the research across all skills. The questionnaire formats can be found in Annexure F.

Some additional factors of the research process included the following:

- The research process was undertaken as far as possible in groups of 4-5.
- During the training and test sessions, each student would be trained and tested with different tools. The students would take turns using the geometric tools and pass the tool on to the next student till all the students in a batch had their turn. This was, both, a result of time constraints and the number of each tool available at the disposal of the researcher.
- The training, test, game and skill-specific questionnaire were completed for each skill at a time, and only then would the researcher move to the next skill (in the majority of cases).

II. Tools Used In the Research

For blind and low vision students, the challenges of teaching and learning a visually, spatially and practically-rich subject like geometry can be reduced with the availability of accessible reading and writing tools and tactually represented diagrammatic content.
For practical geometric constructions, the availability and use of geometry tools is required. There are a wide range of GCKs and tools available in the world for students with blindness and low vision. This research narrowed down on the tools being tested based on a set of criteria. It is important to first understand the rationale for selecting the tools used for testing in this research before familiarising ourselves with each.

Rationale for Selection of Tools

- For the purpose of this study, only tools that permitted same side drawing were selected. This is because the XRCVC team, through its own experience, is of the strong view that reverse-side drawing tools make the construction process complex and is one of the biggest reasons for students giving up on geometry. Hence, efforts need to be made towards building an effective same side GCK.
- The study has restricted itself to the use of only easy-to-carry tools and GCKs. There are some same-side construction kits in the market that are quite bulky and would make their day-to-day usage at school and home nearly impossible. It is for these reasons that certain kits have been left out the study, such as the aluminium version available through the National Institute for the Empowerment of Persons with Visual Disabilities (Divyangjan), previously the National Institute for the Visually Handicapped (NIVH), Dehradun. The purpose is to devise a kit that can be easily carried to the school everyday by the student.
- Since the study was restricted to GCKs for students with total blindness alone, kits for those with low vision have been kept out of the purview of this research.
- It is also important to note, that this research has selected the tool for study based on the XRCVC's training experiences with students. There are other tools available not studied here. The rationale for our selection was based on diversity of methods of tools as also those found most effective in our trainings.

Based on the above rationale, the study has narrowed down on the following tools to be tested.

Actual Tools Used in the Research

As listed in the skill framework, each skill required some primary tools and some base materials and tools that have been used across skills. The following table lists out the key categories and the specific tools under each category used for the study. The particular tools used are further illustrated and elaborated below.

Table 2.4: Tools Used in the Research Process

Tool Category	Specific Tool Names used in the Research
Rulers	RNIB ruler, APH Clip ruler, WT ruler, Draftsman ruler, Squirrel ruler, Garg ruler
Protractors	RNIB protractor, WT protractor, APH wand inside protractor, APH wand protractor, Garg protractor
Compasses	Classmate compass, APH compass, Garg circle markers, Garg arc markers, WT ruler as compass
Drawing Boards	Draftsman board, exam board with Silicon Mat, Garg board
Pins	Regular Board pins, RNIB pins, RNIB knob, Garg point markers
Styluses	Garg stylus, Line markers, typical stylus
Drawing Sheets	Plastic sheet, Braille paper
Tactile Diagrams	Thermoform sheet, Plastic sheet, Braille paper

A detailed description of the specific tools is provided below. It is essential for readers to familiarise themselves with the same before reading further to understand the research findings.

Rulers

1. **Royal National Institute of Blind People Tactile Ruler (hereafter RNIB Ruler)** is a yellow and black, 30 cm (centimetre) ruler with two distinct sides/edges: smooth and grooved. The smooth side of the ruler has long and short tactile lines for every 10 mm (millimetres) and 5 mm mark respectively. The grooved side of the ruler is equipped with a tactile line and a groove for every 10 mm measurement, but for a 5 mm measurement, only a corresponding groove is provided. At every 5 cm measurement an extra-long tactile mark, extending across the width of the ruler from the smooth side to the grooved side, is provided. This ruler has sighted print labels at measurements of 1 cm to 10 cm and then at 15 cm, 20 cm, and 25 cm. It has no braille labels.

Figure 2.1: RNIB Ruler

2. **American Printing House Tactile Ruler (hereafter APH Clip Ruler)** is a 12 inch black plastic ruler with a removable calliper. The ruler is marked in cm (centimetres) along one side, and in inches on the other side. Long and short tactile lines denote every 10 mm and 5 mm mark respectively. Braille labels are provided for every multiple of 2 on the centimetre side and for every inch on the other side. The braille numeric indicator is skipped in the braille labels. It does not have any sighted print labels.

Figure 2.2: APH Clip Ruler

3. **Workshop for the Rehabilitation and Training of the Handicapped Trust (WORTH Trust) Ruler (hereafter WT Ruler/ or WT Ruler as compass)** is a 15 cm ruler with a semi-circular edge at one end. Both sides of the ruler have raised tactile lines and dots that denote every 10 mm and 5 mm measurement respectively. The semi-circular edge of the ruler has a hole for putting a pin through to transform the ruler into a compass. Further, in the central portion along the length of the ruler, a hole corresponding to every dot and line mark is provided i.e. a hole at every 5 mm. This ruler does not have any sighted print or braille labels.

Figure 2.3: WORTH Trust Ruler or WT Ruler

4. **American Printing House Draftsman Tactile Ruler (hereafter Draftsman Ruler)** is an 11 inch ruler with a protruding edge that enables it to be fastened onto the Draftsman board by tightening the screw on the protruding edge. The Draftsman ruler does not have sighted print or braille labels and has a smooth side and a grooved side. An extra-long raised line extends across the width of the ruler denoting every inch mark on the smooth and grooved side. On the smooth side, a short raised line denotes half an inch and an extra-short raised line represents every quarter inch measurement. On the grooved side of the ruler, every groove denotes a quarter of an inch. Every inch is divided by 15 indents represented by short raised lines on the surface of the ruler dividing each inch into 16 parts.

Figure 2.4: Draftsman Tactile Ruler or Draftsman Ruler

5. **Squirrel Devices Tactile Caliper (hereafter Squirrel Ruler)** is a 12 inch ruler with a refreshable braille caliper/clip. The ruler has a fixed clip on the left that denotes the 0 mark. The refreshable braille clip reads the 16 parts of an inch as a fraction i.e. 0/16 for a whole inch and 8/16 for every half an inch, e.g. to represent 3.5 inches, after the clip crosses the 3-inch mark, the Braille on the clip should read 8/16. Braille labels are to the left of the raised lines denoting an inch. It has no sighted print labels.

Figure 2.5: Squirrel Devices Tactile Caliper or Squirrel Ruler

6. **The Garg Ruler** is a 30 cm ruler with a grooved side/edge and a smooth side/edge. The ruler has a long tactile line with two dots below it at 0 cm and every 5 cm measurement. It has a long tactile line with one dot below it at every 1 cm mark. It has a short tactile line at every 5 mm measurement. All the tactile line markings are only towards the grooved side of the ruler. The grooves are at 0 mm and every 5 mm measurement. The ruler has no sighted print or braille

labels. The ruler has three tiny magnets on its reverse side to enable it to somewhat stick to the Garg board.

Figure 2.6: Garg Ruler

Protractors

1. **Royal National Institute of Blind People Tactile protractor (hereafter RNIB Protractor)** is yellow with black visual markings with a semi-circular notch at the centre of the baseline of the protractor. For every 5-degree measurement, the protractor has a short tactile line and a corresponding groove. There are long tactile lines and every second groove representing a 10-degree measurement. An extra-long dashed line extending along the surface of the protractor towards the notch at the centre of the base is marked at 45 degrees and 135 degrees each. Another extra-long but solid line extending along the surface of the protractor towards the notch at the centre of the base is found at the 90-degree mark. The protractor has no sighted print and braille labels.

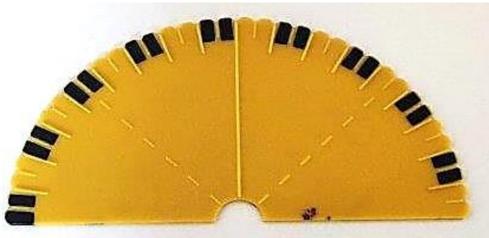


Figure 2.7 RNIB Protractor

2. **Workshop for the Rehabilitation and Training of the Handicapped Trust Protractor (hereafter WT Protractor)** is a small orange protractor with five tips at its base for better alignment to the baseline. There are two immobilisation holes provided on the body of the protractor near the baseline. The protractor has a long raised line and a corresponding groove denoting every 10-degree mark; a raised dot is provided for every 5-degree measurement. An extra-long raised line and a dot below it are provided at 30-, 60-, 90-, 120- and 150-degree measurements.

Figure 2.8: WT Protractor

3. **American Printing House Tactile Protractor (hereafter APH Wand-inside Protractor)** is a transparent protractor with a ruler at its bottom edge (baseline) of the protractor. It is

equipped with a yellow moveable wand, connected at the centre just above the baseline that extends a little over the surface of the protractor, thus crossing or covering the tactile measuring marks under it. Two raised dots denote every 10-degree measurement and a single dot denotes every 5-degree measurement. Three dots are provided to mark 0, 45, 90, 135, and 180 degrees each. Notches are provided at the bottom left and right side for immobilisation. Braille labels are provided at 0, 45, 90, 135 and 180 degrees. It has no sighted print labels.

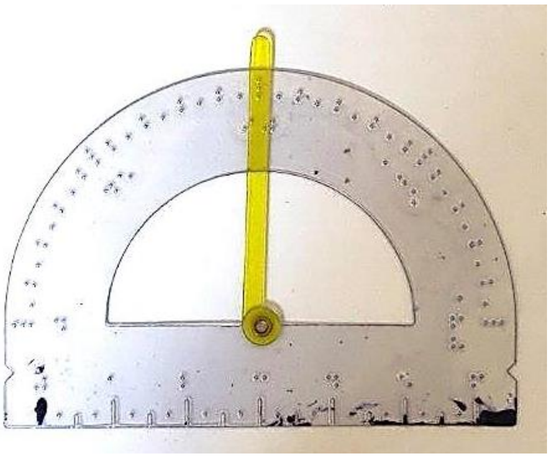


Figure 2.9: APH Wand-inside Protractor

4. **American Printing House Braille-Large Print Protractor: (hereafter APH Wand Protractor)** is a transparent protractor equipped with a large, blue moveable wand that extends much beyond the surface of the protractor. One end of the wand is pointed and ends just below the tactile measuring dots along the semi-circular scale of the protractor. The knob attaching the wand to the baseline of the protractor can be tightened to fix/immobilise the moveable wand in place. The protractor has sighted print measurement markings and two raised dots to denote every 10-degree measurement and a single dot for 5-degree measurement. For ease of measurement, three dots are provided at 0, 45, 90, 135 and 180 degrees. It has no braille labels.

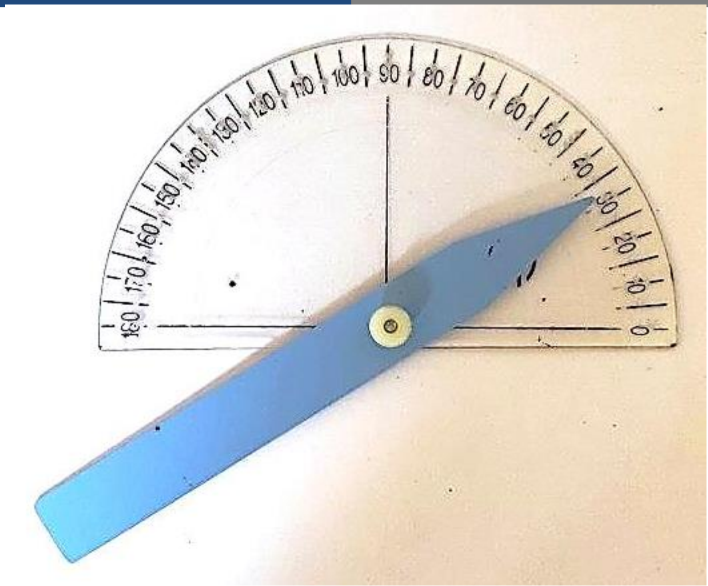


Figure 2.10: APH Wand Protractor

5. **Garg Protractor** is designed like a wheel and has spokes and a central hole for immobilisation. A long arm extends from the protractor that represents the 0-degree mark and the baseline. The protractor has a long raised line for every 10-degree measurement and a raised dot for every 5-degree measurement. A combination of a raised line and dot is seen at the 30-, 60-, 90-, 120-, 150-, 180-, 210-, 240-, 270-, 300-, 330-, 360-degree measurements. The spokes extend only at these measurements. At one of these measurements, where the spokes extend, i.e. at every 30-degree interval), an extended line marker is attached, thus making that the 0-degree and 360-degree mark on the protractor. It has no sighted print or braille labels. It has tiny magnetic bits on its reverse side to enable it to somewhat stick to the Garg board.

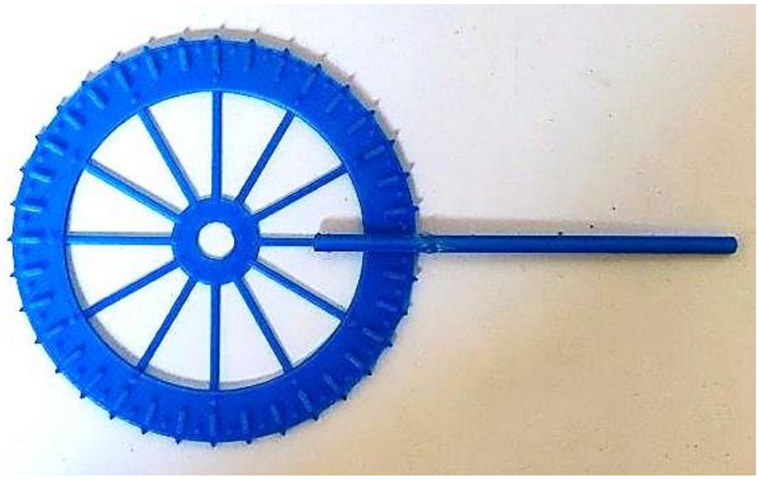


Figure 2.11: Garg Protractor

Compasses

1. **The Classmate Compass** has two legs; a sharp pin leg and a second leg with a slot for fixing a pen / pencil for drawing. The ballpoint pen can be fixed by loosening and tightening the screw. At the top of the compass, a screw type knob is provided to immobilise the two legs in place.

Figure 2.12: Classmate Compass

2. **American Printing House compass (hereafter APH compass)** has two legs; a fixed sharp pin leg and a second leg with a spur wheel. This second leg is movable along a rod which has a ruler. This inbuilt ruler provided on the compass has long and short tactile markings in centimetres on one face/side and in inches on the other. The spur wheel leg slides over the ruler and can be fixed at the desired measurement by tightening the screw placed on top of the spur wheel leg.

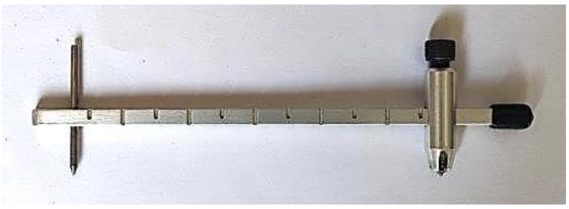


Figure 2.13: APH Compass

3. **Garg Circle Markers (hereafter Circle Markers)** are provided in set radius measurements as part of the Garg kit. The circle markers have a wheel design with spikes and a central immobilisation hole. A braille label is provided near the central immobilisation hole to identify the desired radius measurement for drawing a circle.

Figure 2.14: Garg Circle Markers

4. **Garg arc markers (hereafter Arc Markers)** have a wheel design with a central immobilisation hole. A single wheel has three set radius measurements for drawing arcs. Braille labels are provided near the central immobilisation hole for identifying the required arc for drawing.

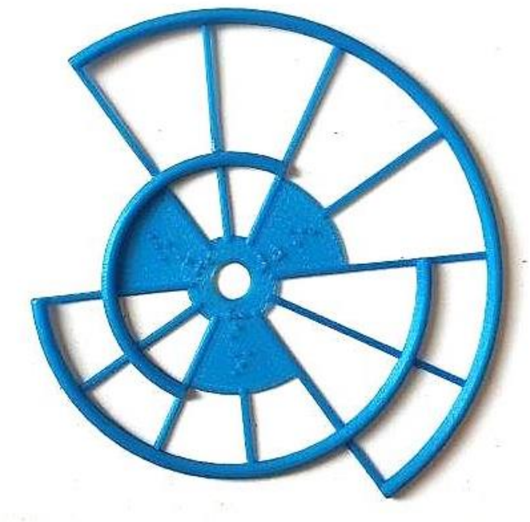


Figure 2.15: Garg Arc Markers

Boards

1. **American Printing House Draftsman Drawing Board (hereafter Draftsman board)** is a rectangular board with a fixed silicon mat and foam screen. The short vertical sides of the board have clasps that open to secure the sheets. The clasps and the top length of the board have ridges that allow for the fastening of the Draftsman ruler. The bottom-right corner of the board has the name of the board in sighted print and braille and the bottom-centre to left has a slot for placing the stylus that comes with the board.

Figure 2.16: Draftsman Board

2. **Exam Board with a Silicon mat** is a rectangular board with a smooth surface which is used vertically. A clip is provided along the upper breadth of the board to secure the sheets and the mat on the board.
   Silicon Mat has a smooth rubbery surface on one side and a foam screen on the other. The sheet being used is to be placed over the smooth side for constructions.

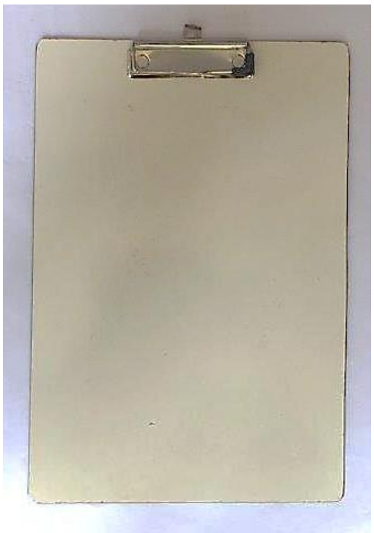


Figure 2.17: Exam Board

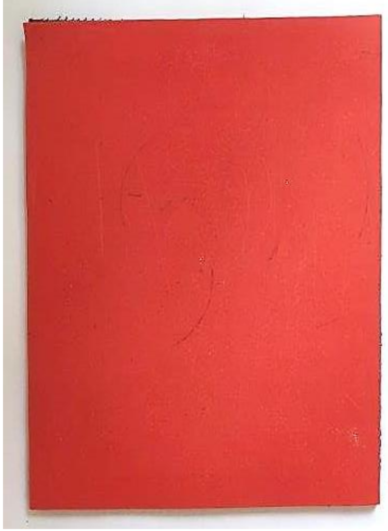


Figure 2.18: Silicon Mat

3. **Garg Drawing Board (hereafter Garg board)** is a rectangular board with a smooth surface which is used vertically. A clip is provided along the upper breadth of the board to secure the sheets and mat on the board. The surface of the board has a metal sheet underneath it to enable the magnet stickers on the tools that are to be used with this board to stick. The clip when opened has two tiny magnet bits to allow it to close securely over the paper. The clip also has two holes on one side and two projections on the other side to create a mark on the paper once set in the board, so that with those marks the paper can easily be reset later, similar to the concept of the braille slate. Along the two vertical edges of the board, tactile indents are provided equally aligned to aid in straight alignment of the ruler on the board, similar to the concept of the wooden braille slate with the removable metal strip.

Figure 2.19: Garg Drawing Board or Garg board

Pins

1. **Push pins or regular board pins (hereafter regular pins)** were used throughout the research by the participants to immobilize some of the tools and the sheet.

Figure 2.20: Push Pin or Regular Board Pin

2. **Royal National Institute of Blind People protractor pins (hereafter RNIB pins)** are yellow RNIB pins that are a part of the RNIB protractor apparatus and are used to mark the vertex point of the angle. It is also used to mark the end points of a segment and/or measurement marks. The metal pin portion of the RNIB pins is longer than that of regular pins and the yellow plastic top of the pin is cylindrical.

   Royal National Institute of Blind People protractor knob (hereafter RNIB Knob) is a yellow cone shaped knob and is part of the RNIB protractor apparatus. The broader base of the cone is placed over the vertex RNIB pin to mark the vertex. The RNIB protractor rests on the RNIB knob at the baseline.

Figure 2.21: RNIB Knob and RNIB Pin

3. **Garg Kit Point Markers (hereafter Point Markers)** are small circular pin with magnets at the base. The magnet pin is attached to a butterfly shaped handle that assists in positioning/moving the pin on the board

Figure 2.22: Garg Point Marker

Styluses

1. **Garg Stylus** is a thin cuboid about 4 inches. The Garg stylus has a small bulge on one end that acts as a hook that is used to draw over the line markers.

Figure 2.23: Garg Stylus

2. **Garg Line Marker (hereafter Line Markers)** are two thin plastic bars of different lengths based on their use. The line markers have a dome-shaped bulge on one side and a flat surface on the other. The flat part of the line marker has an indent that runs along the entire length.
   The **Line Marker Bridge** that comes with the line maker is a square with tactile lines for supporting the line marker. It has a magnetic base.

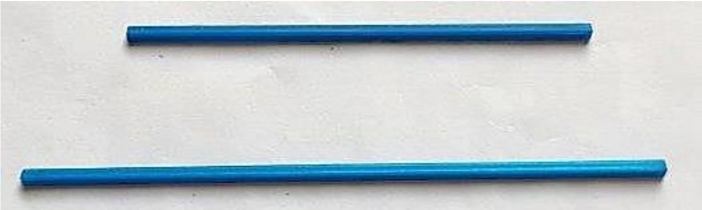


Figure 2.24: Garg Line Markers

Figure 2.25: Line marker bridge

3. **Typical stylus** is the regular round head or wing stylus that has a pointed nib used for braille writing on braille slates.

Figure 2.26: Two Typical styluses

Sheets

1. **Plastic Sheets** are thin translucent sheets or films known commonly as parchment paper/ swell paper/ drawing sheets/ drawing film in different countries. The same are also provided along with the APH Draftsman Board Drawing kit. When placed on a silicon/rubber mat and drawn on with sufficient pressure, they tend to raise on the same side.

Figure 2.27: Plastic Sheet

2. **Braille Paper** is regular braille paper of 120-140 GSM used for braille writing on slates/braillers.

Figure 2.28: Braille Paper

Tactile Diagrams (TDs)

1. **Thermoform Sheets:** TDs created on PVC sheets using the thermoforming process tend to have smooth raised lines that last long.

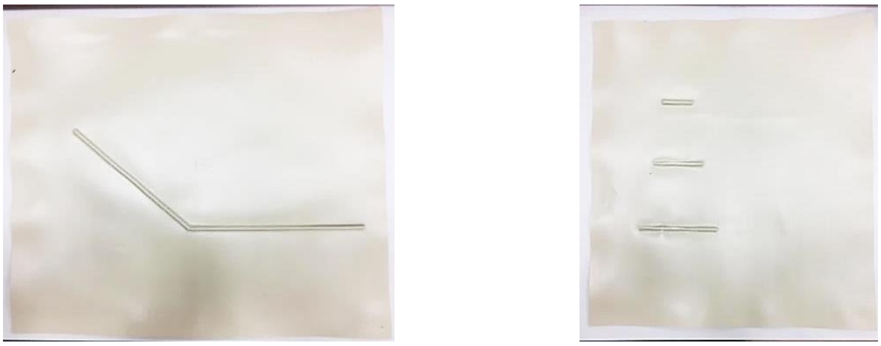


Figure 2.29: Tactile diagrams on thermoform sheets

2. **Plastic Sheets:** TDs that are handmade on the abovementioned plastic sheets may have lines that are tactually thin, but can widen overtime, such as when stored one over the other for long.

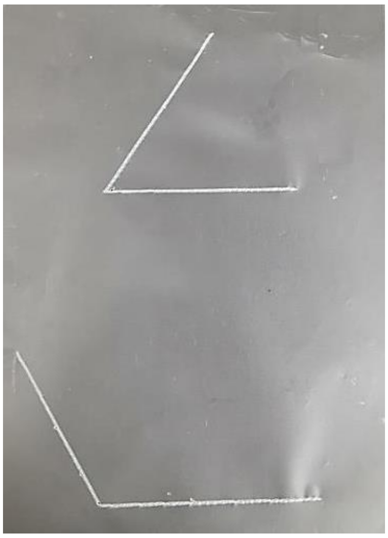


Figure 2.30: Handmade diagrams on a plastic sheet

3. **Braille Paper** are handmade diagrams made on braille paper using reverse side process. The lines are tactual but can flatten overtime with pressure.

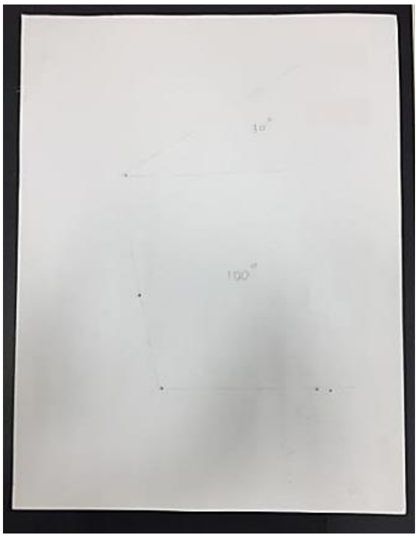


Figure 2.31: Handmade diagram made on Braille paper

III. Tool Combinations across Skills

Having understood the skill framework and tools used in the research, we would like to present below, in which combinations the tools were tested for each of the skills. The combinations were created to ensure a wide variety of exposure and usage for all tools under varying conditions.

Table 2.5: Tool Combinations Across The Six Skills

Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment	Skill 3: Constructing an Angle	Skill 4: Measuring an Angle	Skill 5: Constructing a Circle	Skill 6: Constructing/ Cutting Arcs
1. Exam Board + RNIB Ruler	1. Exam Board + Thermoform sheet + APH Clip Ruler	1. Exam Board + WT Protractor + WT Ruler	1. Exam Board + Thermoform sheet + WT protractor	1. Exam Board + Classmate Compass + APH Clip Ruler	1. Exam Board + Classmate Compass
2. Exam Board + APH Clip Ruler	2. Exam Board + Thermoform sheet + RNIB Ruler	2. Exam Board + WT Protractor + RNIB Ruler	2. Exam Board + Thermoform sheet + RNIB protractor with pins	2. Exam Board + Classmate Compass + RNIB Ruler	2. Exam Board + WT Ruler as compass
3. Exam Board + WT Ruler	3. Exam Board + Thermoform sheet + WT Ruler	3. Exam Board + WT Protractor + APH Clip Ruler	3. Exam Board + Thermoform sheet + APH Wand Protractor	3. Exam Board + Classmate Compass + WT Ruler	3. Exam Board + APH Compass
4. Exam Board + Squirrel Ruler	4. Exam Board + Thermoform sheet + Squirrel Ruler	4. Exam Board + RNIB Protractor + WT Ruler	4. Exam Board + Plastic sheet + WT protractor with pins	4. Exam Board + Classmate Compass + Squirrel Ruler	4. Garg board + Garg circle markers / Arc Markers
5. Draftsman Board + Draftsman Ruler	5. Exam Board + Plastic sheet + APH Clip Ruler	5. Exam Board + RNIB Protractor + RNIB Ruler	5. Exam Board + Plastic sheet + WT protractor without pins	5. Exam Board + WT ruler as compass	
6. Garg Board + Garg Ruler	6. Exam Board + Plastic sheet + RNIB Ruler	6. Exam Board + RNIB Protractor + APH Clip Ruler	6. Exam Board + Plastic sheet + RNIB protractor with pins	6. Exam Board + APH Compass	
	7. Exam Board + Plastic sheet + WT Ruler	7. Exam Board + APH Wand Protractor	7. Exam Board + Plastic sheet + APH Wand Protractor	7. Garg board + Garg circle markers	
	8. Exam Board + Plastic sheet + Squirrel Ruler	8. Exam Board + APH Wand-inside Protractor	8. Exam Board + Braille paper + WT protractor with pins		

Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment	Skill 3: Constructing an Angle	Skill 4: Measuring an Angle	Skill 5: Constructing a Circle	Skill 6: Constructing/Cutting Arcs
	9. Exam Board + Braille paper + APH Clip Ruler	9. Garg Board + Garg Protractor	9. Exam Board + Braille paper + WT protractor without pins		
	10. Exam Board + Braille paper + RNIB Ruler		10. Exam Board + Braille paper + RNIB protractor with pins		
	11. Exam Board + Braille paper + WT Ruler		11. Exam Board + Braille paper + APH Wand Protractor		
	12. Exam Board + Braille paper + Squirrel Ruler		12. Garg Board + Braille paper + Garg protractor		
	13. Garg Board + Braille paper + Garg Ruler				

Some key factors to be recognised in understanding the combinations selected above are as follows:

- For the skill of measuring a line segment, the students were not taught to use the Draftsman board as the immobilizing feature of this board prevents the use of different tactile sheets of varying sizes.
- The Garg board could be used only in combination with the Garg ruler and paper Tactile Diagrams (TDs).
- The Draftsman Board was not used for the skill of constructing an angle as the Draftsman Ruler can only be immobilized on the board horizontally and vertically. The option of using other rulers on the board were not explored.
- The Squirrel Ruler was not used for the skill of constructing angles.

IV. Teaching Pedagogy Used In The Research

One of the most critical challenges of the research was to be able to ascertain the methods of using the various tools available in the market.

As mentioned earlier, our work with students had revealed that either the students did not use the existing tools because they could not understand the method to use them (since the tools themselves did not come with instruction manuals) or the same tools were being used with several different methods as per the understanding of the tutor/student.

In wanting to understand effectiveness of the tools, it was critical to segregate the effectiveness of the methods used in operating the tool v/s the design element of the tool. At some level, the two are interconnected. Hence, a large part of the research landed up becoming the process of documenting a method of 'teaching' the use of the specific tools. This ensured that when the tools were being tested, they would be verified indirectly both for the documented method as also the design.

Additionally, given that the tools used in this research were to test same-side drawing, whereas on the ground, students in India were mainly using reverse-side drawing, or had no experience with any geometry drawing work, the research design, as illustrated in the earlier section, had to include a training element.

Thus, the research process became far richer – both in implementation as also analysis – to not only reflect the most desired design elements of the tools, but simultaneously also in identifying the most desired teaching approaches nececssary for a Geometry Skill teaching curriculum to be adapted from the pedagogy of teaching used in this research for students with blindness and low vision.

We present below the pedagogy used during the training phase of the research process to help readers gain a richer understanding of the analysis in the subsequent chapters.

An effort was made to break down each skill into specific sub-parts of teaching-learning to make the process of learning as well as research more effective and scientific. Before we go into listing the details of the training, the table below provides an overview of the sub-elements of the training involved.

Table 2.6: Overview of Training Elements of the Research

Geometry Pre-Skills	Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment	Skill 3: Constructing an Angle	Skill 4: Measuring an Angle	Skill 5: Constructing a Circle	Skill 6: Constructing/ Cutting Arcs
Orientation and handling of equipment	Explaining the concept of line segment; Orientation to each specific ruler	Revision of the concept of line segment; Introduction to skill of measuring lines	Explaining the concept of an angle	Revision of the concept of an angle; Introduction to the skill of measuring angles	Explaining the concept of a circle; Orientation to the specific compass (each different type)	Explaining the concept of arcs in link with line bisection as an example
Using of board	Finding the area to draw	Orientation to TDs; Use of ruler to measure a line segment on each type of TD, as applicable	Orientation to the specific protractor (each different type)	Orientation to TDs; Use of protractor to measure an angle on each type of TD, as applicable	Setting/ fixing the radius	Orientation and use of each compass to cut arcs for line bisection
Learning how to draw	Teaching how to keep the ruler straight and centralised	Finding the two end points	Finding the area to draw	Aligning protractor to vertex and base line	Finding the area to draw	Orientation to line segment and measurement
	Plotting points and measuring	Aligning the ruler to the line segment	Drawing the base line	Reading the measurement	Drawing the circle	Fixing compass leg to end points of line segment
	Connecting plotted points	Reading the measurement	Finding the vertex; Aligning to vertex and base line			Setting the radius
			Reading the measurement; Plotting the point			Drawing the arc
			Drawing the second arm			Finding the intersecting points; Drawing the bisector

The details of the teaching techniques used for each of the phases of training is presented in Annexure G.

CHAPTER 3. WORLD OF LINES

The preceding chapter provided an overview of the entire research process, the teaching methodology, and a thorough description of the tools used for this research. Having understood in detail the pedagogy involved in conducting the training and test sessions of each skill, the focus of the report now shifts to presenting the results of the training and test sessions.

Since the purpose of the research is to devise an effective GCK, data is presented based on combining skills. Chapter 3 will look at the data of Skills 1 and 2 related to drawing and measuring of line segments; Chapter 4 will look at the data of Skills 3 and 4 concerning drawing and measuring of angles, and Chapter 5 will deal with Skills 5 and 6, i.e. drawing of circles and of arcs.

This chapter will present the data collected through primary research broadly in three sections:

I. Skill 1 Training and Test Results and Observer Inferences
II. Skill 2 Training and Test Results and Observer Inferences
III. Key Design Inferences for the Tools related to the skill of drawing and measuring line segments

I. Skill 1: Constructing a Line Segment (Training and Test Phase Data and Observer Inferences)

For Skill 1 of constructing a line segment, Tables 3.1 and 3.2 below document the highest occurring errors across the six rulers during the test and training phase respectively. Detailed data tables for the same can be found in corresponding table numbers of Annexure H.

Table 3.1: Skill 1: Key Issues: Training Phase (%)

	APH Clip Ruler	Draftsman Ruler	Garg Ruler	RNIB Ruler	Squirrel Ruler	WT Ruler	Total
Points/ point markers/ clip not accurately plotted against the marks	10	62.5	15	42.5	0	42.5	28.75
Ruler movement or going crooked at measuring and plotting end point	20	0	37.5	35	12.5	20	20.83333
Struggled in pushing pins in the board/ Struggled in sliding point markers to position	0	20	65	5	0	2.5	15.41667
Ruler movement at plotting start point	15	0	30	27.5	5	15	15.41667
Drawing before end point	27.5	10	7.5	22.5	2.5	17.5	14.58333
Drawing beyond end point	5	17.5	25	12.5	0	17.5	12.91667
Stylus going away from the ruler while drawing	5	12.5	0	12.5	10	30	11.66667
Using wrong side of the ruler	0	35	2.5	30	0	0	11.25

Table 3.2: Skill 1: Key Issues: Test Phase (%)

	APH Clip Ruler	Draftsman Ruler	Garg Ruler	RNIB Ruler	Squirrel Ruler	WT Ruler	Total
Points/ point markers/ clip not accurately plotted against the marks	15	50	25	47.5	7.5	22.5	27.916 67
Drawing before end point	27.5	27.5	7.5	30	12.5	22.5	21.25
Ruler movement at connecting two points	50	2.5	5	15	30	17.5	20
Ruler movement or going crooked at measuring and plotting end point	15	2.5	30	27.5	12.5	10	16.25
Careless counting mistakes/ Measuring mistakes	12.5	25	7.5	12.5	10	12.5	13.333 33
Struggled drawing on the sheet	5	12.5	22.5	12.5	7.5	12.5	12.083 33
Drawing beyond end point	5	10	17.5	10	10	17.5	11.666 67
Using wrong side of the ruler	5	17.5	2.5	42.5	0	0	11.25

The data presented above is across the entire sample population and presented as percentages. Male-Female differentiation is not presented as the difference was found negligible.

The results of the training and test stages of the research reveal certain common *key issues* as the main drawing challenges for the students:

- **Points/ point markers/ clip not accurately plotted against the marks**: At the time of drawing the lines, when students were instructed to plot the start point by placing a pin/ point marker/ clip as the start point, students were not able to accurately place the same corresponding to the selected marking on the ruler.
- **Ruler movement or ruler going crooked at measuring and plotting end points:** Students had to hold the ruler with one hand while they plotted the end point, and many students struggled in doing the same.
- **Drawing before the end point and drawing beyond the end point:** For constructing a line segment, students were expected to draw from the start point till the end point. But many students struggled to complete the line segment accurately till the end point. They would either stop before or draw beyond.
- **Using the wrong side of the ruler:** Since many of the rulers had two different measurements on both sides, many a time, students would keep using different sides of the ruler during the drawing process leading to measurement errors.

In addition to the common issues, some key issues specific to the training stage were revealed:

- Struggled in pushing pins in the board/ Struggled in sliding point markers to position
- Ruler movement at plotting the start point
- Stylus going away from the ruler whilst drawing. This would lead to students not being able to draw a straight line.

The key issues unique to the test phase were:

- Ruler movement at connecting two points
- Careless counting mistakes/ Measuring mistakes
- Struggled drawing on the sheet

The data presented above, documenting the key challenges for students, highlights the following factors:

- **The accurate plotting of points** was higher with **tools that used clips** rather than tools using pins. This process of locating the measurement mark on the ruler and simultaneously finding the appropriate point on the board to plot the pin caused errors. While using the clip method, students could easily first fix the clip on the ruler to the accurate measurement mark and then place the point on the board by using the clip as the resting point, making the process easier (Refer to Figure 3.1). It is also important to note that for the WT ruler, this error reduced significantly at the test phase which is not the case for the Draftsman and RNIB rulers. This indicates a learning and practice curve in case of the WT ruler.

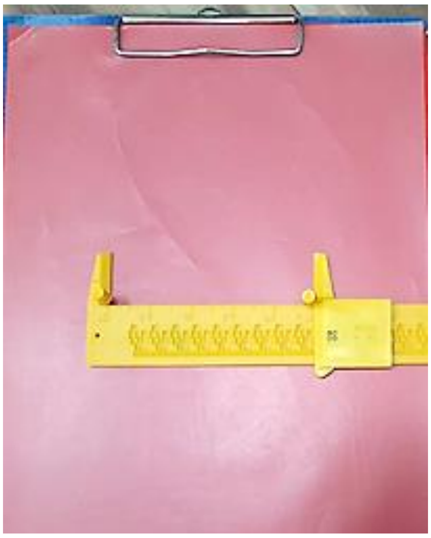


Figure 3.1: Accurate plotting of points using the Squirrel Ruler

- The issue **of drawing before end points occurred more in cases where the ruler used clips as the clips tend to slide and not remain fixed. It was also high in cases where the ruler uses pins for plotting points but the ruler itself cannot be immobilized**. Whereas the issue of drawing beyond end point only occurs for rulers using pins as the clip prevents drawing beyond end points. Hence, an immobilized clip would perhaps be the best design solution for accurate drawing.
- **Rulers with different markings and different sides – smooth and grooved sides – caused confusion; students ended up using the wrong side of the rulers at different steps of the drawing process.** To avoid this error, it might be advisable to equip the ruler with a single measurement unit (inches or centimeters) on any of its sides.

- The issue of ruler movement at plotting end point is noticed most with the Garg and RNIB rulers. The challenge with the Garg ruler stems from **the method of positioning** the point markers into the Garg ruler grooves. The RNIB ruler is not immobilized, therefore, **the lightweight and longer length of the ruler might lead** to greater movement as students might find it difficult to hold down the ruler with one hand and count to identify the accurate groove, hold down the particular groove or measurement mark and place pins in the ruler grooves all with the other hand.

Training Specific

- The struggle of pushing pins in the right spot/groove of the ruler happened significantly more with the Garg Ruler (65%) and Draftsman Ruler (20%). For the Garg ruler, this error is related to **the method used** by the tool that requires students to push the Braille paper on the pins which are placed underneath the paper. This method oftentimes caused the pins to move on the board under the Braille paper because the pin magnets were not very strong. For the Draftsman ruler, the **foam/silicon mat on the board** did not facilitate an easy plotting of pins.
- The issue of ruler movement at plotting the start point is again noticed most in the Garg and RNIB rulers due to the reasons that have already been discussed above.

  The issue of the stylus going away from the ruler as also under the ruler was seen to be highest for the WT ruler (30%). This reflects a critical issue with the WT ruler; whilst it was **immobilized for drawing, it would not stay fully flat on the sheet**. Since, it was immobilized, students would not press it down, leaving a gap between ruler and sheet that caused this drawing error (refer to Figure 3.2a). Hence, it is critical that if the ruler is meant to be immobilized on the sheet, it should be immobilized flush against the sheet, like the Draftsman Ruler (refer to Figure 3.2b), to avoid these issues.

Figure 3.2a: Issue of stylus going under the WT ruler when drawing

Figure 3.2b: Draftsman ruler aligned such that there is no gap between the ruler and sheet

Test Specific

- The movement of the ruler at connecting two points happened more in case of both the **clip rulers**: APH ruler (50%) and Squirrel ruler (30%). The issue with the clip rulers perhaps stems from the **longer length of** the rulers, and the difficulty with holding longer rulers in place. In addition, as the clip is held down at the end point, at times it may be difficult to tell if the ruler has tilted and moved away from the start pin as there is no tactile feedback checked for this shifting.
- 25% of students using the Draftsman ruler made careless counting errors. This may be indicative of the issue the students faced at the **training stage with identifying the grooves and markings** on the Draftsman ruler. This error occurred the least with the Garg Ruler which had clear grooves, line markings and clear dot short cut marks as well.
- The Garg Kit requires working with tools **placed underneath the** Braille **paper. This caused maximum (22.5%) number of errors when drawing on the paper**. The method of placing tools below the paper and drawing from above the paper leaves a higher margin of error for the ruler/line marker to move or be incorrectly aligned and the point markers and stylus to cause tearing of the paper.

Age-wise Variation: Older (O) – Younger (Y) group

With respect to the errors made by the students during the training and the test stages of Skill 1, certain variations were observed between the percentage of errors committed by the older and younger users. The data for the same is available in Table No 3.1.1 and 3.2.1 in Annexure H.

The different challenges faced by the younger and older samples are presented below:

At the Training Phase:

The younger sample struggled with:

- Difficulty with straightening the ruler at the start point
- Centralizing the ruler
- Understanding the 5 mm (0.5 cm) marking
- Drawing after the start point. This was highest for younger students using the APH Clip Ruler since it lacks a marking for zero (0). Using the edge of the ruler as the zero mark to start drawing a line segment can cause confusion in putting the start pin and hence, an error in drawing.

The older students struggled more with:

- Ruler movement at plotting the start point
- Plotting end points (start and end)

At the Test Phase:

The younger students struggled with:

- Immobilizing the paper/sheet on the board with clasps. The Draftsman board has two tight clasps that secure the sheet on the board; the younger students may have struggled in handling the tight clasps.
- Centralizing the ruler on the paper/sheet. This was predominantly an issue for rulers using the edge to edge and board clip method to straighten the ruler. No problems were experienced with the Draftsman ruler, which is easily immobilized on the Draftsman Board.
- Clip movement while plotting the end point, especially for the APH ruler.

Key Reasons for Errors in Test Results

In addition to the above analysis, it was found important to identify if there were any key reasons that repeated in data when the students got the final test result as 'wrong'. The purpose of making this additional layer of analysis is to identify features in tools that lead to final erroneous output so that additional care can be taken to avoid these features.

During the analysis of the test results, it was observed that certain issues the students faced when using the rulers resulted in an incorrect final test result with an inaccurately drawn line segment. It is important to make note of these errors that occurred when using a particular ruler. Note that these recorded errors are a statement of occurrence i.e. in absolute number format and not in percentages.

- When **students struggled in sliding point markers in to position on the Garg board**, of the 21 errors that occurred 13 resulted in an incorrect drawing at the test stage.
- When the **student used the wrong side of the ruler when working with the RNIB ruler**, 12 out of 17 total errors resulted in an incorrect test result for the student.
- When the **pin/point marker or clip was not accurately plotted against the ruler mark when using the Draftsman ruler,** 13 of the total 20 errors resulted in an incorrect test result.

Similarly, when using the RNIB ruler, 17 of 19 total errors resulted in an incorrect test result.

- When the students encountered the **APH Clip Ruler movement when connecting the two end points**, 18 out of 20 times it led to a wrong test answer.
- When the students **stopped drawing before the marked end point with the APH Clip Ruler**, 11 out of 11 times it led to a wrong result for the students.
- When the **students stopped drawing before the marked end point with the RNIB ruler**, 11 out of 12 times it resulted in an incorrectly drawn line segment

II. Skill 2: Measuring a Line Segment (Training and Test Phase Data and Observer Inferences)

For Skill 2 of measuring a line segment, Tables 3.3 and 3.4 below document the highest occurring errors across the six rulers. Detailed data for the same are available in the corresponding tables in Annexure H.

Table 3.3: Skill 2: Key Issues: Training Phase (%)

Errors		APH Clip Ruler	Garg Ruler	RNIB Ruler	Squirrel Ruler	WT Ruler	Total
Errors in placing end point pins on marked TDs	Braille Paper Total	12.5	55	15	6.666667	8.333333	**36.5**
	Plastic Sheet Total	14.16667	0	18.33333	13.33333	15.83333	**46.25**
	Thermoform Sheet Total	1.666667	0	0	0.833333	0.833333	**2.5**
	Total	**28.33333**	**55**	**33.33333**	**20.83333**	**25**	**29.03846**
Ruler not accurately aligned against end point pins/markers	Braille Paper Total	8.333333	22.5	6.666667	2.5	3.333333	**17**
	Plastic Sheet Total	5	0	5.833333	5.833333	4.166667	**15.625**
	Thermoform Sheet Total	4.166667	0	3.333333	3.333333	3.333333	**10.625**
	Total	**17.5**	**22.5**	**15.83333**	**11.66667**	**10.83333**	**14.61538**
Careless counting mistakes/ Measuring mistakes	Braille Paper Total	4.166667	7.5	1.666667	0.833333	1.666667	**6.5**
	Plastic Sheet Total	1.666667	0	3.333333	0.833333	2.5	**6.25**
	Thermoform Sheet Total	7.5	0	9.166667	0.833333	5.833333	**17.5**
	Total	**13.33333**	**7.5**	**14.16667**	**2.5**	**10**	**9.807692**
Ruler movement at start point (during plotting or measurement)	Braille Paper Total	5	7.5	0	0	3.333333	**6.5**
	Plastic Sheet Total	3.333333	0	2.5	1.666667	1.666667	**6.875**
	Thermoform Sheet Total	8.333333	0	4.166667	0.833333	8.333333	**16.25**
	Total	**16.66667**	**7.5**	**6.666667**	**2.5**	**13.33333**	**9.615385**
Gap between ruler and line	Braille Paper Total	1.666667	0	0	1.666667	1.666667	**3**
	Plastic Sheet Total	5	0	0	1.666667	0.833333	**5.625**
	Thermoform Sheet Total	5	0	5	5.833333	0.833333	**12.5**
	Total	**11.66667**	**0**	**5**	**9.166667**	**3.333333**	**6.730769**

Table 3.4: Skill 2: Key Issues: Test Phase (%)

	Paper	APH Clip Ruler	Garg Ruler	RNIB Ruler	Squirrel Ruler	WT Ruler	Total
Errors in placing end point pins on marked TDs	Braille Paper Total	9.166667	55	13.33333	10	15	39.5
	Plastic Sheet Total	15.83333	0	17.5	14.16667	10	43.125
	Thermoform Sheet Total	0.833333	0	1.666667	1.666667	2.5	5
	Total	**25.83333**	**55**	**32.5**	**25.83333**	**27.5**	**30**
Ruler not accurately aligned against end point pins/markers	Braille Paper Total	4.166667	17.5	5.833333	7.5	4.166667	16.5
	Plastic Sheet Total	7.5	0	10	4.166667	3.333333	18.75
	Thermoform Sheet Total	7.5	0	2.5	2.5	3.333333	11.875
	Total	**19.16667**	**17.5**	**18.33333**	**14.16667**	**10.83333**	**15.76923**
Careless counting mistakes/ Measuring mistakes	Braille Paper Total	5.833333	7.5	3.333333	2.5	2.5	10
	Plastic Sheet Total	4.166667	0	5	0.833333	3.333333	10
	Thermoform Sheet Total	5	0	3.333333	1.666667	3.333333	10
	Total	**15**	**7.5**	**11.66667**	**5**	**9.166667**	**10**
Student putting the start point at the 0.5 cm mark leading to measurement errors later	Braille Paper Total	5.833333	5	2.5	0	3.333333	8
	Plastic Sheet Total	4.166667	0	3.333333	0	3.333333	8.125
	Thermoform Sheet Total	4.166667	0	1.666667	0	2.5	6.25
	Total	**14.16667**	**5**	**7.5**	**0**	**9.166667**	**7.5**
Ruler movement at start point (during plotting or measurement)	Braille Paper Total	3.333333	7.5	0	0.833333	1.666667	5
	Plastic Sheet Total	5	0	0.833333	0	1.666667	5.625
	Thermoform Sheet Total	6.666667	0	2.5	2.5	3.333333	11.25
	Total	**15**	**7.5**	**3.333333**	**3.333333**	**6.666667**	**7.115385**

The results of the training and test stages of the research reveal that certain common *key issues* have emerged as the main measuring challenges for the students:

- Errors in placing end point pins on marked Tactile Diagrams (TDs)
- Ruler not accurately aligned against end point pins/markers
- Careless counting mistakes/ Measuring mistakes
- Ruler movement at start point (during plotting or measurement)

In addition to the common issues, some key issues specific to the training stage were revealed:

- Gap between the ruler and line: This meant if there was a gap left between the two, the ruler would not be straight and hence accurate measurement would not be possible.

The key issue unique to the test phase was:

- The student putting the start point at the 0.5 cm mark leading to measurement errors later. When aligning the ruler to the TD line, students wrongly place a pin / point marker at the 0.5 cm position, as against 0 or 1, leading to measurement errors.

The data presented above documenting the key challenges for the students highlight the following factors:

- The highest number of **errors in placing the end pins on the marked TDs** is observed when using the Garg kit across training and test. The challenge with the Garg kit may stem from the fact that the **point markers of the Garg kit are placed on the TD from below the paper, leaving a larger margin for errors**. The percentage of errors for the Garg kit is consistent across training and test (55%) indicating that the students struggled in learning the method with no improvement being recorded at the test phase. Across all other ruler and sheet combinations, the greatest number of **errors are observed on the plastic sheet as the diagrams on the plastic sheets were regarded as less tactile by the sample.**
- The issue of the **ruler not being accurately aligned against end point pins/markers was encountered when the ruler was not correctly resting against the plotted pins.** Across the training and test phases, this issue with Braille paper was highest for the Garg ruler, whereas on the Plastic and Thermoform sheets, the error was highest for the APH clip ruler. **For the Garg kit, this error could be due to the method being used, whereas for the APH kit, the slipping off would be due to lack of clear grooves for resting the pins.**
- The careless counting errors made during the training and test phase are consistently higher for the Garg ruler when a Braille paper is being used and the APH clip ruler and the RNIB ruler when Plastic and Thermoform sheets are being used. It is also important to note, that the errors are the least across all sheets for the Squirrel Ruler. The **RNIB ruler is designed with different line markings on the grooved side and on the smooth side, while the APH clip ruler has different units of measurement on either side (cm/inch) which may cause confusion** when counting. Further, because the APH clip ruler does not have grooves for resting the pins, the ruler can slide away during measurement. For the Garg ruler, the errors could also be happening as the point markers would slide at the time of measurement. The Squirrel Ruler had the least errors mainly due to the fixed clip at the start which rests accurately against the point markers/TDs. Furthermore, the errors in the Squirrel Ruler were also due to braille labels for easy reading of measurement. The inches system of the Squirrel Ruler also meant fewer tactile markings to count leading to ease of measurement.
- The ruler movement at the start point during measurement was higher on the Thermoform sheet across the training and test phase. **The students might have struggled with the slippery surface of the sheet and in aligning the ruler to the raised thermoform line**. The issue was consistently high for the APH clip ruler. The **APH clip ruler does not have a clear mark for 0 cm or a clear groove to align and rest the pins. Therefore, aligning the edge of the ruler to the start pin could cause the ruler to tilt and shift away from the start point**.

This issue **occurs more with the rulers using pins and is the lowest for the Squirrel Ruler that has a fixed start clip**. Therefore, a fixed start clip is advisable for the ruler to prevent the ruler moving at the start point.

Training Specific:

- The raised line of the thermoform sheet and its smooth and slippery finish might have caused ruler movement and **a gap between the ruler and the line**. This issue of the gap between the ruler and the line was the highest on the Thermoform sheet and **highest for longer rulers that cannot be immobilised like the APH clip ruler, the RNIB ruler and the Squirrel ruler. This is indicative of the repeated difficulty in holding down longer rulers during measurement**.

Test Specific

- The issue of the **student putting the start point at 0.5 cm mark leading to measurement errors** shows that the students **struggled in understanding the marking systems on the rulers**. The errors were highest for the APH clip ruler (14.1%) that does not have a clear 0 mark, followed by the WT ruler (9.1%) which has small dot and line marks that can be difficult to differentiate, or the ruler shaking away from the cm mark and going to the 0.5 mark also made this error happen.

Age-wise Variation: Older (O) – Younger (Y) group

With respect to the errors made by the students during the training and the test stages of Skill 2, certain variations were observed between the percentage of errors committed by the older and younger sample. The data for the same is available in Table No 3.3.1 of Annexure H.
The different challenges faced by the younger and older samples are presented below:

At the Training Phase:
The younger sample struggled with:

- Using the wrong side of the ruler: The younger students struggled most with using the APH clip ruler across specifically with the Plastic Sheet with the wrong side of the ruler.
- Ruler movement at start point (during plotting or measurement) on Plastic, Thermoform and Braille paper.
- Gap between the ruler and the line.

At the Test Phase, no variations were recorded amongst the older and younger samples. This indicates the learning curve on the part of the younger and older sample from practice and exposure to the tools was enough to eliminate the error seen at the training phase.

Key Reasons for Errors in Test Results:

During the analysis of the test results, it was observed that certain issues that the students faced when using the rulers in combination with the sheets resulted in an incorrect test result with a wrong measurement of the line segment. It is important to make note of these errors that occurred when using a particular combination of sheet and ruler. Note that these recorded errors are a statement of occurrence i.e. in absolute number format and not in percentages.

- When the students made errors in placing the end point pin on the marked TD, their measurement of the line segment tended to be incorrect irrespective of the ruler uses.

- When using the APH clip ruler in combination with the Braille paper, 10 out of 11 times the final measurement was incorrect; on the Plastic Sheet 16 out of 19 times the final reading of the measure was incorrect.

- When using the Garg ruler with braille paper, 14 out of 22 times the final reading was incorrect.
- When using the RNIB ruler, 13 out of 16 times on Braille paper and 13 out of 21 times on the Plastic sheet, the final reading was incorrect.
- With the Squirrel ruler, 12 of the 17 errors in placing the pins accurately at the end point led to incorrect measurement of the line segment.
- With the WT ruler 16 out of 18 pin placement errors on the braille paper and 11 of 12 pin placement errors on the plastic sheet led to an incorrect final reading at the test stage.

This indicates that the **students struggled to use the ruler and pins in combination with the less tactile Braille paper and Plastic sheet**. Very few pin placement errors were recorded for the thermoform sheet.

III. Key Design Inferences for the Tools related to the Skill of Constructing and Measuring Line Segments

Based on the primary data made available by the training and test session conducted for Skill 1 and Skill 2, certain inferences regarding the quality and design of the tools can be drawn. These inferences might, therefore, prove beneficial to create an effective tactile ruler design, incorporating the following suggestions:

- **Size - Medium with stoppers:** A medium size ruler which can be held in place with an average hand span, i.e. about the maximum distance between the tips of the thumb and little finger, would be most effective. The movement of the ruler is limited with good stoppers below the ruler like that on the Squirrel ruler. Hence, stoppers are recommended for all rulers.
- **Measurement System - Any one measurement system on any one side of the ruler:** This prevents confusion on using wrong side of the ruler and also permits use of the clip method more effectively.
- **Markings on the ruler - Clear and Multiple:**
  - It is advisable to use distinctive differentiated markings for whole and decimal numbers.
  - A clear marking for 0 at the start of the ruler. This mark should be at the edge of the ruler with a jutting out clip and not with a gap from the beginning of the ruler to the 0 mark.
  - A clear shortcut method for counting multiples.
  - Any braille labels be placed below the tactile marking rather than on the side to avoid placement / measurement confusion.
  - Using a combination of line markings, shortcuts, braille labels and grooves makes it most easy to identify and count with. Across the ruler, lines are an effective marking and shortcut system.
  - It might also be useful to put sighted print labels on the tools to enable sighted teachers working with the student to check their work at a glance.
- **Immobilization System - Make the tool fully immobilized and flat on the sheet.** It is critical that the immobilized tool can rest flat on the sheet to avoid challenges while drawing. Furthermore, it is important to always have the immobilization option on the tool as a whole as well as on any moving parts on the tool like clips. To make this

possible, it might be essential to look at the pin design to be used with the tool as also the board being used. It is vital to ensure that the pin fits in tightly in the immobilization hole, and the length of the pin is enough for it to be sturdily placed in the drawing board being used, without any gap. The image below shows the new metric system Squirrel ruler which has holes for immobilizing the moving clip on the ruler, as well as for immobilizing the ruler.

Figure 3.3: Immobilization System on the new metric system Squirrel ruler

- **Resting System - Deep enough for effective resting:** A fixed clip at the beginning of the ruler, and an additional movable clip which can be immobilized on the ruler, are very effective for making end points, and, hence, for drawing and measuring. Alternatively, if grooves are being used, then the same need to be deep enough for pins to settle inside well, without movement. Smooth edge/side rulers are not as effective as there is increased movement with them.
- **Tool Usage Method - Same side and simple:** It is critical to keep the tool usage method as simple as possible with fewer steps. Also, it is highly recommended that all functions take place on the same side of the paper.
- **TD Quality: Distinguishable and Non-Slippery:** It is more effective to have TDs that are raised well and on sheets which have a non-skid surface as far as possible.

Specifically for younger populations, it is also essential that the following design elements be factored in:

- **Board Design and Paper mounting - Paper fixable with ease and smoothness, and facilitates mounting of tools straight and centralized:** The paper fixing system should be smooth and easy to open and close.
- **Ruler system for keeping it straight and centralized: it is** critical to ideate on design for the same. This could be factored in in the tool design or the board design. Something that will enable easy placement of tools on boards.
- **For tools using clip method, Clip Immobilization:** For younger students, the clips are necessary to be immobilized for effective drawing.

CHAPTER 4. WORLD OF ANGLES

Having analyzed results for Skills 1 and 2 in the previous chapter, this chapter will look into the combined skills related to constructing and measuring angles i.e. Skill 3 and Skill 4. This chapter will present the data collected through primary research broadly in 3 sections:

I. Skill 3 Training and Test results and Observer Inferences

II. Skill 4 Training and Test results and Observer Inferences

III. Key Design Inferences for the Tools related to the skill of constructing and measuring angles

I. Skill 3: Constructing an Angle (Training and Test Phase Data and Observer Inferences)

For Skill 3 of constructing an angle, Tables 4.1 and 4.2 below document the highest occurring errors across the five protractors in the training and the test phase, respectively. Detailed data tables for the same can be found in corresponding table numbers of Annexure I.

Table 4.1: Skill 3: Key Issues: Training Phase (%)

		APH Wand-inside Protractor Total	**APH Wand Protractor Total**	**Garg Protractor Total**	**RNIB Protractor Total**	**WT Protractor Total**	**Total**
Difficulty in straightening the ruler/protractor/point markers for baseline drawing	APH Clip Ruler	0	0	0	5.309735	6.837607	**18.66667**
	None	20.51282	37.5	15	0	0	**24.36975**
	RNIB Ruler	0	0	0	3.539823	1.709402	**7.594937**
	WT Ruler	0	0	0	13.27434	11.96581	**38.15789**
	Total	**20.51282**	**37.5**	**15**	**22.12389**	**20.51282**	**22.34957**
Struggled in aligning protractor to vertex and baseline	APH Clip Ruler	0	0	0	6.19469	8.547009	**22.66667**
	None	2.564103	2.5	5	0	0	**3.361345**
	RNIB Ruler	0	0	0	7.964602	13.67521	**31.64557**
	WT Ruler	0	0	0	10.61947	11.96581	**34.21053**
	Total	**2.564103**	**2.5**	**5**	**24.77876**	**34.18803**	**20.63037**
Ruler/Protractor resting against wrong pins causing drawing/measurement errors	APH Clip Ruler	0	0	0	7.964602	7.692308	**24**
	None	5.128205	0	2.5	0	0	**2.521008**
	RNIB Ruler	0	0	0	8.849558	6.837607	**22.78481**
	WT Ruler	0	0	0	4.424779	1.709402	**9.210526**
	Total	**5.128205**	**0**	**2.5**	**21.23894**	**16.23932**	**13.18052**
Stylus going underneath the protractor/wand/ruler while drawing	APH Clip Ruler	0	0	0	0	0	**0**
	None	43.58974	40	0	0	0	**27.73109**
	RNIB Ruler	0	0	0	0.884956	0	**1.265823**
	WT Ruler	0	0	0	2.654867	3.418803	**9.210526**
	Total	**43.58974**	**40**	**0**	**3.539823**	**3.418803**	**11.74785**
Did not draw till end point	APH Clip Ruler	0	0	0	1.769912	2.564103	**6.666667**
	None	12.82051	12.5	10	0	0	**11.76471**
	RNIB Ruler	0	0	0	6.19469	6.837607	**18.98734**
	WT Ruler	0	0	0	4.424779	1.709402	**9.210526**
	Total	**12.82051**	**12.5**	**10**	**12.38938**	**11.11111**	**11.74785**
Protractor/Ruler movement while drawing second arm	APH Clip Ruler	0	0	0	0.884956	2.564103	**5.333333**
	None	12.82051	32.5	0	0	0	**15.12605**
	RNIB Ruler	0	0	0	0.884956	4.273504	**7.594937**
	WT Ruler	0	0	0	5.309735	4.273504	**14.47368**
	Total	**12.82051**	**32.5**	**0**	**7.079646**	**11.11111**	**11.17479**

Table 4.2: Skill 4: Key Issues: Test Phase (%)

		APH Wand-inside Protractor	APH Wand Protractor	Garg Protractor	RNIB Protractor	WT Protractor	Total
Struggled in aligning protractor to vertex and baseline	APH Clip Ruler	0	0	0	16.66667	11.66667	42.5
	None	5	2.5	0	0	0	2.5
	RNIB Ruler	0	0	0	13.33333	13.33333	40
	WT Ruler	0	0	0	15	13.33333	42.5
	Total	**5**	**2.5**	**0**	**45**	**38.33333**	**28.61111**
Difficulty in straightening the ruler/protractor/point markers for baseline drawing	APH Clip Ruler	0	0	0	10	7.5	26.25
	None	12.5	40	30	0	0	27.5
	RNIB Ruler	0	0	0	7.5	5	18.75
	WT Ruler	0	0	0	10.83333	12.5	35
	Total	**12.5**	**40**	**30**	**28.33333**	**25**	**26.94444**
Did not draw till end point	APH Clip Ruler	0	0	0	5.833333	3.333333	13.75
	None	25	25	10	0	0	20
	RNIB Ruler	0	0	0	7.5	5.833333	20
	WT Ruler	0	0	0	5	3.333333	12.5
	Total	**25**	**25**	**10**	**18.33333**	**12.5**	**16.94444**
Errors/Difficulty in placing pins on marked TDs/drawings (vertex/on arms)	APH Clip Ruler	0	0	0	4.166667	5	13.75
	None	12.5	5	5	0	0	7.5
	RNIB Ruler	0	0	0	5.833333	6.666667	18.75
	WT Ruler	0	0	0	9.166667	9.166667	27.5
	Total	**12.5**	**5**	**5**	**19.16667**	**20.83333**	**15.83333**
Ruler/Protractor resting against wrong pins causing drawing/measurement errors	APH Clip Ruler	0	0	0	8.333333	8.333333	25
	None	12.5	0	0	0	0	4.166667
	RNIB Ruler	0	0	0	3.333333	5	12.5
	WT Ruler	0	0	0	2.5	3.333333	8.75
	Total	**12.5**	**0**	**0**	**14.16667**	**16.66667**	**11.66667**

The data presented above is across the entire sample population and presented as percentages. Male-Female differentiation is not presented as the difference was found negligible.

The results of the training and test stages of the research reveal certain common *key issues* as the main drawing challenges for the students.

- **Difficulty in straightening the ruler/protractor/point markers for baseline drawing:** As a first step to draw the angle, students were taught to draw the base arm. However, most students struggled in aligning the ruler straight for drawing the base arm.
- **Struggled in aligning protractor to vertex and baseline:** For drawing an accurate measurement, it is critical to align the protractor to the exact vertex point and straight against the base arm. Many students struggled with this, later leading to inaccurate drawings.
- **Ruler/Protractor resting against wrong pins causing drawing/measurement errors:** Since drawing the angle meant drawing lines in different angles for the arms, it often means that

the tools have to be removed and realigned for marking measurements and drawing arms. It is during this period that oftentimes in realigning the tool, it gets rested against wrong pins.

Figure 4.1 Rulers resting against wrong pins to draw the second arm of the angle

- **Did not draw till end point of the vertex:** This error is similar to that found during the drawing of line segments.

In addition to the common issues, some key issues specific to the training stage were revealed:

- The stylus going underneath the protractor/wand/ruler while drawing
- A gap between the pin and ruler/protractor while drawing or measurement causing errors
- The protractor/ruler movement while drawing the second arm

The key issues unique to the testing phase were:

- Errors/Difficulty in placing pins on marked TDs/drawings (vertex/on arms)

The data presented above documenting the key challenges for the students highlight the following factors:

- The issue of straightening the protractor for drawing the baseline during the training and test phase is the highest for the APH wand protractor**. The APH wand protractor does not make use of a ruler to draw the baseline. The challenge with this protractor is in placing it straight while placing it in the correct orientation (upside down); and centralising the protractor on the paper/board.** During the training phase, the sample struggled with straightening the APH wand protractor to draw the baseline. However, the error with straightening the APH wand protractor significantly dropped at the test stage indicating a learning curve.

Conversely, the error of straightening the Garg point markers and line markers for drawing the baseline doubled at the test phase indicating the possibility that the students struggled in determining the correct alignment of these tools without verbal cues.
When rulers are used for drawing baselines, the **WT ruler recorded the maximum error for keeping the baseline straight across protractors using rulers, whereas the RNIB ruler recorder the least errors**. This could be due to the fact that the **method of keeping the ruler straight is easier for the RNIB ruler because of its length and width as against the WT ruler which becomes difficult to keep it centralised and straight**.

- The issue of aligning the protractor to the vertex/baseline is consistently high across the training and the test phases for the WT protractor and RNIB protractor. This issue is reflective of the design challenges of these protractors. **The knob used to align/rest the RNIB protractor does not remain fixed, and, hence, when the protractor is rested against the same, the alignment to the baseline is disturbed, and if the protractor is aligned to the baseline the protractor tends to slip under the knob.**

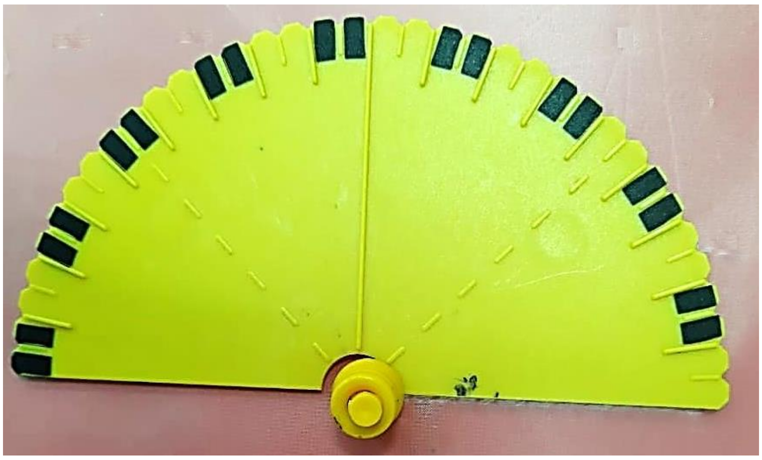


Figure 4.2: RNIB protractor slipped under the knob while aligned to the baseline

For the WT protractor, the multiple tips again tend to see-saw when attempting to align it to the baseline. The 3rd tip at the bottom-centre tends to keep sliding away from the vertex point pin.

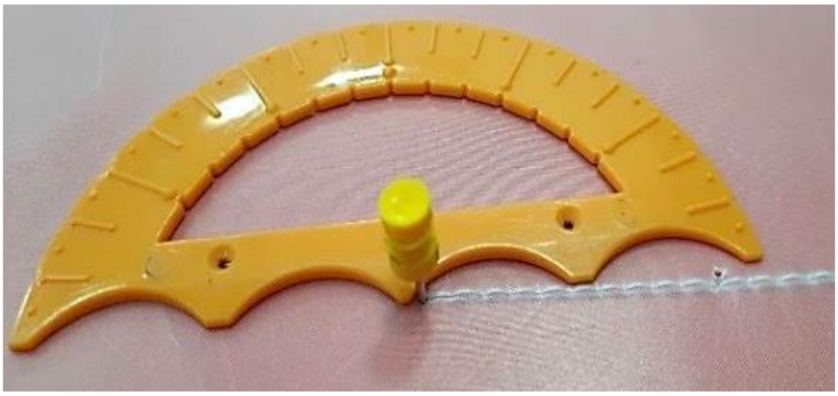


Figure 4.3a: WT protractor aligned incorrectly to the vertex pin

Figure 4.3b: WT protractor aligned correctly to the vertex pin and baseline

This error occurred minimally for **the APH Wand-inside and the APH Wand Protractors as these protractor designs have the base arm drawing incorporated in the tool itself**. Between the RNIB and WT protractors, while the errors recorded were higher for the WT protractor, the tip-arc design was found useful by students to enable them to feel the base arm as opposed to the straight line and solid-body design of the RNIB protractor which did not permit them to feel the protractor alignment to the baseline. In the Garg protractor, this alignment to the vertex point issue gets taken care of due to its centre circle feature i.e. the hole for immobilisation, that rests on the point marker. And the alignment to the baseline issue gets taken care of because of its system of the line marker attached to the protractor that fits on point marker.

- At the training and test phase, the issue of the ruler/protractor resting against the wrong pins when drawing the second arm was the highest when either the APH Clip ruler or the RNIB ruler were used to draw the second arm. **The APH clip ruler and the RNIB ruler are long rulers whereby the chances of the rulers accidently resting against the immobilising pins at the bottom of the sheet or on the board clip increases.**

Figure 4.4: APH clip ruler resting on the wrong pins

- At the training stage, the issue of the students not drawing till the end point (i.e. the vertex point) is recorded consistently across protractors. This issue might be reflective of the cautious attitude of the students when constructing an angle. In an attempt to neither push the vertex pin or second arm pin nor draw beyond the pins, the students might have not drawn till the end point. At the test stage, this error is seen significantly more for protractors not using rulers i.e. APH wand-inside and APH wand protractor. This reflects that the initial caution errors at the time of training do tend to wean out but for protractors not using rulers their design causes this error. **For example, with the APH wand protractor, there is always a gap between the wand and the sheet not making the vertex point clear for drawing.** For the APH wand-inside, the method itself is complex creating the error.

Training Specific:

- The issue of the stylus going under the protractor when drawing is significantly high for the APH wand-inside protractor (43.5%) and the APH wand protractor (40%). This could be indicative of the design flaws of these protractors. Although the APH wand-inside protractor can be immobilised, the body of the protractor is thin/malleable and cannot be immobilised flush against the sheet. Similarly, the APH wand protractor, with its protruding/bulky wand, does not sit flat against the paper even when held down correctly, causing the stylus to go under the protractor/wand when drawing.
- The issue of the protractor or ruler moving when drawing the second arm was highest for the APH wand protractor (32.5%) which might mean that the students struggled in holding down the protractor when drawing. However, the APH wand-inside (12.8%) protractor, WT protractor (11.1%) and RNIB protractor (7%) are protractors that are immobilised before drawing hence lower error rates on movement for these.

Test Specific:

- The issue of placing pins on the marked TDs is high for the WT Protractor (20%) and RNIB Protractor (19.1%). This issue may be indicative of the fact that the students could not draw sharp lines using the rulers and eventually struggled in identifying the endpoints on TD correctly. The problems of placing pins for the APH wand-inside protractor (12.5%) may be owing to the methods used for this protractor that require the students to replot the vertex pin at a previously made vertex mark.

  This issue was lowest for the APH wand protractor (5%) and the Garg protractor (5%) as in their case the drawing happens at one go, and hence, there is no need for placing of pins on marked TDs.

Age wise Variation: Older (O) – Younger (Y) group

With respect to the errors made by the students during the training and the test stages of Skill 3, certain variations were observed between the percentage of errors committed by the older and younger samples. The data for the same is available in Tables 4.1.1 and 4.2.1 of Annexure I.

The different challenges faced by the younger and older samples are presented in a concise manner below:

At the Training Phase:

The younger sample struggled more with:

- The protractor/ruler **movement** while drawing the baseline with the APH Wand Protractor
-

- The protractor/ruler **movement** while drawing the second arm with the WT Protractor and RNIB ruler
- Reading **measurement**/Difficulty in understanding markings on RNIB Protractor
- Stylus not touching the protractor/wand/ruler when **drawing** with the APH Wand-inside protractor
- Difficulty in placing the measurement wand exactly at the **groove/mark** with APH Wand-inside protractor

The older students struggled more with:

- The protractor/ruler **movement** while drawing the second arm with the WT protractor and ruler
- **Drawing** beyond edge of protractor/ruler for baseline with the APH Wand protractor
- Did not **draw** till the end point with the APH Wand protractor
- Did not **draw** till the end point with the RNIB protractor
- Errors in **measurement due to non-familiarity with the 45-90 system** in APH Wand protractor

At the Test Phase:
The younger students struggled more with:

- Placing the Protractor in the right **orientation** with the APH wand protractor
- Did not **draw till the end point** with the Garg Protractor
- **Protractor slipping under the knob** with the RNIB protractor

Whereas the older students struggled more with:

- Difficulty in **straightening** the ruler/protractor/point markers for baseline drawing with the APH Wand-inside protractor
- Careless **counting/measuring mistakes** with the RNIB Protractor
- Did not **draw till the end point** with the APH Wand Protractor
- **Placing RNIB Knob in the right direction**, removing it etc.

Key Reasons for Errors in Test Results
During the analysis of the test results, like in the previous chapter, it was observed that certain issues that the students faced when using the protractors resulted in incorrect final test results with incorrectly drawn angles. It is important to make note of these issues that occurred when using a particular protractor. Note that these recorded errors are a statement of occurrence i.e. in absolute number format and not in percentages.

- When the students struggled to place the APH Wand protractor in the correct orientation, 11 out of 13 times it resulted in an incorrect angle and a wrong test result for the student.
- 11 out of 16 times when using the APH Wand protractor, the students struggled in straightening the protractor for drawing the first arm, the final test result recorded was wrong.
- When using the WT ruler in combination with the WT protractor to draw the baseline, the final result was wrong 11 out of 15 times, as the students struggled to straighten the ruler for drawing the baseline.
- With the RNIB protractor, the students struggled to align the protractor (with the APH clip ruler) 20 times, of which 16 errors resulted in an incorrect test result. When the RNIB protractor was

used in combination with the RNIB ruler, 16 alignment errors were made and 11 resulted in an incorrect final result.

- With the WT protractor, the students struggled to align the protractor (with the APH clip ruler) 14 times, of which 11 errors resulted in an incorrect test result. When the WT protractor was used in combination with the RNIB ruler, 16 alignment errors were made and 13 resulted in an incorrect final result for the students. The WT protractor and the WT ruler combination resulted in 13 incorrect results of the 16 total errors.
- The difficulty in placing pins on the marked TDs when using the WT protractor occurred 11 times of which 10 times it led to an incorrect final result.
- The difficulty in placing the measurement point/pin exactly at the groove/mark of the APH Wand-inside protractor occurred 15 times, and resulted in an incorrect test result 10 times of 15.
- When using the Garg protractor, the struggle of fixing the line marker across the point markers and the protractor occurred 15 times, of which 11 incorrect test results were recorded.

II. Skill 4: Measuring an Angle (Training and Test Phase Data and Observer Inferences)

For Skill 4 of Measuring an angle, Tables 4.3 and 4.4 below document the highest occurring errors across the four protractors. Detailed data for the same is available in the corresponding tables in Annexure I.

Table 4.3: Skill 4: Key Issues: Training Phase (%)

		APH Wand Protractor	**Garg Protractor**	**RNIB Protractor**	**WT Protractor**	**Grand Total**
Struggled in aligning protractor to vertex and baseline	Braille Paper Total	11.66667	5	10	15.57789	**29.5**
	Plastic Sheet Total	10	0	10	14.07035	**32.7044**
	Thermoform Sheet Total	15.83333	0	9.166667	11.05528	**43.33333**
	Grand Total	**37.5**	**5**	**29.16667**	**40.70352**	**34.02923**
Careless counting/measuring mistakes	Braille Paper Total	4.166667	17.5	5.833333	9.045226	**18.5**
	Plastic Sheet Total	8.333333	0	8.333333	10.55276	**25.78616**
	Thermoform Sheet Total	4.166667	0	9.166667	6.532663	**24.16667**
	Grand Total	**16.66667**	**17.5**	**23.33333**	**26.13065**	**22.3382**
Errors/Difficulty in placing point pins on marked TDs/drawings (vertex/on arms)	Braille Paper Total	5.833333	45	1.666667	4.522613	**18**
	Plastic Sheet Total	6.666667	0	10.83333	7.537688	**22.64151**
	Thermoform Sheet Total	0	0	5.833333	0	**5.833333**
	Grand Total	**12.5**	**45**	**18.33333**	**12.0603**	**16.49269**

Protractor movement while plotting measurement/ measuring	Braille Paper Total	0.833333	2.5	1.666667	3.517588	**5.5**
	Plastic Sheet Total	0.833333	0	3.333333	4.522613	**8.805031**
	Thermoform Sheet Total	1.666667	0	2.5	2.01005	**7.5**
	Grand Total	**3.333333**	**2.5**	**7.5**	**10.05025**	**7.098121**
Difficulty aligning wand to second arm pins	Braille Paper Total	6.666667	0	0	0	**4**
	Plastic Sheet Total	9.166667	0	0	0	**6.918239**
	Thermoform Sheet Total	5	0	0	0	**5**
	Grand Total	**20.83333**	**0**	**0**	**0**	**5.219207**
Struggled in Placing the Protractor with right orientation	Braille Paper Total	1.666667	2.5	0.833333	0.502513	**2.5**
	Plastic Sheet Total	5	0	1.666667	0.502513	**5.660377**
	Thermoform Sheet Total	4.166667	0	2.5	1.005025	**8.333333**
	Grand Total	**10.83333**	**2.5**	**5**	**2.01005**	**5.010438**

Table 4.4: Skill 4: Key Issues: Test Phase (%)

		APH Wand Outside Protractor	**Garg Protractor**	**RNIB Protractor**	**WT Protractor**	**Total**
Struggled in aligning protractor to vertex and baseline	Paper Total	15.83333	17.5	11.66667	24.47917	**44.38776**
	Plastic Sheet Total	16.66667	0	15.83333	17.70833	**46.79487**
	Thermoform Total	8.333333	0	14.16667	10.41667	**39.16667**
	Grand Total	**40.83333**	**17.5**	**41.66667**	**52.60417**	**43.85593**
Careless counting/measuring mistakes	Paper Total	7.5	17.5	7.5	6.25	**18.87755**
	Plastic Sheet Total	2.5	0	5.833333	8.333333	**16.66667**
	Thermoform Total	7.5	0	7.5	4.166667	**21.66667**
	Grand Total	**17.5**	**17.5**	**20.83333**	**18.75**	**18.85593**
Errors/Difficulty in placing pins on marked TDs/drawings (vertex/on arms)	Paper Total	5	47.5	5	2.604167	**18.36735**
	Plastic Sheet Total	5	0	7.5	1.5625	**11.53846**
	Thermoform Total	0	0	2.5	0	**2.5**
	Grand Total	**10**	**47.5**	**15**	**4.166667**	**12.07627**
Difficulty aligning wand to second arm pins	Paper Total	15	0	0	0	**9.183673**
	Plastic Sheet Total	15.83333	0	0	0	**12.17949**
	Thermoform Total	16.66667	0	0	0	**16.66667**
	Grand Total	**47.5**	**0**	**0**	**0**	**12.07627**
Struggled in Placing	Paper Total	3.333333	12.5	0.833333	2.604167	**7.653061**

the Protractor with right orientation	Plastic Sheet Total	3.333333	0	1.666667	5.208333	**10.25641**
	Thermoform Total	4.166667	0	0.833333	2.604167	**9.166667**
	Grand Total	**10.83333**	**12.5**	**3.333333**	**10.41667**	**8.898305**

The results of the training and test stages of the research reveal certain common *key issues* as the main measuring challenges for the students:

- Struggled in aligning protractor to vertex and baseline
- Careless counting/measuring mistakes
- Errors/Difficulty in placing pins on marked TDs/drawings (vertex/on arms)
- Difficulty aligning wand to second arm pins
- Struggled in placing the protractor in the right orientation

The key issues specific to the training stage were:

- Protractor movement while plotting measurement/measuring

The data presented above documenting the key challenges for the students highlights the following factors:

- **The struggle of aligning the protractor to the baseline/vertex was the highest recorded error across the training and test phase.** As opposed to the training stage, the test recorded higher errors in aligning protractors to the baseline/vertex. This shows that instructional intervention may be required for the students to realise their aligning mistakes. Across the training and test phase, this issue was consistently high, across sheets, for all protractors. These errors might be indicative of the design challenges of the protractors. For the WT protractor, aligning with the 5-tip design, with the RNIB protractor, placing and resting it on the knob, and the upside-down protractor orientation of the APH wand protractor for measurement might have caused alignment errors. For the Garg protractor, when using the Braille paper, the difficulty in aligning to the vertex and baseline increased at the test stage, and might be indicative of the struggle in placing the protractor on the point markers in the correct orientation.
  During the training, the aligning mistake was the highest for the **thermoform sheet (43.3%).** However, in the test stage, the alignment errors were consistent across all sheets**. Given that the thermoform sheet is smooth and slippery, it is possible that the students found it difficult to align and hold the protractors to the raised lines of the thermoform sheet**. **For the plastic sheet and braille paper, however, if the TDs were not distinct enough it could cause difficulty in aligning the tools.**
- When measuring the angle, students committed careless counting mistakes during the training and test phases. What is crucial is these errors were made across protractors for different reasons. **On braille paper, the Garg compass had the highest counting errors during the training and test. The markings on the Garg protractor are thicker, and hence, are too close together making it difficult to distinguish when counting**. **Across the training and test phases, the counting mistakes were higher for the WT protractor and RNIB protractor. The WT protractor does not have a clear 0-degree mark while the RNIB protractor uses both line marks and grooves for every 5- and 10-degree multiple along with the 45-90 system of measurement increasing confusion. For the APH wand protractor, the consistent counting errors across the training and test indicate no improvement and a continued struggle in**

understanding its upside-down method of measurement.
During the training, the counting mistakes were the highest on the plastic sheet followed by the thermoform sheet. However, in the test stage, the counting mistakes were highest with the thermoform sheet followed by the braille paper. Given the thermoform sheet is smooth and slippery, it is possible that the students found it difficult to align and hold the protractors to the raised lines of the thermoform sheet. For the plastic sheet and Braille paper, however, if the TDs were not distinct enough, it could cause difficulty in aligning the protractor to the TD to read the measurement.

- The issue of struggling to place the end pins on the marked TDs is reflective of the difficulty in identifying the TD and the end points/vertex of the given angle. This issue occurred most on the plastic sheet (22.6%) during training and on the braille paper (18.3%) during the test phase. For the plastic sheets and braille paper, if the **TDs were not distinct enough**, it could be difficult to place the pins on the TDs. **It is also possible that the TDs on the braille paper and the plastic sheet had flattened by repeated usage increasing the level of difficulty**.
  On braille paper, this issue was consistently and significantly higher for the Garg protractor across the training and test phases. The challenge with the Garg protractor lies in the ability to feel the TD on the Braille paper and drag and position the point markers from **underneath the paper**.
- The error of struggling to align the wand to the second arm pins is an error specific to the APH wand protractor. The number of wand alignment errors nearly doubled at the test stage for the APH wand protractor. This could be reflective of the design challenge of the protractor. **The APH wand protractor has a protruding/bulky wand that does not sit flat against the sheet at the vertex point even when held down correctly, causing the wand movement/alignment mistakes. Further, if the TD was large, the second arm pins were placed too high up on the TD for the wand to reach the pin.** At the testing phase, the students made twice the number of wand alignment errors than that of the training phase. This might indicate that instructional intervention or verbal cues may be required for the students to realise their wand aligning mistakes by asking students to use multiple pins on second arm in case of large TDs.
- **The issue of struggling to place the protractor in the right orientation was highest for the APH wand protractor across the training and test stages**. The students might have struggled with the new/different orientation of the APH wand protractor; the APH wand protractor is required to be placed upside-down on the line with the wand immobilised at the mark for reading the measurement.
  The issue of struggling to place the protractor in the right orientation at the test phase increased significantly for the Garg protractor which is required to be aligned to the point markers accurately to read the measurement. Similarly, this issue occurred significantly more for the WT protractor. With the WT protractor, the multiple grooves on the protractor and the 5-tip design are bound to cause confusion with identifying its correct orientation.
  Only the RNIB protractor did not report this error, perhaps due to its clear and simple shape with one solid semi-circle and a flat line.

Training Specific:

- The issue of the protractor moving when measuring is higher for the WT protractor (10%) and the RNIB protractor (7.5%). This struggle might be reflective of the struggle in holding down the protractors at the baseline/vertex. The students might have struggled with understanding that the 3rd tip of the protractor, at the bottom-centre, was slipping from the vertex pin causing the protractor to tilt. For the RNIB protractor , the struggle with the RNIB knob (moving/coming off) might have caused the protractor to move

- Both the WT protractor and the RNIB protractor recorded higher movement on the plastic sheet or braille paper. It is possible that the TDs were not distinctly felt on these sheets and the slippery surfaces of these sheets made it difficult to hold down the tool on the TD when measuring. However, the issue of the protractor moving on the thermoform sheet may also be linked to the sharp and raised lines on the thermoform sheet, which might make it difficult to hold down the tool to the line. It is important to note that the reason for lesser errors on the Garg and APH wand protractors is that once the protractors are aligned to the angle to be measured, they remain either in fixed position or rested against the Pins/TDs making them move less.

Age wise Variation: Older (O) –Younger (Y) group

With respect to the errors made by the students during the training and the test stages of Skill 4, certain variations were observed between the percentage of errors committed by the older and younger sample. The data for the same is available in Table No 4.3.1 and 4.4.1 in Annexure I.

The different challenges faced by the younger and older samples are presented in a concise manner below:

At the Training Phase:

The younger sample struggled more with:

- Protractor **movemen**t while plotting measurement/measurement for the RNIB protractor
- Careless **counting/measuring mistakes** for the APH Wand protractor
- Errors in using the **shortcut** for measurement with the APH Wand due to **unfamiliarity with the 45-90 system** of the APH Wand protractor
- **Wand movemen**t causing drawing/measurement errors with the APH Wand protractor

The older students struggled more with:

- **Aligning** protractor to vertex and baseline
- **Aligning** wand to second arm pins
- Errors/Difficulty in **placing pins** on marked TDs/drawings (vertex/on arms)

At the Test Phase:

The younger students struggled more with:

- Protractor movement while plotting measurement/measuring
- Careless counting/measuring mistakes
- Errors in using the shortcut for measurement
- Errors in measurement due to unfamiliarity with the 45-90 system

There were no specific issues that the older students struggled with at the test phase.

Key Reasons for Errors in Test Results

During the analysis of the test results, it was observed that certain issues that the students faced when using the protractors resulted in an incorrect final test result with an incorrect measurement of the angle. It is important to make note of these errors that occurred with a particular sheet and protractor combination. Note that these recorded errors are a statement of occurrence i.e. in absolute number format and not in percentages.

-

- When using the APH Wand protractor and the braille paper, the students struggled with aligning the protractor to the vertex and first arm of the given angle. This led to an incorrect final measurement 18 out of 19 times. When using the APH Wand protractor with the plastic sheet, of the 20 alignment errors 15 resulted in an incorrect final measurement.
- With the RNIB protractor and the plastic sheet, 19 errors were made when aligning the protractor to the vertex and first arm, and 13 of those led to an incorrect test result. When using the RNIB protractor in combination with the thermoform sheet, 13 out of 17 times the final test result was recorded as incorrect.
- When using the WT protractor with the braille paper, 47 errors were made when aligning the protractor to the vertex and first arm and 30 of them led to an incorrect final reading. When using the WT protractor in combination with the plastic sheet, of the 34 total alignment errors that the students made, 27 resulted in an incorrect final test result. When using the thermoform sheet, of the 20 times they struggled with alignment, 17 resulted in an incorrect test result.
- When using the Garg protractor with the braille paper, of the 19 times the students struggled with point markers on the TD, 14 resulted in an incorrect final measurement.
- Of the 16 times students made a counting mistake on the WT protractor with the plastic sheet, 15 led to an incorrect test result for the student.
- The students struggled with aligning the APH wand protractor's second arm to the plotted pins on all three sheets. On the braille paper, 13 of 18 errors resulted in an incorrect test result. On the plastic sheet, 14 of 19 errors led to wrong test results. On the thermoform sheet, of the 20 errors, 14 led to a wrong test result for the student.

III. Key Design Inferences for the Tools related to the Skill of Constructing and Measuring Angles

Based on the primary data made available by the training and test sessions conducted for Skill 3 and Skill 4, certain inferences regarding the quality and design of the tools can be drawn. These inferences might, therefore, prove beneficial for creating an effective protractor design. Further, what this also demonstrates is specific features needed for these skills.

Thus, when designing a ruler, features linked to construction and measurement of line segment as also angles need to be kept in mind. This section outlines features for rulers, protractors and TDs linked to drawing and measuring of angles specifically.

For Protractors:

- **Protractor Markings:** For both drawing and measuring angles, having effective measurements are critical. We recommend the following:
  - A clear 0 marking on the protractor to start
  - A local based system of shortcut measurement marks of either 30-60-90 or 45-90 to be used
  - Having alternate degrees marked with lines and dots as against all lines might be more useful to keep the markings more distinct from one another
  - Tactile markings to be distinctive but not thick that they clutter and become too close to one another
  - Shortcut distinguishing mark at 30-60-90 or 45-90 is important and useful
-

- **Wand Designs:** If protractor is using a wand, it is critical that the following features are looked into:
  - Tightening screw of the wand to be as flat as possible to ensure that the wand can sit as flat as possible on the sheet. Gap here is the biggest cause of error in drawings.
  - Depending on the method being used for drawing, it would be useful to have the drawing end of the wand jutting out of the protractor's main body for placing pins more easily against the mark rather than it ending on the edge of the protractor.

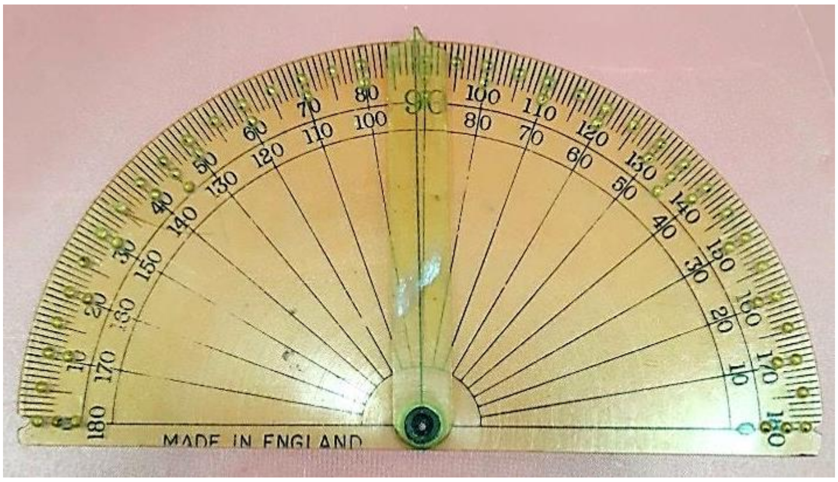


Figure 4.5: **Protractor with the wand jutting out**

  - It is also important that if the drawing end of the wand is jutting out then the placement of the wand on the marking should be devised such that it can sit right next to the desired degree rather than on top of it.

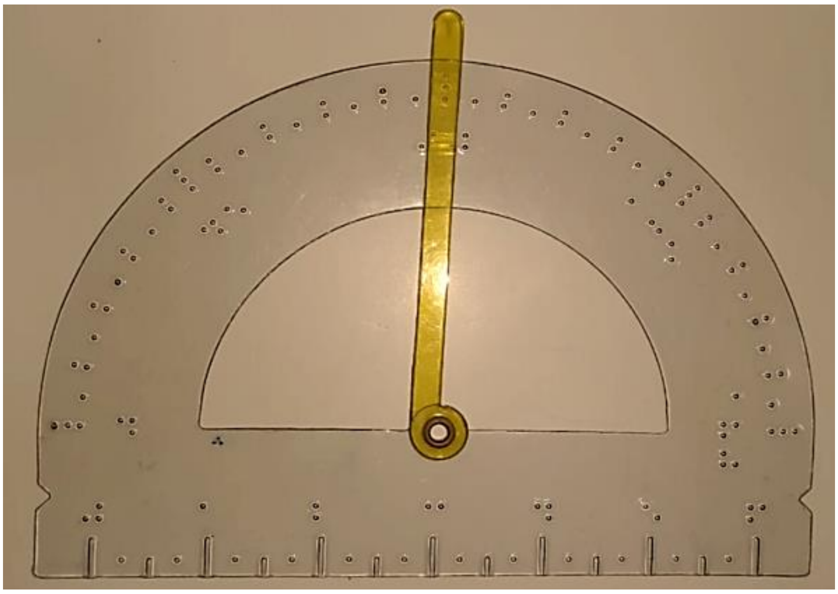
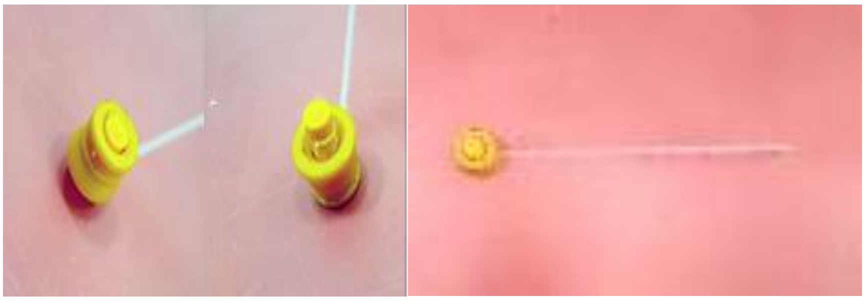


Figure 4.6: Wand of the APH wand-inside protractor resting on top of the measurement mark

  - It would also help if the wand itself had a hole for an immobilization pin to fix it flat on the jutted-out section.
-

- **Knob Designs:** For protractors when using knobs like the RNIB protractor, it is important for the knob:
    - To remain fixed on a pin and fully flat on the sheet
    - To be fixable only in one direction. And this could also mean that there is a knob sized pin itself



✗ ✓

Figure 4.7: Knob Designs

-
    - If there is a knob sized pin being used, the method of using the protractor will then have to vary as against the one being currently used with a removable knob on the pin. It would need the student to remove the knob sized pin and replace it with a drawing pin at the start of drawing the angle which would still reduce errors compared to use of the removable knob currently.
- **Immobilization Method:**
    - It is critical that one devises a tool which can be immobilized at each step of the skill.
    - Further, it is more useful to have immobilization done through having holes inside the body of the tool as against the edge grooves to ensure more fixability.

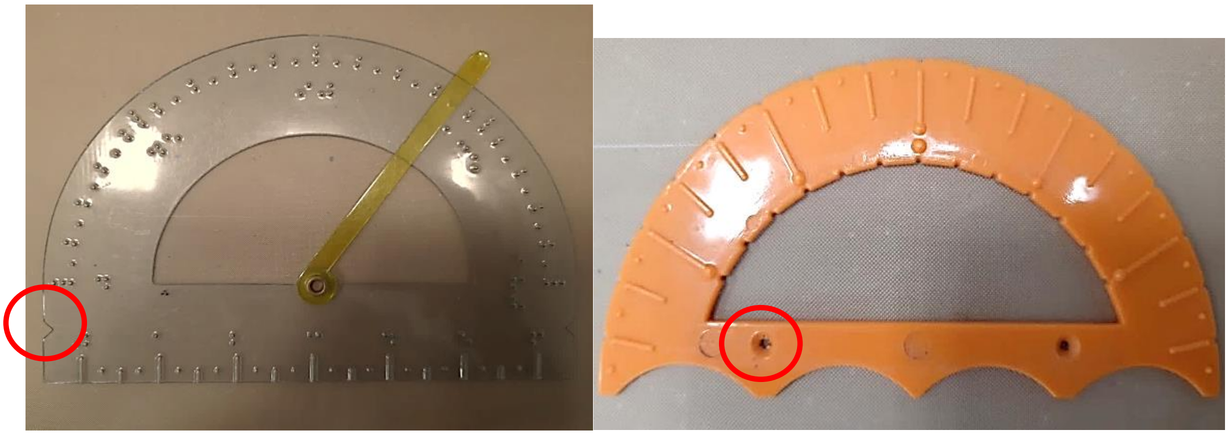


Figure 4.8: Immobilization Method Used for Different Protractors

-
    - For the tool to remain fixed after being immobilised, it is important to look at the pin and the board design and their respective heights in relation to the tool being used. The pin cannot be of a longer height after being placed on the mat and the tool as that makes the tool wobble even after fixing the immobilization pin.
-

- **Protractor Design:** Depending on the method being used, the protractor size, shape and sturdiness needs to be determined.
    - For keeping the protractor straight and flat: The protractor design has to be distinctive enough with a curve on one side and flat on the other as far as possible to have a clear understanding of orientation and keeping the tool straight.
    - For ensuring better alignment of the vertex to the baseline: It is useful to have some gaps along the base of the protractor that will enable the student to align it. However, the current tip design of the WT is found too wobbly. Hence, some design solution for the same has to be thought of.
- **Protractor Size:** It is ideal to have a mid-sized solid protractor to ensure that it does not either wobble too much or cover the arms drawn.
- **Method of Using the tool:** The biggest challenge seen in all protractors tested is a lack of effectiveness in the methods being used by them. Each tool has shown a significant concern in the key stages of the skill of constructing and measuring angles. The method employed by the APH wand protractor, whilst being the simplest and overcoming the issues of protractor alignment to baseline and vertex, due to the gap left between its wand and the drawing board leads to several errors and at the time of measurement, has also been found to be extremely difficult to align to regular TDs. **On the other hand, protractors using rulers are not able to have an effective method for** aligning the protractor to the baseline and vertex point. Some design thinking is needed to resolve this challenge.

For Rulers:

- **Ruler Size**: For constructing angles, long rulers cause greater errors, and hence, a shorter ruler/medium-sized ruler is more advisable. Whilst younger students struggled with larger rulers in this skill, the older students struggled with smaller rulers hence, a medium length ruler which is broad enough to be sturdy and with good stoppers would be the ideal size of the ruler.

For TDs:

- **TD Quality:** It is more effective to have TDs that are raised well and on sheets which have a non-skid surface as far as possible.

It is further critical that, especially for younger populations, the following design elements need to be factored in:

- **Keeping the tool straight and immobilized is very critical.**
- **Measurements systems to be simple and clear as described above.**

For older populations who tend to make careless drawing errors, it would be useful for the tool to have the following

- **Better drawing guide on the tool:** For protractors, since the arms of the angles are rays and not line segments, the current tools have not looked at stop points for drawing. However, this leads to several drawing errors**. It would be useful to have a clear stop system on the protractor that could act as guide for end point for drawing the arms of the agnles**. These could be in the design of clear grooves on protractors if they are to be used for drawing (like the APH wand protractor).

CHAPTER 5. WORLD OF CIRCLES AND ARCS

The chapters so far looked at the skills of constructing and measuring line segments and angles. This chapter looks at the final set of two skills related to constructing of circles and arcs – Skill 5 and Skill 6. For the purpose of the research the skill of arcs was taught with reference to drawing of line bisectors. This chapter highlights the errors made by the students when constructing a circle and a line bisector.

This chapter will present the data collected through primary research broadly in 3 sections:

I. Skill 5 Training and Test results and Observer Inferences
II. Skill 6 Training and Test results and Observer Inferences
III. Key Design Inferences for the Tools related to the skill of constructing circles and arcs

I. Skill 5: Constructing a Circle (Training and Test Phase Data and Observer Inferences)

For Skill 5 of constructing a circle Table 5.1 and Table 5.2 below document the highest occurring errors across the four compasses used for the research. Detailed data tables for the same can be found in corresponding table numbers of Annexure J.

Table 5.1: Skill 5: Key Issues: Training Phase (%)

		APH Compass	Classmate Compass	Garg Compass	WT ruler as compass	Total
Not able to maintain radius while drawing circle	APH Clip Ruler	0	13.75	0	0	**55**
	NA	5	0	0	7.5	**4.166667**
	RNIB Ruler	0	10	0	0	**40**
	Squirrel Ruler	0	11.875	0	0	**47.5**
	WT Ruler	0	12.5	0	0	**50**
	Total	**5**	**48.125**	**0**	**7.5**	**29.28571**
First leg of compass coming off while drawing circle	APH Clip Ruler	0	4.375	0	0	**17.5**
	NA	57.5	0	2.5	7.5	**22.5**
	RNIB Ruler	0	9.375	0	0	**37.5**
	Squirrel Ruler	0	5.625	0	0	**22.5**
	WT Ruler	0	7.5	0	0	**30**
	Total	**57.5**	**26.875**	**2.5**	**7.5**	**25**
Drawing light and not neat	APH Clip Ruler	0	5	0	0	**20**
	NA	30	0	27.5	35	**30.83333**
	RNIB Ruler	0	5	0	0	**20**
	Squirrel Ruler	0	3.75	0	0	**15**
	WT Ruler	0	5.625	0	0	**22.5**
	Total	**30**	**19.375**	**27.5**	**35**	**24.28571**
Plastic sheet tearing while drawing	APH Clip Ruler	0	1.875	0	0	**7.5**
	NA	2.5	0	27.5	20	**16.66667**
	RNIB Ruler	0	1.25	0	0	**5**
	Squirrel Ruler	0	0.625	0	0	**2.5**
	WT Ruler	0	1.25	0	0	**5**
	Total	**2.5**	**5**	**27.5**	**20**	**10**

		APH Compass	Classmate Compass	Garg Compass	WT ruler as compass	Total
Paper folding and creasing while drawing	APH Clip Ruler	0	1.25	0	0	**5**
	NA	12.5	0	7.5	10	**10**
	RNIB Ruler	0	3.125	0	0	**12.5**
	Squirrel Ruler	0	2.5	0	0	**10**
	WT Ruler	0	3.125	0	0	**12.5**
	Total	**12.5**	**10**	**7.5**	**10**	**10**

Table 5.2: Skill 5: Key Issues: Test Phase (%)

		APH Compass	Classmate Compass	Garg Compass	WT Ruler as compass	Total
Not able to maintain radius while drawing circle	APH Clip Ruler	0	12.5	0	0	**50**
	NA	10	0	0	10	**6.666667**
	RNIB Ruler	0	12.5	0	0	**50**
	Squirrel Ruler	0	11.25	0	0	**45**
	WT Ruler	0	11.25	0	0	**45**
	Total	**10**	**47.5**	**0**	**10**	**30**
Drawing light and not neat	APH Clip Ruler	0	5.625	0	0	**22.5**
	NA	27.5	0	20	25	**24.16667**
	RNIB Ruler	0	6.25	0	0	**25**
	Squirrel Ruler	0	4.375	0	0	**17.5**
	WT Ruler	0	3.75	0	0	**15**
	Total	**27.5**	**20**	**20**	**25**	**21.78571**
Difficulty in setting the second leg to the accurate measurement (includes Squirrel clip movement)	APH Clip Ruler	0	5.625	0	0	**22.5**
	NA	25	0	0	5	**10**
	RNIB Ruler	0	4.375	0	0	**17.5**
	Squirrel Ruler	0	10	0	0	**40**
	WT Ruler	0	5	0	0	**20**
	Total	**25**	**25**	**0**	**5**	**18.57143**
First leg of compass coming off while drawing circle	APH Clip Ruler	0	6.875	0	0	**27.5**
	NA	30	0	5	7.5	**14.16667**
	RNIB Ruler	0	4.375	0	0	**17.5**
	Squirrel Ruler	0	3.75	0	0	**15**
	WT Ruler	0	2.5	0	0	**10**
	Total	**30**	**17.5**	**5**	**7.5**	**16.07143**
Paper folding and creasing while drawing	APH Clip Ruler	0	1.875	0	0	**7.5**
	NA	5	0	15	20	**13.33333**
	RNIB Ruler	0	2.5	0	0	**10**
	Squirrel Ruler	0	3.75	0	0	**15**

	WT Ruler	0	1.25	0	0	5
	Total	**5**	**9.375**	**15**	**20**	**11.07143**

The results of the training and test stages of the research reveal certain common *key issues* as the main drawing challenges for the students:

- **Not able to maintain radius while drawing circle:** Due to the compass not having strong locking mechanisms, and since tactile drawing involves some amount of pressing down of the pen/stylus, the legs would often shift while drawing leading to difficultly in maintaining the radius whilst drawing.
- **First leg of compass coming off while drawing circle:** Since the drawing of a circle entailed the use of both hands i.e. for turning the board along with drawing, this often proved challenging for students to keep the leg of the compass fixed as shown in the image below. And if the first leg gets lifted from the plastic sheet, the students when placing it down might not place it back at the exact same point, thus, shifting the centre of the circle that they are drawing, and hence, ending up with a circumference that does not meet at the end.

Figure 5.1: First Leg of classmate compass coming off

- **Drawing light and not neat:** Unlike line segments and angles where students had to draw straight and hence were able to maintain pressure whilst drawing, for circles, because of the curve, the construction itself was slightly more challenging and hence, led to drawing light i.e. with not enough pressure, or unclear.
- **Paper folding and creasing while drawing:** Once again, due to the turning of the paper/tool whilst drawing, it was difficult to keep the paper flat as it would often crease on turns. For the WT ruler as a compass, to make space for rotating the ruler to draw the radius, students would have to remove the sheet and mat from the clip of the board and 3 immobilizing pins at the bottom of the sheet before beginning to draw. This would be a big reason for the sheet to crumple/tear/fold.

In addition to the common issues, some key issues specific to the training stage were revealed:

- Plastic sheet tearing while drawing

The key issues unique to the testing phase were:

- Difficulty in setting the second leg to the accurate measurement

The data presented above documenting the key challenges for the students highlight the following factors:

- For the training and the test phases, the **issue of not being able to maintain the radius when drawing the circle was the highest recorded issue**. This issue was seen to consistently occur, across training and test phases, when using the **Classmate compass, indicating no improvement on completion of the training session**. Since the **legs of the Classmate compass are not adequately immobilised after setting the radius**, the students might have struggled in holding the Classmate compass when drawing, and pushed the legs together altering the radius. Further, because students had to press and draw, it also led to leg movement. This issue also occurred for the WT ruler as a compass at the training stage and increased slightly at the test stages. **For the WT ruler being used as a compass, if the stylus comes out from the measurement hole when drawing, the students might not bother to count and to put the stylus back in the same hole causing the radius to change**.

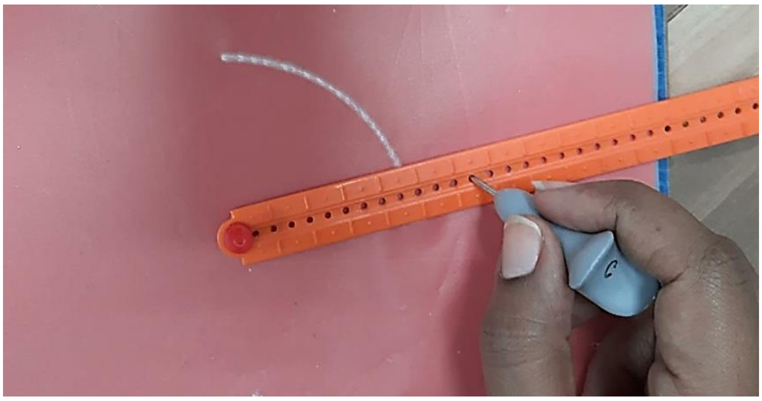


Figure 5.2: WT ruler as compass with stylus placed in the wrong hole while drawing

- The issue of the radius changing when drawing a circle, doubled at the test stage for the APH compass. This is linked to the issue of the first leg coming off, as mentioned below.
- The **issue of the first leg coming off when drawing was higher for the compasses that use a sharp pin/point leg to mark the centre of the circle**. This issue is linked to the student's ability to push down the pin tightly enough into the sheet before drawing. If point legs are lightly pressed down, they can come off while drawing because of the way the compass is held. Further, for the APH compass, the tip of the first leg was not sharp enough to be firmly inserted in the silicon mat. Across training and test, this issue was occurring more for the conventional 2-leg compasses. **For the APH compass and Classmate compass, if the first leg isn't firmly pushed down it would lift when pressing down on the second leg/stylus and when turning the board to draw the circle. It is possible that the first leg of the APH compass is not sharp enough to pierce the plastic sheet and the silicon mat.** However, it is important to note that this issue decreased for **the APH and the Classmate compasses** at the test stage **indicating improvement when practice is given** with these tools. For the Classmate compass, the first leg also tends to come off due to loss of balance when drawing with extra pressure ~~gets~~ put on the second leg or placing the full grip only on the second leg whilst drawing, thus leading to a see-saw lifting of the first leg.
- This issue of the first leg coming off also seemed to remain constant at the training and test

stages for the **WT ruler as compass.** The angle and force used when turning the board and pressing and drawing caused the centre pin to snap out. Across the training and test stages, **the issue of not drawing dark/thick enough was a consistent problem across the compasses. However, the test stage recorded slight improvement in drawing across compasses.** When using the APH and classmate compasses, the errors recorded reduced marginally at the test phase. **The spur wheel tactile lines appear on the other side of the page, the students may have struggled in determining the amount of force required when using the spur wheel** to get neat and sharp lines. For the **Classmate compass, not drawing dark enough might have been a consequence of the students being overly cautious when pressing down the stylus/pointed leg of the compass to draw in order to maintain the radius, not move the pen/stylus and to keep the first leg fixed.**

For the **WT ruler as a compass and the Garg Compass, the mistake of drawing light decreased significantly at the test stage, indicating a learning curve**. For the **WT ruler as compass**, the students might have **begun to judge the force and angle required to draw with the stylus**, whilst for **the Garg, the students may have accurately grasped the method of holding the stylus and getting the stylus grip over the line markers** placed below the sheet.

- The **issue of the paper folding and creasing when drawing occurred consistently across the training and test stages for the Classmate compass**. This issue **is possibly a consequence of the students struggling to immobilise the paper flat against the sheet and board when using the Classmate compass**. However, for the APH compass the issue of the paper folding when drawing decreased at the test stage perhaps indicating a learning curve in how the compass was being turned.

  The percentage of **errors for the paper folding and creasing when drawing seemed to have doubled at the test stage for the WT ruler as compass and the Garg compass**. For the **Garg compass, the paper is only immobilised at the top of the board and lifted and replaced over the point markers multiple times increasing the chances of the paper creasing**. For the **WT ruler as a compass, the paper might crease if the stylus is held perpendicular** to the sheet when drawing. This might cause the stylus to get stuck in the paper, and the paper to crease or tear when drawing.

Training Specific:

- The issue of the sheet tearing when drawing was significantly higher for the Garg compass (27.5%) and the WT ruler as compass (20%). For the Garg compass, either the point markers or the use of the stylus could cause the paper to tear. While drawing, the stylus would slip when on top of the circle marker and tear the sheet. **When using the Garg stylus, if the students struggled in holding the stylus or were not able to get the correct grip over the circle marker and used excessive force, the sheet may have torn**. For the WT ruler as a compass, **if the students had held the stylus perpendicular to the sheet** or **used the stylus at an extreme slant, the instances of the paper tearing would be high.**

  The issue of the sheet tearing when drawing also occurred for the Classmate and the APH compasses, however, the recorded errors were the least of the four compasses. The design of the 2-leg compasses is such that the stylus/spur wheel is already at an effective angle for drawing. Therefore, the instances of the sheet tearing because of stylus use are lower.

Test Specific:

- The **issue of setting the second leg at the accurate ruler measure mark was happening more for the conventional 2-leg compass**. For the APH compass, (25%) the students might have struggled in moving the second leg to the accurate compass ruler mark. The start point of the marking on the compass ruler is 1 instead of 0 causing confusion when counting. Further, the markings on the compass were indents which were not clear causing measurement errors. For the Classmate compass, (25%) the students might have struggled in holding down the ruler with one hand while holding down the first leg at the 0 mark and pulling the second leg to measure the mark with the other hand. **Further, this issue was highest for both the clip rulers. What would often happen, is that the clips on the Squirrel ruler and the APH clip ruler might have moved from the measure mark or were pushed away from the accurate mark by the leg of the Classmate compass when setting the radius.**

  Conversely, when the WT ruler and RNIB ruler were being used, the difficulty in setting the second leg at the measurement mark was reduced. This is possibly because the WT ruler and RNIB ruler have holes and grooves respectively corresponding to the measurement marks where the compass legs can rest when counting and setting the radius. For the WT ruler, because the ruler is immobilised, the student is able to freely set the compass using both their hands rather than having to hold down the ruler with one hand. Due to the size, weight and non-skid stoppers of the RNIB ruler it permits resting on the immobilisation pins at the bottom of the silicon mat permitting ease of use.

  This issue of setting the second leg at the accurate measure occurred for the WT ruler as a compass i.e. the students struggled in locating the corresponding hole to the accurate measure mark along the length of the WT ruler as compass for drawing.

Age wise Variation: Older (O) – Younger (Y) group

With respect to the errors made by the students during the training and the test stages of Skill 5, certain variations were observed between the percentage of errors committed by the older and younger sample. The data for the same is available in Table No 5.1.1 and 5.2.1 in Annexure J.

The different challenges faced by the younger and older samples are presented in a concise manner below:

At the Training Phase:

The younger sample struggled more with:

- Ruler movement while setting the radius with the Squirrel Ruler
- First leg of the compass coming off while drawing a circle
- Drawing light and not neat
- Centre/end point tears causing errors

All of these issues were seen with the Classmate Compass.

The older students struggled more with:

- First leg of compass coming off while setting radius with the WT ruler

At the Test Phase:

The younger students struggled more with:

- Difficulty locating the centre of the sheet to draw with the APH Compass and Garg
- Drawing light and not neat for the Garg
- Centre/end point tears causing errors for the Classmate compass
- Paper folding and creasing while drawing for the Garg

The older students struggled more with:

- First leg at 0.5 mark causing measurement errors for the Classmate compass
- Random counting mistakes for the APH compass
- Ruler movement while setting radius for the Classmate compass
- Drawing light and not neat for the Classmate compass
- Centre/end point tears causing errors with the APH compass
- Plastic sheet tearing while drawing with the Garg Compass

Key Reasons for Errors in Test Results

During the analysis of the test results, it was observed that certain issues that the students faced when using the compasses resulted in an incorrect final test result with an incorrectly drawn circle. It is important to make note of these errors that occurred in combination with the compasses. Note that these recorded errors are a statement of occurrence i.e. in absolute number format and not in percentages.

- When using the APH Compass, while the first leg of the compass moved from the centre point in 12 instances, it resulted in 10 incorrect test results.
- When using the Classmate compass, the first leg of the compass moved from the centre point in 11 instances, and all 11 times it led to an incorrect test result.
- When using the Classmate compass, the students were not able to maintain the radius (the radius on the compass changed) when drawing the circle. When used in combination with the APH clip ruler, 20 out of 20 times, it led to an incorrect final result. When used with the RNIB ruler, 18 of the 20 errors led to an incorrect test result. With the Squirrel ruler, 17 out of 18 times it led to an incorrectly drawn circle. When used with the WT ruler, 16 of the 18 errors led to an incorrect test result.
- The students struggled in setting the second leg of the Classmate compass to the accurate ruler mark on the Squirrel ruler. Of the 16 errors that occurred, all 16 led to incorrect test result.

II. Skill 6: Constructing/Cutting Arcs: Line Bisector (Training and Test Phase Data and Observer Inferences)

For Skill 6 of Constructing/Cutting Arcs: Line Bisector, Table 5.3 and Table 5.4 below document the highest occurring errors across the six rulers. Detailed data for the same are available in the corresponding tables in Annexure J.

Table 5.3: Skill 6: Key Issues: Training Phase (%)

	APH Compass	Classmate Compass	Garg Circle Marker/ Arc Marker	WT Ruler as Compass	Total
Difficulty in identifying intersection points/Placement of pins off the mark at intersection point	35	57.5	40	50	**45.625**
Placement of pins/first leg off the mark at end points	20	35	30	40	**31.25**
Drawing light and not neat (incomplete)	10	15	17.5	25	**16.875**

Table 5.4: Skill 6: Key Issues: Test Phase (%)

	APH Compass	Classmate Compass	Garg Circle Marker/ Arc Marker	WT Ruler as Compass	Total
Difficulty in identifying intersection points/Placement of pins off the mark at intersection point	35	62.5	28.20512821	45	**42.7673**
Placement of pins/first leg off the mark at end points	37.5	42.5	20.51282051	55	**38.9937**
Drawing light and not neat	20	17.5	15.38461538	35	**22.0126**
Not able to maintain radius while drawing arc	5	47.5	5.128205128	2.5	**15.0943**

The results of the training and test stages of the research reveal certain common *key issues* as the main drawing challenges for the students:

- Difficulty in identifying intersection points/Placement of pins off the mark at intersection point
- Placement of pins/first leg off the mark at end points
- Drawing light and not neat

In addition to these, some key issues specific to the training stage were:

- Struggle with using the stylus

The key issues unique to the testing phase were:

- Not able to maintain radius while drawing arc

The data presented above documenting the key challenges for the students highlights the following factors:

- The issue of struggling to identify intersection points and to place pins on them occurred in close to half of all attempts made on the compasses at the training and test stages. This issue is linked to the student's struggle in estimating the amount of force required to create sharp tactile lines/intersection points when using the different stylus/pen/spur wheel drawing tools. At the training stage, this issue was highest for the Classmate compass and it increased even further at the test stage, **indicating that the students could not effectively grasp the method of pressing down the stylus leg and turning the board to draw,** which eventually led to light lines and errors in identifying the intersection points. For the WT ruler as a compass, the percentage of errors recorded at the test stage decreased indicating a learning curve. However, with the **WT ruler as a compass, it is possible that the students struggled with holding the stylus at an effective angle to create sharp tactile diagrams, making it difficult to identify the intersection points**.

  For the APH compass, the percentage of errors was constant at the training and test stage. **The spur wheel on the APH compass creates sharp tactile lines on the opposite side** of the sheet, not on the side being used to draw. On the other hand, the recorded errors in identifying the intersection points decreased by 12% at the test stage for the Garg Compass. This indicates a definitive improvement in the performance of the students after practicing with the Garg kit.

It is important to note that the errors happened more for compasses that used pointed edges at the drawing arm. The pointedness of the drawing arm along with board movement perhaps causes greater errors in drawing, subsequently making intersection points difficult to identify. **The smooth wheel of the APH compass and the fixed design of the Garg compass are easier to draw arcs with.**

- The issue of the pin/first leg being off the end point was the key issue that was encountered at the training and test stage. This issue is reflective of the student's struggle in correctly identifying the TDs on the sheet. For the Classmate compass, the APH compass and the WT ruler as a compass, the issue of placing the first leg/pin at the end points of the line segment increased at the test stage. This might be reflective of the fact that the students may have required instructional cues to correctly identify the end points. The students might have struggled in using one hand to feel the line while using the other hand to accurately place the first leg/pin.

  For the Garg compass however, the number of errors recorded in placing the point markers on the end points decreased at the test stage. This indicates that the process of identifying the TD from above the sheet while positioning the point markers from underneath the braille paper can be learnt with practice. This improvement in identifying the endpoints when using braille paper might show that the TDs on the braille paper are preferred over lightly drawn TDs on plastic sheets whilst using the other compasses.

- The issue of drawing light/not neat/ incomplete might indicate that the students were too cautious when using the stylus/spur wheel/pen so as not to tear the sheet. This issue was the highest for the WT ruler as a compass across the training and test stage. In fact, this issue of drawing lightly increased for the WT ruler as a compass at the test stage. It is possible that with the WT ruler as a compass, students continued to struggle with holding the stylus at a gradual slant when drawing and determining the amount of force to be used to create sharp lines. **It is also possible that the WT ruler as a compass got caught in the board clip or the immobilisation pins because of its length making it difficult to draw complete and dark arcs. Further, due to the design of the WT ruler as a compass, the line was being drawn under the ruler and the student could not feel it whilst drawing.**

  The issue of drawing light doubled at the test stage for the APH compass. The APH compass uses the spur wheel mechanism which creates sharp lines on the opposite side of the page. The students may have struggled to identify the tactile lines on the drawing side. Further, if they did not use adequate amount of force when drawing, it may have created light and incomplete diagrams. Also, being a wheel, it would move on the board very quickly and smoothly even if no pressure was applied. Further, since the first leg of the APH compass was not sharp enough, students struggled to keep it inserted if pressure was applied to the second leg. Hence, they sometimes cautiously applied less pressure on the drawing side of the leg leading to light lines.

  For the Classmate compass, the issue of drawing light and incomplete was consistent at the training and test stages. This issue might indicate the challenge with the Classmate compass. **The pen of the compass moved often when drawing or came off from the compass if too much pressure was put on it. This might have created light and incomplete lines when drawing.**

  Test Specific

- The issue of not being able to maintain the radius when drawing (15%) was significantly high for the Classmate compass (47.5%). **The legs of the Classmate compass are not immobilised tightly enough after setting the radius.** When drawing, the students are expected to hold down the first leg while pressing down the second leg to draw. However, it is possible that the students pressed the two legs together instead, shifting the radius.

On the other hand, for the APH compass whose screw has a better tightening system and the Garg and WT protractor who had set grooves for measurement this issue occurred at a negligible level.

Age wise Variation: Older (O) – Younger (Y) group

With respect to the errors made by the students during the training and the test stages of Skill 6, certain variations were observed between the percentage of errors committed by the older and younger sample. The data for the same is available in Table No 5.3.1 and 5.4.1 in Annexure J.

The different challenges faced by the younger and older samples are presented in a concise manner below:

At the Training Phase:

The younger sample struggled more with:

- Drawing light and not neat (incomplete) with WT
- Centre/end point tears causing errors with Classmate
- Plastic sheet tearing while drawing with WT

The older students struggled more with:

- First leg of compass coming off while drawing an arc with the APH compass
- Immobilization pins/clips coming in the way of drawing with WT

At the Test Phase:

The younger students struggled more with:

- First leg of compass coming off while drawing arc
- Arc drawn is not long enough to create an intersection point

Key Reasons for Errors in Test Results

During the analysis of the test results, it was observed that certain issues that the students faced when using the compasses resulted in an incorrect final test result with an incorrectly drawn line bisector. It is important to make note of these errors that occurred when using a particular compass. Note that these recorded errors are a statement of occurrence, i.e. in absolute number format and not in percentages.

- When using the Classmate compass, the students were not able to maintain the radius (i.e. the radius on the compass changed) when drawing the arcs. This error occurred 19 times of which 18 errors led to an incorrect test result.
- When the students found it difficult to identify the intersection points of the arcs or place pins exactly at the intersection points after having used the Classmate compass, 19 of the 25 times this error was made resulted in an incorrect line bisector in the test.

  Similarly, when the students found it difficult to identify the intersection points of the arcs or place pins exactly at the intersection points after having used the WT ruler as a compass, 13 of the 18 times this error was made resulted in an incorrect line bisector in the test.
- With the struggle of placing the first leg of the APH compass at the exact end points of the given line segment, 10 of the 15 errors made resulted in an incorrect test result.

  When the students used the Classmate compass and struggled with placing the first leg and the end points of the given segment, 14 of 17 errors led to an incorrect test result.

- When using the WT ruler as a compass, when the students struggled in placing the first leg pin at the exact end point of the line segment, of the 22 times this error was recorded, 16 times it led to an incorrect test result for the student.

III. Key Design Inferences for the Tools related to the Skill of Constructing Circles and Arcs

Based on the primary data made available by the training and test session conducted for Skill 5 and Skill 6, certain inferences regarding the quality and design of the tools can be drawn. These inferences might therefore prove beneficial for creating an effective tool design. An effective tool designs must, therefore, incorporate these suggestions:

For Compasses:

- **Leg Tightening**: For 2-leg compasses, the **knob for tightening legs** should be easy to use but also immobilize the arms tightly enough that ensure that on pressing the legs they don't move away from position. One can also explore ideas related to **some kind of stopper cork** that can be inserted once radius is set between the 2 arms to ensure that they don't fold in. Alternatively, the design of the **APH compass is quite effective** to ensure leg placement.
- **First Leg Fixing:** To ensure that the first leg does not come off whilst drawing, **the tip of the first leg needs to be sharper** to be inserted effectively not only in the sheet but also through the rubber mat. Alternatively, if pins are being used with rulers (Worth Trust) **pin height has to be such that it fixes the ruler fully flat on the mat**. Some other **innovative support system** to keep the first leg fixed can be ideated upon.
- **Sheet fixing and Compass Size:** This is **critical for drawing circles** and arcs. Further, whatever system is used to keep the sheet fixed should be **at a distance that full size of the compass can rotate** on the sheet without being interfered by any obstructions. **It is also critical that since in this skill there is movement of boards, the fixing of the sheet needs to be tighter and flatter on the mat as compared to other skill to avoid creasing and folding of paper. Hence, a tight locking system is critical.**
- **Drawing Methods:**
    - Feeling the line while drawing: Same-side drawing is better as it allows for students to feel their drawing when still working at it, which is more critical for arcs and circles to successfully complete the task. And also, the design of the compass should not cover the line being drawn (as is the case with the WT).
    - Drawing Leg Tip Design: In order to prevent sheet tearing but at the same time drawing dark enough, one needs to have varied drawing tip designs than available. One can also explore this to provide variety of textures drawing possibility by making the drawing leg a changeable tip end.
    - Drawing leg fixed: Whatever tip is being used at drawing leg side, it should remain completely fixed with the compass body (APH design works well. Unlike the Classmate compass where the drawing end tip came off from the compass body on more pressure).
    - Better Grip: Also, to stabilize the first arm, it might help to look at a design for a better grip for the second arm whilst drawing/overall compass itself whilst drawing to ensure

balance. (e.g. the first leg of the APH should be as thick as the second leg to offer better grip).

- **Setting Radius:**
    - Measurement marking clarity and tool design: Whether the compass has a self-measuring tool or an independent tool is being used, the measurement markings should ideally have the following:
    - Starting of measurement should have a clear 0 rather than 1
    - The 0.5 and whole number markings to be distinguishable enough
    - Avoidance of any non-fixable clips for setting measurement
    - If the compass has the ability to slide the second leg on the measurement tool (like the APH compass) then the same to provide some audio click feedback at measurement marks rather than a smooth slide.
    - If the compass uses an independent measurement tool, there should be a system available for fixing/resting of the legs of the compass in measurement tool

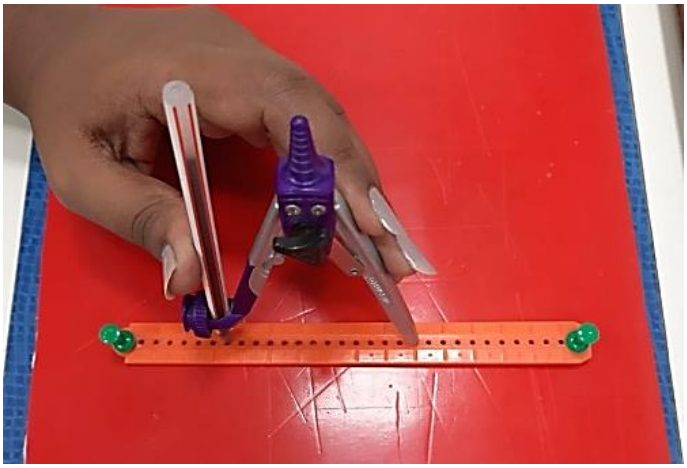


Figure 5.3: Fixing legs of compass in measurement tool

For Rulers:

- For compasses making use of separate rulers to set the radius, the following design recommendations are made:
    - The designed ruler must remove the clip mechanism as often the clip is pushed away from the measure mark by the compass legs. However, if the ruler does incorporate the clip mechanism it must be such that the clips can be immobilized to limit any clip movement.
    - For accurately marking radius, it is also recommended that the ruler make provisions for holes or grooves where the compass legs can rest rather than merely provision line and dot marks along the smooth edge of the ruler to slide the compass against.

For TDs:

- **Quality of TD: TD Quality:** It is more effective to have TDs that are raised well and on sheets which have a non-skid surface as far as possible.

CHAPTER 6. TOOL-SPECIFIC ANALYSIS: RULERS

In Chapters 3-5, the focus was on providing a comprehensive overview of all the critical errors that the students made while participating in the training and test stages for Skill 1 to Skill 6. The errors documented in Chapters 3-5 are based purely on objective data derived from skill-specific observer/researcher inferences and the students' performances at the test stage. The preceding chapters, therefore, offer insights and improvements on skill-specific user difficulties and not tool-specific errors.

Chapters 6-8 will focus on highlighting the tool-specific errors the students made when using a specific tool across all relevant skills. These chapters will also include the comparative user (student) feedback received about the tools through the questionnaires administered to the student on the completion of each skill. Further, the chapter will also analyse the effectiveness of tools across skills by looking at test-level data of final result errors. Therefore, the purpose of these chapters is not merely to point out the errors made when performing a skill using a geometry tool but to suggest tool-specific design modifications that will improve the overall effectiveness and likeability of the tool for the end user.

We hope that this data will be of value to the designers/producers of the specific tools tested for their future modifications.

Chapter 6 will focus on the various rulers used in the research. Chapter 7 will look at the protractors and Chapter 8 will look at compasses, drawing mats and pins.

This chapter is divided into a section discussing unique features for each of the six rulers, followed by a cross ruler analysis of the questionnaire responses.

I. APH Clip Ruler
II. Draftsman Ruler
III. Garg Ruler
IV. RNIB Ruler
V. Squirrel Ruler
VI. WT Ruler
VII. Effectiveness of Tools Across Skills
VIII. Questionnaire Responses: User Experience

I. APH Clip Ruler

Table 6.1: Summary of Key Issues of APH Ruler across Relevant Skills

Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment	Skill 3: Constructing an Angle	Skill 5: Constructing a Circle
Clip Movement: The ruler clip moved as the students attempted to mark the end point of the segment using the clip and while drawing the line segment.	**Ruler Movement**: Students encountered the problem of the ruler moving when aligning the ruler to the start point of the segment and when attempting to measure the given line segment.	**Ruler Placement:** The students made the error of resting the ruler against the wrong pins when drawing the second arm of the angle leading to errors. The students also struggled in aligning the ruler flush against the plotted pins leading to a gap between the pins and the ruler when drawing.	**Ruler Movement:** The APH clip ruler moved as the students used the ruler to measure and set the desired radius on the compass.
Drawing Issues: Students made the error of starting to draw the line segment after the desired start point, and stopped drawing the segment before reaching the end point.	**Ruler Placement:** The students struggled in aligning the ruler flush against the given line segment TD causing a gap between ruler and line segment.	**Ruler Movement:** The students encountered the difficulty of the ruler becoming crooked as they tried to straighten the ruler in order to draw the baseline of the angle.	**Measurement Error:** The students accidentally put the first leg of the compass at the 0.5 mark on the ruler causing radius measurement errors. They also faced a difficulty in bringing the second leg of the compass to the accurate measurement mark on the APH clip ruler.
Ruler Movement/Going Crooked: Students encountered the problem of the ruler moving while measuring and marking/plotting the desired end point. The ruler also moved as the	**Measurement Error:** The students made measurement errors as they accidentally aligned the start point of the given line segment to the 0.5 mark on the ruler leading to a wrong reading of the final		

students attempted to centralise the ruler and draw the segment connecting the start and end point.	measurement.		
Measurement Errors: The students made measurement errors as they aligned the inner edge of the ruler clip against the ruler mark instead of the required jut-out or protruding edge.			

Table 6.1 above documents the errors that occurred when using the APH Clip ruler across relevant skills. Detailed data tables for the above summary table can be found in Annexure K Tables 6.1-6.11. This report proposes the following design ideas/design improvements for the APH Clip ruler that will help to reduce the occurrence of the abovementioned errors significantly.

- **Clip Design:** The ruler can ideally have **two clips. One fixed clip at the start** of the ruler that would help it rest well against TDs and **a second movable measurement clip which is non-removable** (as that loosens the clip over time). The **second clip** however should **have an immobilisation mechanism** to ensure better measurement and drawing. The first clip should ideally be of a shorter height to avoid the mistake of resting the pins against top edge of the clip causing the ruler to be crooked. Further, the design of the second clip can be such that **a flat edge of the clip is aligned to the ruler measurement mark to avoid confusion** in alignment. Preferably, the clip design should be straightforward without too many grooves and jut-outs.
- **Ruler Markings**: It is advisable for the APH clip ruler to be equipped with a **clear 0 mark**. It would be useful to have **alternate line and dot markings to distinguish between 0.5 and whole number marks**. It is advisable for the APH clip ruler to **have any one measurement unit (cm vs inches) on the ruler** rather than different ones on both sides to minimize confusion.
- **Ruler build**: The ruler should **not be hollow or light-weight.** A sturdy build for the ruler can limit ruler movement. A **medium sized ruler with stoppers would be an ideal design.** The extra length of the ruler leads to ruler movement when straightening, centralizing, and plotting start points. Ruler movement can be limited with good stoppers below the ruler like on the Squirrel ruler to aide better grip.
- **Immobilized Ruler: The ruler itself should be easily immobilized flush against the sheet** to allow for better precision in plotting points, counting and drawing.
- **Ruler system for keeping it straight and centralized:** The ruler design needs to factor in the method of straightening and centralizing the tool for drawing the baseline. A **board-mounted ruler might be effective in achieving this.** A variation of this design can be to equip the boards with tactile marks at set distances along the length of the board to which the rulers can be aligned to keep the ruler straight and central.
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- **Age Variation of Users:** Clear system of immobilization and ruler size is more critical for those who struggled more with movement, whilst clear markings and measurement system are critical for the older group who tend to make careless mistakes with confusing markings.
- **Board Design and Paper Fastening:** The exam board design has to be ideated upon to create a comprehensive board that can be effectively used across skills. The board design must have an integrated, non-bulky mechanism for fastening the sheets. Especially for the skill of constructing an angle, the use of multiple immobilisation pins and a protruding exam board clip causes confusion and drawing challenges.

II. Draftsman Ruler

Table 6.2: Summary of Key Issues of Draftsman Ruler across Relevant Skills

Skill 1: Constructing a Line Segment
End Point Plotting: The students struggled in plotting the measurement pins accurately against the measurement marks of the ruler. The students also struggled in pushing the pins into the sheet and the Draftsman board placed below.
Ruler Placement: The students used the wrong side of the ruler when drawing or plotting end points.
Measurement Errors: The students struggled with finding the 0.5-inch measurement mark/groove on the ruler and made careless counting mistakes/measuring mistakes.
Immobilisation struggle: Students struggled to immobilize the ruler and paper on the Draftsman board.
Drawing Issues: Students stopped drawing before the end point pin.

Table 6.2 documents the errors that occurred when using the Draftsman ruler for performing Skill 1. Since the Draftsman ruler could only be used with the Draftsman board, it was used only for Skill 1. Detailed data tables for the above summary table can be found in Annexure K Tables 6.12-6.15. This report proposes the following design ideas/design improvements for the Draftsman ruler that will help to reduce the occurrence of the abovementioned errors and its wider usage across skills.

- **Board Mat/Surface:** The silicon mat provided on the Draftsman board is tough which makes pushing the pins onto the paper and mat difficult. The **mat surface of the Draftsman board and silicon mat should be such that pins can effectively pierce its surface.**
- **Immobilized paper**: It is important that the Draftsman board has a **user-friendly design to mount tools and paper**. **Clasps** need to fix/immobilise the paper tightly but at the same time be **smooth to operate** or else they will not be shut properly especially by younger students. Further, it would be advisable for the **clasps on the board to have a notch or groove that helps identify and aid the grip over the clasps**.
- **Ruler Immobilisation**: The **knob** of the ruler that helps to fix and tighten the ruler to the board must be **bigger** for better grip over the knob, making the immobilization of the ruler more effective.
- **Clear Ruler Marking:** If the Draftsman ruler is using the **mount/groove design, the same should be clear and not too close to one another**. The mount **dent** should be clear enough to **feel the groove and deep enough for the pin to rest**. Further, for effective counting, it is
-

useful for the ruler to make use of mounts, combined with **clear and alternating dot markings and line markings** which signify the 0.5 and whole number respectively.

- **Age Variation of Users:** For the younger sample, it is critical for the ruler to have clear markings and well-defined grooves. Further, the immobilisation mechanism (knob) of the ruler can be improved for effective immobilisation and drawing. Similarly, the older sample also requires a simpler and effective ruler immobilisation mechanism to limit careless drawing errors. Further, it is critical that the silicon mat on the board allows for easy and effective plotting by the older sample.

III. Garg Ruler

Table 6.3: Summary of Key Issues of Garg Ruler across Relevant Skills

Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment
Point marker Struggles: The students struggled in sliding/moving the magnetic point markers to a position on the Garg board.	**Point marker Struggles:** The students struggled in sliding/moving the magnetic point markers to a position on the Garg board.
Ruler movement/going crooked: The Garg ruler moved when plotting the start point, and end point, and when measuring the line segment.	**End point plotting:** The point markers did not fit exactly into the grooves of the Garg ruler when plotting the end points. Additionally, the students struggled to re-plot the correct point markers from under the paper once a pin mark was made.
Line marker struggle: The students struggled with the line marker moving when they were drawing.	
End point plotting: The point markers did not fit exactly into the grooves of the Garg ruler when plotting the end points.	
Drawing Issues: The students drew beyond the end point and faced difficulty in using the Garg stylus. The students struggled with drawing on the sheet because of the paper tearing or the tool alignment moving under the paper.	

Table 6.3 above documents the errors that occurred when using the Garg ruler across relevant skills. Detailed data tables for the above summary table can be found in Annexure K Tables 6.16-6.22. This report proposes the following design ideas/design improvements for the Garg ruler that will help to reduce the occurrence of the above errors.

- **Method of Drawing:** The method of **aligning tools under the paper and drawing over the paper is problematic** especially for younger students. This method causes unnecessary errors when drawing with the stylus as the students are not able to get the grip of the stylus over the tools placed below the paper, causing drawing errors and paper tearing. The method of placing end point pins from below the marked TDs is bound to cause multiple errors and result in confusion and should be avoided.
-

- **Ruler immobilization**: It is imperative for the Garg ruler **grooves to be deep and sharp** for the ruler to effectively rest on the point markers. The deep and sharp grooves on the ruler will **ensure immobilization** of the ruler limiting ruler movement while plotting the start and end points. Further, it would also help to have the magnets under the ruler to have a stronger grip.
- **Clear Markings:** The deep grooves will need to be complemented with **clear and spaced out 0.5 and whole number** markings, thus limiting counting/measurement errors.
- **Point Marker:** The **strength of the magnet** on the Garg point markers has to be **improved** such that the point markers do not move at the slightest touch. The design of the point markers must be altered according to the design of the corresponding ruler and **line marker design so that the grooves of the ruler/line marker are flush against the point marker** ensuring effective immobilization.
- **Line Marker:** The build of the Garg line marker must be improved. The **line marker should be made sturdier and heavier** so that they do not move when users draw over them. The length of the line markers needs to be ideated upon to ensure that the students do not draw beyond the end points.
- **Garg Stylus:** The **Garg stylus could be provided with a tactile mark** so that the students can identify the correct way to use the stylus. The stylus can be built studier and with a better hook mechanism to ensure better grip over the line marker.
- **Age Variation of Users:** For the younger sample, it is important to improve the design of the Garg stylus and line marker to limit drawing errors beyond the end points. The older sample, on the other hand, requires the Garg ruler to have clear markings and sharp/identifiable grooves to limit careless counting errors. The careless errors of the older students also requires for the ruler to be easily immobilised for use. Further, for the younger and older samples, it is essential for the given TDs to be sharp and easily identifiable to prevent end point plotting errors. The method of aligning tools below the sheet and drawing from above must, therefore, be avoided.

IV. RNIB Ruler

Table 6.4: Summary of Key Issues of RNIB Ruler across Relevant Skills

Skill 1: Constructing a Line Segment	**Skill 2: Measuring a Line Segment**	**Skill 3: Constructing an Angle**	**Skill 5: Constructing a Circle**
Ruler Movement/going crooked: The students struggled with the ruler moving when plotting the start point and end point, and when drawing to connect the two points.	**Ruler Movement:** The students struggled with the ruler moving when it was aligned to the start point for measuring.	**Drawing Issues:** The students did not draw till the marked end point pin.	**Ruler Movement:** The students struggled with the ruler moving when using it to set the radius.
End Point Plotting: The end point pins were not accurately plotted against the ruler marks/in the	**Measurement Error:** Students accidently put the start point pin at the 0.5 mark	**Ruler alignment:** The students struggled to straighten the ruler while drawing the	**Measurement errors:** Students made counting errors when using the ruler.

ruler grooves.	on the ruler leading to measurement errors. The students also made careless counting mistakes/measuring mistakes.	baseline of the angle.	
Ruler placement: The students used the wrong side of the ruler for drawing/measuring.	**Ruler placement:** The students struggled to accurately align the ruler against the plotted end point pins, the students used the wrong side of the ruler for measuring.	**Ruler Placement:** The students made use of the wrong side of the ruler for drawing the angle. The RNIB ruler rested against the wrong pins when drawing the arms of the angle. The students also struggled in placing the ruler in the correct orientation against the plotted pins for drawing; a gap between the pins and ruler whilst drawing/ measurement caused errors.	**Setting Radius with Ruler:** When using the ruler to set the radius the first leg of compass came away from the marking of the ruler; the students found it difficult to bring the second leg of the compass to the accurate/desired ruler mark.
Drawing Issue: The students stopped drawing before the marked end point pin.			

Table 6.4 above documents the errors that occurred when using the RNIB ruler across relevant skills. Detailed data tables for the above summary table can be found in Annexure K Tables 6.23-6.33. This report proposes the following design ideas/design improvements for the RNIB ruler that will help to reduce the occurrence of the abovementioned errors:

- **Medium Size Ruler:** Longer rulers, like the RNIB one, cause ruler movement. **Ruler movement can be limited by a medium-sized ruler with good stoppers** below the ruler like that on the Squirrel ruler. Hence, stoppers are recommended for all rulers. Further, in cases like angle drawing, a long ruler often lands up resting against wrong pins.
- **Immobilized ruler:** It is important to have an **immobilization mechanism** available on the RNIB ruler to ensure that the **ruler can lay flat** against the sheet to **avoid drawing challenges and to limit the ruler movement** while plotting and drawing.
- **Clear Markings:** The RNIB ruler uses the **groove and mount design**, the same should be **clear rather than too close** to one another with **small, sharp grooves**. For the RNIB ruler, making the **grooves deep and sharp will ensure that the pins can rest** effectively in the grooves avoiding minute measurement errors. Further, for effective counting it is useful for the ruler **to use grooves but alternate between clear line marks and dot marks to distinguish between 0.5 and whole numbers** limiting 0.5 measurement errors.

- **Ruler system for keeping it straight and centralized:** The ruler design needs to **factor in the method of straightening and centralizing the tool** for drawing the baseline. A **board-mounted ruler might be effective** in achieving this. A **variation of this design can be to equip the boards with tactile marks at set distances along the length of the board** to which the rulers can be aligned to keep the ruler straight and central.
- **Method of counting and adjusting compass:** Using the same hand to count and mark the accurate measure on the ruler and to adjust the legs of the compasses is complicated and should be modified.
- **Board Design and Paper mounting: Aligning paper:** It is important to ideate upon a **user-friendly design of the exam board**, especially for younger students. The board clip should be tight enough to immobilize the mat and paper but the **clip itself should be smooth and easy to open and close**. The **clip on the board should open all the way** so that the mat and clip can be pushed all the way up and the paper does not crumple. The board design must have an **integrated, non-bulky mechanism for fastening the sheets**. Especially for the skill of constructing an angle, the use of multiple immobilisation pins and a protruding exam board clip causes confusion and drawing challenges.
- **Age Variation of Users:** For both, the younger and older sample, it is critical for the RNIB ruler to have clear markings to limit counting errors. The provision of an immobilisation mechanism on the ruler could limit the multiple drawing and ruler movement challenges faced by the participants. A system for alternating between the ruler sides is essential for the older samples.

V. Squirrel Ruler

Table 6.5: Summary of Key Issues of Squirrel Ruler across Relevant Skills

Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment	Skill 5: Constructing a Circle
Clip movement: The students struggled with the Squirrel refreshable braille clip moving when using it to plot/mark the end point of the segment and when drawing.	**Braille reading**: Some students were not fluent in reading braille and struggled with reading the braille numbers when using the ruler.	**Braille Reading**: Some students were not fluent in reading braille and struggled with reading the braille numbers when using the ruler.
Ruler movement: The ruler moved when attempting to centralise it and when connecting the two end points.	**Ruler Placement:** The students struggled to accurately align the ruler straight against the plotted end point pins; the student struggled to align the ruler flush against the pins leading to a gap between the ruler and line. The exact corner fixed clip of the ruler would not be aligned to the first pin.	**Setting Radius with Ruler:** The students struggled to keep the first leg of the compass against the accurate/desired ruler mark when setting the radius using the ruler.

Measurement error: The students struggled with understanding the mathematical concept of 16 parts of an inch represented on the ruler.	**Measurement errors:** The students struggled with understanding the mathematical concept of 16 parts of an inch represented on the ruler, they struggled with 0.5 measures and made careless counting mistakes/measuring mistakes.	**Clip movement:** The refreshable braille clip moved from the mark when the students brought the second leg of the compass to the clip to set the accurate radius.
Braille Reading: Some students were not fluent in reading braille and struggled with reading the braille numbers when using the ruler. The students struggled in reading the braille on the refreshable clip due to the quality of the clip, and the raised dots not being readable as the clip became loose with wear and tear.		**Ruler movement:** The Squirrel ruler moved when setting radius.

Table 6.5 above documents the errors that occurred when using the Squirrel ruler across relevant skills. Detailed data tables for the above summary table can be found in Annexure K Tables 6.34-6.42. This report proposes the following design ideas/design improvements for the Squirrel ruler that will help to reduce the occurrence of the abovementioned errors:

- **Medium Size ruler**: It would be advisable for the **Squirrel ruler to be medium-sized** to limit instances of ruler movement. Further, reducing the length of the ruler will ensure that the **moveable clip does not slip to the end of the ruler** and get caught against the mat and sheet tilting the ruler in the process while pushing the ruler to the left.
- **Clip Quality:** It is essential to ensure that the **build of the clip is sturdier and tighter** such that is does not become loose with repeated use. A **loosening of the clip** can **hamper the quality of the refreshable braille** as the braille dots will not appear raised.
- **Immobilised Clip:** An **immobilised refreshable braille clip** will ensure that the clip does not have to be pressed down to read the braille. A refreshable clip that can be immobilized at the correct mark will be effective for accurately plotting points and will limit clip movement when drawing. The **short-fixed clip at the start** is useful for resting the start pins against the ruler. The fixed clip should be short because it is possible that the pins might rest along the long section of the fixed clip and the ruler tilts and causes a gap between the ruler and the line.

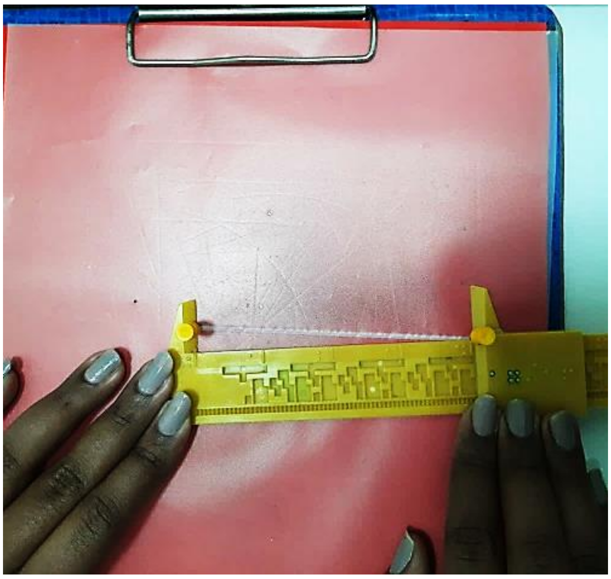

Figure 6.1: The length of the fixed clip making the ruler tilt

- **Ruler system for keeping it straight and centralized:** The **ruler design needs to factor in the method of straightening and centralizing the tool** for drawing the line segment. The ruler design needs to be complemented by a board design for keeping the tool straight and needs to be ideated upon.
- **Tool Limitation: Mathematical and Braille knowledge:** This ruler finds **efficient use only for students who have sufficient knowledge and practice of reading braille** as well as a basic understanding of the mathematical concepts like 16 parts of an inch. Also, the refreshable braille does not raise sufficiently making it difficult to read and the height of the pin and the clip needs to be redefined for better and clear refreshing of dots.
- **Age Variation of Users**: When using the Squirrel ruler, the younger sample struggled with braille reading and mathematical errors that might be a big limitation for the use of this tool among a younger population. The provision of immobilising the clip and ruler are critical for younger users. For the older sample, the primary requirement is a design improvement to straighten the ruler for plotting points.

VI. Worth Trust Ruler

Table 6.6: Summary of Key Issues of Squirrel; Ruler across Relevant Skills

Skill 1: Constructing a Line Segment	Skill 2: Measuring a Line Segment	Skill 3: Constructing an Angle	Skill 5: Constructing a Circle
End Point Plotting: The students struggled to plot the end point pins accurately against the ruler measurement marks.	**Ruler Movement/going crooked:** The ruler moved when aligned to the start and end point when measuring.	**Ruler alignment:** The students struggled in straightening the ruler for drawing the first arm of the angle.	**Measurement errors:** The first leg of the compass was aligned to the 0.5 mark on the ruler causing radius measurement errors.
Immobilising Ruler: The students struggled when immobilizing the ruler as it either moved, or was immobilised crooked etc.	**Ruler placement:** The students struggled to accurately align the ruler markings to the end point pins.	**Ruler Movement:** The students struggled with the ruler moving when drawing the second arm of the angle.	**Setting Radius with Ruler:** The students struggled in bringing the second leg of the compass to the accurate measurement mark on the ruler to set the radius. The first leg of the compass came away from the aligned mark when setting the radius.
Ruler movement/going crooked: The ruler moved when plotting the end points and when drawing to connect the two end points.	**Measurement Errors:** The students counted the start point mark on the ruler as 1 instead of 0 or often aligned the start point pin to the 0.5 mark leading to measurement errors. The students also made careless counting mistakes when using the ruler.		
Drawing Issues: The students stopped drawing before the end point pins or continued to draw beyond end points. The students struggled as their stylus moved away from the ruler while drawing.			

Table 6.6 above documents the errors that occurred when using the WT ruler across relevant skills. Detailed data tables for the above summary table can be found in Annexure K Tables 6.43-6.52. This report proposes the following design ideas/design improvements for the WT ruler that will help to reduce the occurrence of the abovementioned errors.

- **Ruler Size and Build:** The **WT ruler should be made sturdier** so that is does not bend and can be **immobilised flat against any sheet**. Further, a **medium-sized ruler with stoppers** is advisable so as to limit ruler movement at counting and immobilisation. A medium–size ruler would ensure effective alignment to the second arm and vertex pins when drawing the angle.
- **Clear Markings**: When measuring, it is essential for the WT ruler to have a **clear 0 mark** that will aid the alignment of the ruler accurately to the start point. The WT ruler could also make **provisions of shortcut marks** along the length of the ruler for start point alignment. For effective plotting of pins against the ruler marks and counting, **the marks should be made sharper and well-spaced out along the length of the ruler.**
- **Ruler immobilisation: Flat Against Sheet Surface:** The WT ruler itself should be **immobilized and fully touching the paper** which is critical for accurately drawing against the ruler. The **immobilisation holes** on the ruler should **correspond to the size and width of the pins** and the pin height should be the same as the sum total of the height of the mat and ruler ensuring that the ruler does not move after being immobilised by the students. Currently, this is not happening, thus leaving the ruler shaky even when immobilization pins are used.
- **Pin Design for Drawing Point to Point:** A design of pins complimentary to the ruler might ensure that both the ruler and pins sit flat against the sheet which guarantees that the students can draw from pin to pin.
- **Ruler system for keeping it straight and centralized:** The **ruler design needs to factor in the method of straightening and centralizing the tool** for drawing. The ruler design needs to be complemented by a board design for keeping the tool straight and needs to be ideated upon.
- **Age Variation of Users**: For the younger sample, it is critical for the WT rulers to have clear markings. Further, a system to keep the ruler straight and centralised and immobilised flat against the sheet is critical to limit movement and drawing errors. The older sample struggled with the ruler movement despite being immobilised reiterating the need for the height of the pins to compliment the ruler design for effective immobilisation.

VII. Effectiveness of Tools Across Skills

Having looked at tool-specific issues and design ideas before we go to analyse user feedback responses, we are presenting below the results of the effectiveness of the tools across the different skills. Presented below is data of test results for rulers in the skills that they were used.

Table 6.7.Test Stage Results for Skill 1: Drawing a Line Segment (%)

Tools	Right	Wrong
APH Clip Ruler	10	90
Draftsman Ruler	42.5	57.5
Garg Ruler	52.5	47.5
RNIB Ruler	22.5	77.5
Squirrel Ruler	45	55
WT Ruler	37.5	62.5

Table 6.8 Test Stage Results for Skill 2: Measuring a Line Segment (%)

	Braille Paper		Plastic Sheet		Thermoform Sheet	
	Right	Wrong	Right	Wrong	Right	Wrong
APH Clip Ruler	48.78049	51.21951	50	50	70	30
Garg Ruler	55	45	NA	NA	NA	NA
RNIB Ruler	60	40	62.5	37.5	80	20
Squirrel Ruler	52.5	47.5	60	40	72.5	27.5
WT Ruler	58.97436	41.02564	74.35897	28.20513	79.48718	23.07692

Table 6.9 Test Stage Results for Skill 3: Constructing an Angle (%)

Test Skill 3: Constructing an Angle										
	APH Wand-inside Protractor		APH Wand Protractor		Garg Protractor		RNIB Protractor		WT Protractor	
	Right	Wrong	Right	Wrong	Right	Wrong	Right	Wrong	Right	Wrong
APH Clip Ruler	0	0	0	0	0	0	32.5	67.5	37.5	62.5
None	25	75	32.5	67.5	50	50	0	0	0	0
RNIB Ruler	0	0	0	0	0	0	47.5	52.5	40	60
WT Ruler	0	0	0	0	0	0	55	45	37.5	62.5

Table 6.10 Test Stage Results for Skill 5: Constructing a Circle (%)

Test Skill 5: Constructing an Angle								
	APH Compass		Classmate Compass		Garg Compass		WT ruler as a compass	
	Right	Wrong	Right	Wrong	Right	Wrong	Right	Wrong
APH Clip Ruler	0	0	10	90	0	0	0	0
NA	42.5	57.5	0	0	90	10	65	35
RNIB Ruler	0	0	22.5	77.5	0	0	0	0
Squirrel Ruler	0	0	25	75	0	0	0	0
WT Ruler	0	0	27.5	72.5	0	0	0	0

The data presented above highlights the following:

- For Skill 1, the highest errors were recorded with the APH Clip ruler and the least with the Garg Ruler. The next most effective ruler post Garg was the Squirrel ruler.
- For Skill 2, maximum errors were recorded for TDs on Braille Paper, followed by plastic sheets, and least for Thermoform sheets. Maximum errors recorded were with the APH Clip Ruler across sheets. The least errors were recorded with the RNIB Ruler across sheets.
- For Skill 3, when the RNIB protractor was used, least errors occurred with the WT ruler and maximum errors once again with the APH Clip Ruler. Whilst using the WT protractor, the three rulers had similar error rates.
- For Skill 5, when the rulers were used to set the radius with the Classmate compass, the least errors were with WT ruler and maximum once again with the APH clip ruler.
- **This data once again reiterates the finding in the earlier section. The clip movement of the APH clip ruler led to wrong measurements and errors across skills. The shorter length of the WT rulers led to least errors whilst drawing arms of angles as the longer rulers rested against wrong pins causing errors. For Setting of circle radius, the WT ruler was most effective due to having resting points in the ruler for the legs of the compass and since it could be immobilized before setting the compass.**

VIII. Questionnaire Responses: User Experience

Having looked at individual tools for their features, this section collates the data from user experience questionnaires to provide two levels of analysis.

a. Student preferences of tools
b. Reasons for student preferences

a. Student Preferences of tools

As explained in Chapter 2 of the research process, during the course of the research, in addition to the training and test phases, participants also filled a questionnaire indicating their preferences of tools, and they also had an open-ended game session which permitted participants to use tools of their preference. This section collates data of the same along with data on test results to provide a cross-tool analysis from user experiences. Detailed data for the same are available in Annexure K Tables 6.53- 6.66.

Table 6.11: Questionnaire response of Users for Rulers across Skills (%)

	Easiest Ruler				**Most Liked**				**Most Difficult**				**Least Liked**			
Tools	**Skill 1**	**Skill 2**	**Skill 3**	**Skill 5**	**Skill 1**	**Skill 2**	**Skill 3**	**Skill 5**	**Skill 1**	**Skill 2**	**Skill 3**	**Skill 5**	**Skill 1**	**Skill 2**	**Skill 3**	**Skill 5**
APH Clip Ruler	7.317073	4.761905	22.5	16.21622	6.666667	7.142857	25	2.777778	22.5	22.5	36.58537	33.33333	9.52381	41.46341	40	27.77778
Draftsman Ruler	14.63415	NA	NA	NA	22.22222	NA	NA	NA	27.5	NA	NA	NA	23.80952	NA	NA	NA
Garg Ruler/ Line Marker	4.878049	9.52381	NA	NA	15.55556	16.66667	NA	NA	22.5	20	NA	NA	23.80952	14.63415	NA	NA
RNIB Ruler	17.07317	26.19048	45	27.02703	4.444444	16.66667	40	22.22222	7.5	15	19.5122	19.44444	11.90476	4.878049	15	19.44444
Squirrel Ruler	36.58537	47.61905	0	24.32432	28.88889	52.38095	0	27.77778	10	25	0	30.55556	14.28571	19.5122	0	36.11111
WT Ruler	19.5122	11.90476	30	32.43243	22.22222	7.142857	35	47.22222	10	15	36.58537	13.88889	16.66667	19.5122	45	11.11111

Table 6.12: Rulers selected for Games Across Skills (%)

Tools	Skill 1	Skill 2	Skill 3	Skill 5
APH Clip Ruler	2.5	10	5	0
Draftsman Ruler	20	NA	NA	NA
Garg Ruler/ Line Marker	20	12.5	5	NA
RNIB Ruler	15	22.5	17.5	2.777778
Squirrel Ruler	22.5	42.5	NA	2.777778
WT Ruler	20	12.5	17.5	0
None	NA	NA	55	94.44444

The tables above highlight the student's choice of ruler based on the likeability (most or least liked) and usability (easy or difficult) of the tool. The following inferences can be drawn based on the presented data:

- The **Squirrel ruler** was consistently chosen as the easiest and most liked ruler for Skill 1 and Skill 2. 36.5% and 47.6% students selected the Squirrel ruler as the easiest ruler for Skill 1 and Skill 2 respectively. Similarly, 28.8% and 52.3% students chose the Squirrel ruler as the most liked ruler for **Skills 1 and 2** respectively.
- For **Skill 3** i.e. drawing an angle, however, the students preferred the **RNIB ruler**; it was the easiest (45%) and most liked (40%) for drawing an angle.
- The choice of ruler changes yet again for the **skill of drawing a circle (Skill 5)**. The students preferred the **WT ruler** and it was deemed the easiest (32.4%) and most liked (47.2%) ruler for setting the circle radius.
- Conversely, the Draftsman ruler was only used for the skill of drawing a line segment (Skill 1); at 27.5% it was considered the most difficult ruler and was also the least liked ruler with 23.8% of the students expressing their dislike for the ruler.
- For Skill 2, surprisingly the Squirrel ruler was selected at the most difficult (25%) ruler but the least liked ruler was the APH Clip ruler at 41.4%. This variation in data regarding the usability (easy/difficult) and likeability of the ruler might reveal interesting informationThe likeability of the tool seems to be associated with the accuracy of the the tool.
- The APH Clip and the WT rulers were picked as the most difficult and least liked rulers for Skill 3. **For Skill 5, the APH Clip ruler and the Squirrel ruler were deemed the most difficult and lest liked rulers. This might indicate that the clip mechanism is not helpful when setting the radius with a compass**.

- The preference of the **Squirrel ruler for drawing and measuring a line segment** is reiterated as 22.5% and 42.5% students respectively selected it at the game phase. However, the APH clip ruler was the least selected ruler at the game phase for Skill 1 and Skill 2. The Squirrel clip is sturdier and more accurate in its results while the APH clip can become loose with continuous use and can be difficult to hold down. Therefore, the APH clip ruler might have been least preferred for the game.
- **For Skill 3 and Skill 5, the students didn't pick a ruler in 55% and 94.4% of the cases. This indicated that the students preferred to use tools like protractors and compasses that didn't require the support of a ruler when drawing an angle and a circle**.

b. Reasons for student preferences

We have gone into some basic analysis of the reasons presented by participants whilst making their choices. Due to the nature of the data, this information is more of a collation of responses and no statistical compilation in terms of percentages has been done for the same.

Table 6.13: Reasons for Easiest and Most liked Rulers across skills

Tools	Skill 1	Skill 2	Skill 3	Skill 5
APH Clip Ruler	Clip makes it easier to draw	Can measure directly (without counting individual digits), Easy to count/measure, Likes the method of using the ruler finds it easy to understand, Clip makes it easier to draw/ measure	Ruler was easy (draw/use), Liked the ruler, Easy to keep the ruler straight (counting/drawing)	Easy to set the radius with the ruler, Easy to count/measure, Clip makes it easier to set the radius, Easy to find and read the measurement markings/grooves on the ruler
Draftsman Ruler	Can immobilize/fix the ruler easily, Easy to count/draw with the ruler after immobilization, the ruler was easy (draw/use), It was easy to keep the ruler straight (counting/drawing)	NA	NA	NA

Garg Ruler	Easy to find and read the measurement markings/grooves on the ruler, can immobilize/fix the ruler easily, It was easy to keep the ruler straight (counting/drawing), Easy to work with point markers	Easy to put clip/pins accurately against measurement mark of the ruler, likes the method of using the ruler finds it easy to understand, can immobilize/fix the ruler easily	NA	NA
RNIB Ruler	It was easy (draw/use), Easy to find and read the measurement markings/grooves on the ruler, Easy to keep the ruler straight (counting/drawing)	Ruler was easy (draw/use), Easy to find and read the measurements markings/grooves on the ruler, Likes the method of using the ruler finds it easy to understand, Easy to put clip/pins accurately against measurement mark of the ruler, Easy to keep the ruler straight (counting/drawing)	Ruler was easy (draw/use), Likes the ruler, Can immobilize/fix the ruler easily, Easy to keep the ruler straight (counting/drawing), Easy to put clip/pins accurately against measurement mark of ruler, Ruler involves less work and its quick/fast to use, Easy to find and read the measurement markings/grooves on the ruler	Easy to find and read the measurement markings/grooves on the ruler, Easy to count/measure, Easy to set the radius with the ruler

Squirrel Ruler	Clip makes it easier to draw, Liked/Easy because of the braille readings, Easy to count, Ability to use the ruler without using pins, It was easy, Easy to keep the ruler straight (counting/drawing)	Easy to keep the ruler straight (counting/drawing), Easy to put clip/pins accurately against measurement mark of ruler, Clip makes it easier to draw/ measure, Liked/Easy because of the braille readings, Can measure directly (without counting individual digits), Easy to count/measure, Ruler was easy (draw/use), Easy to find and read the measurement markings/grooves on the ruler	NA	Liked/Easy because of the braille readings, Can measure directly (without counting individual digits), Easy to count/measure, Clip makes it easy to set the radius, Easy to set the radius with the ruler
WT Ruler	It was easy, Can immobilize/fix the ruler easily, Easy to find and read the measurements markings/grooves on the ruler, Easy to count/draw with the ruler after immobilization, The ruler was fun to use, Easy to keep ruler straight (counting/drawing)	Easy to find and read the measurement markings/grooves on the ruler, Easy to keep the ruler straight (counting/drawing), Likes the method of using the ruler finds it easy to understand, Can immobilize/fix the ruler easily	Ruler was easy (draw/use), Can immobilize/fix the ruler easily, Easy to keep the ruler straight (counting/drawing)	Can immobilize/fix the ruler easily, Easy to find and read the measurement markings/grooves on the ruler, Easy to count/measure, Easy to set the radius with the ruler, Easy to set the radius because the ruler can be immobilized

Across Skill 1 and Skill 2, the Squirrel ruler was consistently selected as the easiest and most-liked ruler by the research participants. This preference for the Squirrel ruler is reiterated as the Squirrel ruler was the most selected ruler for the game by the students for Skills 1 and 2. The reasons for the preference for the Squirrel ruler as reported by the participants are as follows:

- Clip makes it easy to draw
- Liked/Easy because of Braille
- Easy to keep ruler straight(counting/drawing)

For the skill of constructing an angle, the RNIB ruler was picked as both the easiest and most-liked ruler; it was also the highest-selected ruler for the game for Skill 3. The following reasons were mentioned by the students in favour of the RNIB ruler:

- Can immobilize/fix easily (ruler)
- Easy to keep ruler straight(counting/drawing)
- Easy to put clip/pins accurately against measure of ruler
- Easy to find/read markings/measurements/grooves

For the skill of constructing a circle, however, the WT ruler was selected as the easiest and most-liked ruler. When setting the radius with the WT ruler, the following reasons regarding its usability were reported:

- Easy to find/read markings/measurements/grooves
- Ease with counting/measuring
- Easy to set radius with the ruler/APH compass
- Easy to set radius because of immobilized ruler

However, for the Skill 5, the students did not prefer or select rulers as their preference for compasses with an inbuilt ruler or radii was very high.

Table 6.14: Reasons for Most Difficult and Least Liked Rulers across Skills

Tools	Skill 1	Skill 2	Skill 3	Skill 5
APH Clip Ruler	Difficulty to find and read the measurement markings/grooves on the ruler, struggled to understand the method of using the ruler, finds it confusing/dislikes method, clip made it difficult to draw	Difficulty to find and read the measurement markings/grooves on the ruler, struggled with counting on the ruler, difficult to keep the ruler straight (counting/drawing), ruler was moving too much, clip made it difficult to draw/measure, ruler was difficult, difficulty placing pins at exact measurement mark/groove on the ruler	Struggled to understand the method of using the ruler, finds it confusing/dislikes method, difficult to keep the ruler straight (counting/drawing), clip made it difficult to draw/measure, ruler resting against clip/immobilisation pins when drawing, stylus kept moving away from ruler when drawing, confusion in using the right side of ruler, ruler was moving too much, ruler was difficult	Difficult to keep the ruler straight when setting the radius, difficult to set the radius with ruler, clip moved whilst setting radius
Draftsman Ruler	Struggled in immobilizing the ruler, struggled in finding grooves to lock ruler on the Draftsman board, difficulty to find and read the measurement markings/grooves on the ruler, struggled to understand the method of using the ruler, finds it confusing/dislikes method,	NA	NA	NA

	confusion in using the right side of ruler, ruler was moving too much, difficulty in placing the pins at exact mark/groove on the ruler			
Garg Ruler	Difficulty to find and read the measurement markings/grooves on the ruler, struggled to understand the method of using the ruler, finds it confusing/dislikes method, ruler was moving too much, difficulty in placing the point marker pins at the exact mark/groove on the ruler, point marker struggles (moving), line markers struggles (moving)	Difficulty to find and read the measurement markings/grooves on the ruler, ruler was moving too much, point marker struggles (moving), difficulty in placing the point marker pins at the exact mark/groove on the ruler	NA	NA
RNIB Ruler	Confusion in using the right side of ruler, struggled to understand the method of using the ruler finds it confusing/dislikes method.	Difficulty to find and read the measurement markings/grooves on the ruler, short cut mark for multiples of 5 not of value/gets missed when counting/measuring, difficulty placing pins at the exact measurement mark/groove on the ruler.	Ruler resting against clip/immobilisation pins when drawing, difficult to keep the ruler straight (counting/drawing), confusion in using the right side of ruler.	Difficulty to find and read the measurement markings/grooves on the ruler, difficult to keep the ruler straight when setting the radius, difficult to set the radius with the ruler.

Squirrel Ruler	Clip made it difficult to draw, struggled/made mistakes reading braille or was braille illiterate, struggled to understand the method of using the ruler, finds it confusing/dislikes method	Struggled/made mistakes reading braille or was braille illiterate, clip made it difficult to draw/measure	NA	Did not like the ruler because of braille, struggled/ made mistakes reading braille or was braille illiterate, difficult to keep the ruler straight when setting radius, clip moved when setting radius, difficult to set the radius with the ruler
WT Ruler	Did not like working with pin, struggled in immobilizing the ruler, ruler was moving too much, difficulty to find and read the measurement markings/grooves on the ruler	Difficulty to find and read the measurement markings/grooves on the ruler, ruler was moving too much, struggled with counting on the ruler, difficult to keep the ruler straight (counting/drawing)	Stylus was moving away from ruler when drawing the angle, difficult to keep the ruler straight (counting/drawing), difficulty in placing pins at exact the measurement mark/groove on the ruler, struggled to understand the method of using the ruler, finds it confusing/dislikes method, ruler was moving too much, ruler was difficult	Difficulty to find and read the measurement markings/grooves on the ruler, difficult to set the radius with the rule

Most difficult/Least liked Rulers

For Skill 1 i.e. Constructing a Line Segment, the Draftsman ruler was the least preferred by the participants and was also considered the most difficult to use. The reasons for the struggle with the tool are detailed below:

- Struggled immobilizing (ruler)
- Struggled in finding grooves to lock ruler
- Difficulty to find/read markings/measurements/grooves
- Did not like/ understand/ /struggled in understanding the method
- Confusion in using the right side of ruler
- Difficulty placing pins at exact mark/groove on ruler

The APH Clip Ruler has been consistently recorded as one of the most difficult and least-liked rulers across skills. The following reasons regarding its usability were reported:

- Difficult to keep ruler straight (counting/drawing)
- Clip made it difficult to draw
- Difficulty to find/read markings/measurements/grooves
- Did not like/ understand/ /struggled in understanding the method

The difficulties with the APH Clip Ruler are evident from the data showing the rulers selected for the game phase. As the APH Clip Ruler was consistently the least preferred ruler for the games among the participants.

CHAPTER 7. TOOL-SPECIFIC ANALYSIS: PROTRACTORS

Continuing the tool-specific analysis, this chapter will look at Protractors.

This chapter is divided into a section discussing unique features for each of the five protractors, followed by a cross-tool analysis of the questionnaire responses.

I. APH Wand-inside Protractor
II. APH Wand Protractor
III. Garg Protractor
IV. RNIB Protractor
V. WT Protractor
VI. Effectiveness of Tools Across Skills
VII. Questionnaire Responses: User Experience

I. APH Wand-inside Protractor

Table 7.1 Summary of Key Issues of APH Wand-inside Protractor across Relevant Skills

Skill 3: Constructing an Angle
Drawing Issues: The students struggled with either the **s**tylus going underneath the protractor when drawing or drew without touching the stylus to protractor.
Drawing Method: The students struggled to follow the 3-pin method of the APH Wand-inside protractor for drawing an angle i.e. one pin at the end of the base arm, one at the vertex and one at desired degree measurement for the second arm.
Protractor Placement: The students found it difficult to straighten the protractor for drawing the first arm.
Wand Movement: The students struggled with the wand moving which caused drawing/measurement errors.
Measurement Errors: The students struggled with placing the second arm/measurement pin accurately at the measurement groove/mark of the protractor.

Table 7.1 above documents the errors that occurred when using the APH Wand-inside Protractor for Skill 3. Detailed data tables for the above summary table can be found in Annexure L Tables 7.1-7.4. This report proposes the following design ideas/design improvements for the APH Wand-inside protractor that will help to reduce the occurrence of the abovementioned errors:

- **Protractor Build:** The APH wand-inside protractor should be made **thicker and sturdier** so that it does not bend with use and **stays flat against the sheet when drawing or counting**.
- **Immobilised Protractor:** It is recommended that the design of the APH Wand-inside protractor should provide **distinct holes on the body of the protractor rather than immobilisation grooves** along its edges for the immobilisation pins, so that the protractor can be fully immobilised flat against the sheet. This would prevent protractor movement and limit drawing challenges**.** Further, there should also be a method through which the

protractor can be immobilised at each step of drawing the angle for e.g. when drawing the base arm, plotting the vertex point, drawing the second arm.

- **Immobilised wand:** Since the protractor is using a wand, it is critical that the **tightening/immobilising mechanism of the wand is as flat** as possible to ensure that the wand can sit as flat as possible on the sheet. A gap between wand and sheet causes error in drawings. It would also help if the **wand itself had a hole** for an immobilization pin on the jut out section to fix it flat against the sheet.
- **Wand Marking System**: It is also important that the placement of the wand against the protractor marking should be changed. Currently, the wand sits over the marking causing confusion instead **the wand could be devised such that it can sit right next to the desired measurement mark.**
- **Method of Using the tool**: The method of using this protractor involves **too many steps, the removal and re-plotting of pins causes confusion** and more unassessable errors and should be avoided.
- **Method for keeping tool straight**: The relative size of the APH Wand-inside protractor might make it difficult to straighten the protractor for use. The protractor does not use a separate ruler and has no method or design element to achieve a straight baseline and this causes maximum errors. A design element for the same needs to be incorporated.
- **Age Variation of Users:** The younger sample struggled with multiple aspects of the APH wand-inside protractor. A protractor with straight forward design and clear marking is required to limit drawing/counting errors. A protractor and wand that is easily immobilised is critical to limit drawing errors. An integrated method for keeping the protractor straight and centralised is essential for younger users. On the other hand, for the older sample, a protractor immobilised flat against the sheet is required to limit drawing errors.

II. APH Wand Protractor

Table 7.2 Summary of Key Issues of APH Wand Protractor across Relevant Skills

Skill 3: Constructing an Angle	Skill 4: Measuring an Angle
Drawing errors: The students did not draw till the end point and struggled with the stylus slipping underneath the protractor or under the protractor wand when drawing the angle.	**Protractor Placement:** Students struggled to accurately align the protractor to the vertex and base arm of the given TD. The students also struggled to place the protractor in the correct orientation (upside down) for measuring the angle.
Protractor placement: It is difficult to straighten the protractor for drawing the base arm, they struggled in placing the protractor in the correct orientation (upside down) to draw the angle.	**Measurement Errors:** The students struggled with the unfamiliar 45-90-degree shortcut marking system on the protractor causing measurement errors, the students made careless counting/measuring mistakes.
Wand movement: The issue of the wand moving caused drawing/measurement errors.	**Wand movement:** The issue of the wand moving caused drawing/measurement errors, the students found it difficult to align the wand flush against the second arm pins.
Measurement Errors: The students struggled with the unfamiliar 45-90-degree marking system on the protractor causing measurement	

errors, the students made careless counting/measuring mistakes.	
Protractor movement: The protractor moved when drawing the first and second arm of the angle.	

Table 7.2 above documents the errors that occurred when using the APH Wand protractor across relevant skills. Detailed data tables for the above summary table can be found in Annexure L Tables 7.5-7.12. This report proposes the following design ideas/design improvements for the APH Wand protractor that will help to reduce the occurrence of the abovementioned errors.

- **Method to align protractor to vertex/baseline**: The current method to align protractor to baseline especially for measuring angle is extremely ineffective. There has to be an attempt to relook at the design that enables the protractor to do the same.
- **Immobilised Protractor:** It is recommended that the APH wand protractor be immobilised for use. It is advisable that **the design of the protractor should provide distinct holes or sharp grooves on the body** of the protractor for pins so that the protractor can be **immobilised flat against the sheet.** This would prevent protractor movement when drawing the second arm/first arm.
- **Wand design:** Since the protractor is using a wand it is critical that **the tightening/immobilising mechanism of the wand is as flat as possible** to ensure that the wand can sit as flat as possible on the sheet. It is advisable for the wand on the protractor to have a **hole along its length for an immobilization pin on the jut out section** to fix it flat on the sheet. The immobilisation hole would limit wand movement.
- **Clear Markings:** The protractor could **alternate between line and dot markings** that makes it easier for the students to distinguish between 5- and 10-degree multiples. It is critical that **the shortcut methods being used are in line with the local educational system** being used. The 45-90-degree marking system of the protractor caused increased errors as against the 30-60-90 methods that Indian students are used to.
- **Method for keeping tool straight**: The relative size of the APH Wand protractor and the method of placing it upside down for drawing might make it difficult to straighten the protractor for use. The protractor does not use a separate ruler and has no method or design element to achieve a straight baseline, thus causing maximum errors. A design element for the same needs to be incorporated.
- **Age Variation of Users**: For the younger sample, it is critical to make improvements for the protractor and wand to be immobilised flat against the sheet to limit movement and drawing/alignment errors. Further, a locally prescribed counting system (30-60-90) and clear markings are essential design aspects for younger users. The older sample primarily requires a system for straightening, centralising and aligning (to vertex/baseline) the protractor for use. To limit careless drawing errors, it would be useful to have a clear stop system on the protractor which could act as a guide for end point for drawing of the arm.

III. Garg Protractor

Table 7.3 Summary of Key Issues of the Garg Protractor across Relevant Skills

Skill 3: Constructing an Angle	Skill 4: Measuring an Angle
Protractor Placement: The students struggled to place the protractor flat on the point marker to immobilise it.	**Protractor Placement:** The students struggled with aligning the protractor to the vertex and base arm of the given TD; they faced an issue with placing the Garg protractor in the right orientation and struggled to place the protractor flat on the point marker to immobilise it.
Drawing Issues: The students drew beyond vertex point and faced difficulties when using the Garg stylus.	**Line marker issues:** The students struggled in fixing the line marker securely on point markers and protractor measurement grooves for the drawing of the second arm.
Point marker struggles: The students struggled in straightening the point markers on the board and below the sheet for drawing the base arm. The point markers also moved below the sheet after drawing the first arm.	**Measurement errors:** The students made careless counting/measuring mistakes.
Line marker Issues: The line marker moved while the students were drawing. The students struggled in fixing the line marker securely on point markers and protractor measurement grooves for the drawing of the second arm.	**Immobilisation Struggle:** The students struggled to immobilize the paper on the Garg board.
Measurement Errors: The students made careless counting/measuring mistakes.	

Table 7.3 above documents the errors that occurred when using the Garg protractor across relevant skills. Detailed data tables for the above summary table can be found in Annexure L Tables 7.13-7.20. This report proposes the following design ideas/design improvements for the Garg protractor that will help to reduce the occurrence of the abovementioned errors.

- **Method of using the tool**: **Placing tools under the sheet and drawing over the sheet and aligning is more complicated** causing more unassessable drawing errors and tool movement errors and should be avoided as far as possible.
- **System for straightening the protractor and placing it in correct orientation:** Currently, this is challenging, and hence, a design solution for the same has to be thought of.
- **Protractor Design:** The **wheel-like design of the protractor should be avoided** as the space around the spokes can be confused with the central immobilisation hole of the protractor leading to alignment error. The **protractor should be a solid circular disk with one central hole for immobilisation.**
- **Protractor markings**: The protractor **markings can be slimmer and well-spaced out over the disk** to prevent counting errors. Since the protractor markings also function as

immobilisation grooves for the line marker placed on it, **the grooves can be made taller for better line marker immobilisation.**

- **Line Marker Design:** It is recommended that the **line-marker is made sturdier and heavier** for better hand grip over the tool and to prevent any bending, slipping or moving of the tools when drawing. An **extra lengthy line marker design should be avoided** to prevent difficulties in identifying the end points and to limit drawing challenges from above the paper. The design of the **immobilisation duct/bridge that runs below the line marker must be made deeper** thereby efficiently immobilising the line marker against the raised grooves of the point marker/protractor.
- **Point markers:** It is also advisable to **make the magnet on the point markers stronger** to prevent the point marker movement at the slightest touch, especially among younger students. The **butterfly edge of the point marker can be thicker** for better grip over the point marker when positioning it on the board.
- **Garg Board:** The **clip on the Garg board** needs to **be pushed down firmly to immobilise** the paper. A louder **audible click sound** made by the clip can help the students immobilise the paper effectively.
- **Stylus:** It is recommended that **the stylus is made sturdier and heavier** for better hand grip over the tool. A **tactile mark on the stylus can indicate the correct way of holding the stylus**. Further, the design of the stylus claws needs to be the same width as the line marker for better grip over the tools placed below.
- **Age Variation of Users**: The younger sample requires the markings on the Garg protractor to be clear and well-spaced for counting. Further, for the younger sample, it is essential to improve the point marker design to limit movement and to avoid the use of line markers that cause drawing errors. On the other hand, for the older sample, sturdier line markers are required for easier immobilisation against the protractor groove. For both, the older and younger samples, the use of too many tools below and above the paper cause multiple drawing errors.

IV. RNIB Protractor

Table 7.4 Summary of Key Issues of RNIB Protractor across Relevant Skills

Skill 3: Constructing an Angle	Skill 4: Measuring an Angle
Protractor Placemat: The students struggled in aligning the protractor to the vertex and base arm of the angle.	**Protractor Placemat:** The students struggled in aligning the protractor to the vertex and base arm of the given TD.
Protractor Movement: The students struggled with the protractor moving whilst plotting angle measurement.	**Measurement errors:** The students made careless counting/measuring mistakes when using the RNIB protractor.
RNIB Knob issue: The students struggled with the RNIB knob i.e. they placed it upside down or forgot to use it etc. Once the knob was placed the protractor often slipped under the knob.	**Protractor movement:** The students struggled with the protractor moving while attempting to measure the given angle.
	RNIB Knob issues: The students struggled with the RNIB knob i.e. they placed it upside down or forgot to use it etc. Once the knob was placed the protractor often slipped

	under the knob.

Table 7.4 above documents the errors that occurred when using the RNIB protractor across relevant skills. Detailed data tables for the above summary table can be found in Annexure L Tables 7.21-7.27. This report proposes the following design ideas/design improvements for the RNIB protractor that will help to reduce the occurrence of the abovementioned errors:

- **Improved design for aligning protractors to vertex/baseline**
- **Protractor Size:** The younger students struggled with the protractor size; the protractor is too big for their hand grip. A medium-size protractor would also be effective as it would not cover the given TDs in the skill of measuring angles.

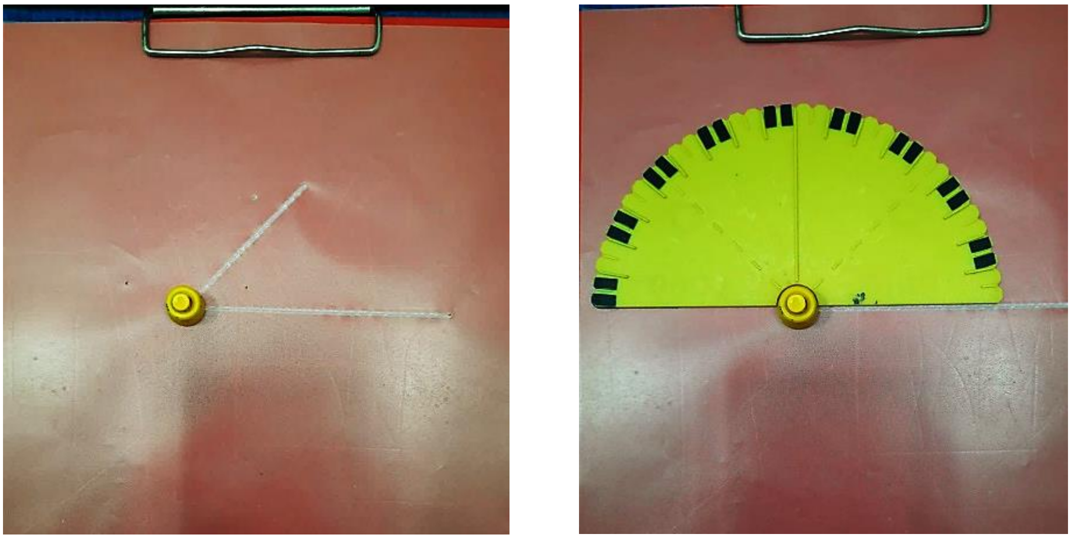

Figure 7.1: RNIB protractor covering the second arm of the angle to be measured

- **Protractor Markings:** The RNIB protractor has a long and short mark to distinguish between 5- and 10-degree marks with corresponding grooves for pin placement. This homogenous marking system was especially difficult for the younger students. The **protractor could alternate between pronounced line and dot marks** to distinguish between 5- and 10-degree measures.
- **Marking measurement as per local system used:** It is critical that the **marking and shortcut methods** being used are in line with the **local educational system** being used. The **45-90 marking system caused more errors as against the 30-60-90** methods that Indian students are used to.
- **Immobilised protractor:** It is recommended that the RNIB protractor should provide **sharper grooves for the immobilisation pins** to rest so that the protractor can be fully **immobilised flat against the sheet.** This would prevent protractor movement. Further, **immobilisation holes on the body** of the protractor might be a better choice as there would be no scope for the immobilization pins to move in the grooves.
-

- **Knob Designs:** The RNIB protractor knob can be improved to have **the knob and the pin remain fixed as one unit** and fully flat on the sheet this will make it fixable only in one direction.
- **Age Variation of Users**: For the younger students, it is essential for the protractor to incorporate a system for straightening, centralising and aligning (to vertex/baseline). Further, an improved immobilisation mechanism to keep the protractor flat and clear markings are also essential for the younger audience. Conversely, the older students require the stable and fixed knob to limit RNIB knob issues.

V. WT Protractor

Table 7.5 Summary of Key Issues of WT Protractor across Relevant Skills

Skill 3: Constructing an Angle	Skill 4: Measuring an Angle
Protractor placement: The students struggled in aligning the protractor to the vertex and base arm of the angle.	**Protractor placement:** The students struggled in aligning the protractor to the vertex and baset arm of the angle; the students also struggled in placing the protractor in the right orientation to measure the given angle.
	Measurement errors: The students made careless counting/measuring mistakes when using the WT protractor.
	Protractor movement: The students struggled with the protractor moving while measuring the angle. The WT protractor also kept slipping from the vertex point pin (WT).

Table 7.5 above documents the errors occurring when using the WT Protractor across relevant skills. Detailed data tables for the above summary table can be found in Annexure L Tables 7.28-7.35. This report proposes the following design ideas/design improvements for the WT Protractor that will help to reduce the occurrence of the abovementioned errors significantly. The following design ideas/improvements are proposed:

- **Method of Aligning Protractor to Baseline/vertex:** Because of the protractor design with multiple tips, it was difficult to align the protractor to the vertex and simultaneously keep it straight on the baseline. An alternative design solution is needed for achieving both.

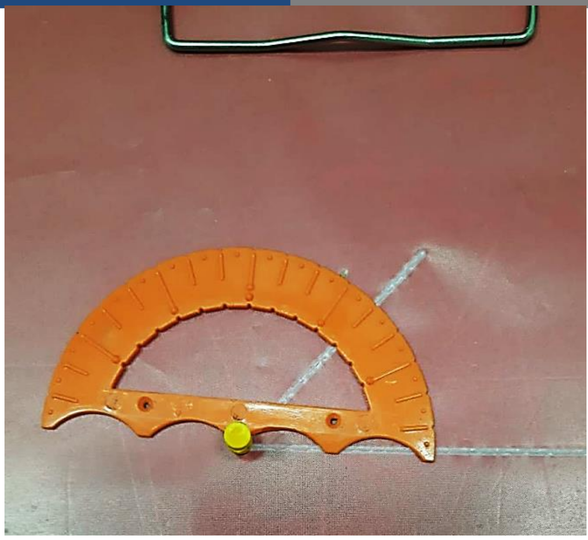

Figure 7.2: WT protractor aligned slightly off the baseline

- **Protractor Design:** A **medium-size** protractor might be advisable for a better grip over the WT protractor. The WT protractor's design with multiple arches and tips can cause confusion. Therefore, **a solid body protractor design with one single distinct 180-degree curve** might be vital to prevent protractor orientation/alignment mistakes. In addition, making **the arches at the baseline on the protractor less pronounced** and providing the **3rd tip (the vertex tip) with a sharp groove** may allow for the students to identify the vertex tip and rest the tip on the vertex pin without it slipping.
- **Clear Markings:** The careless counting mistakes on the WT protractor can be reduced by adding a **clear 0-degree mark** on the protractor. The WT protractor can make the 5- and 10-degree multiple **marks more raised and distinguishable.**
- **Protractor Immobilisation Holes:** There could be **immobilisation holes** on the body of the protractor that **correspond to the size and width of the pins** ensuring that the protractor does not move despite being immobilised by the students.
- **Age Variation of Users**: For the younger sample, a solid body protractor is critical to limit protractor placement issues. For the older sample struggling with protractor movement, an improved immobilisation mechanism is key. Further the older sample also struggled with placing measurement pins in the grooves highlighting the need for deeper and sharper grooves to rest the pins. Both the older and younger samples require sheets with sharper TDs to limit errors in placing pins on marked TDs.

VI. Effectiveness of Tools across Skills

Having looked at tool-specific issues and design ideas before we go to analyse user feedback responses, we are presenting below the result effectiveness of the tools across the different skills. Presented below is data of test results for protractors in the skills that they were used.

Table 7.6 Test Stage Results for Skill 3: Constructing an Angle (%)

	APH Wand-inside Protractor		**APH Wand Protractor**		**Garg Protractor**		**RNIB Protractor**		**WT Protractor**	
	Right	**Wrong**	**Right**	**Wrong**	**Right**	**Wrong**	**Right**	**Wrong**	**Right**	**Wrong**
APH Clip Ruler	0	0	0	0	0	0	32.5	67.5	37.5	62.5
None	25	75	32.5	67.5	50	50	0	0	0	0
RNIB Ruler	0	0	0	0	0	0	47.5	52.5	40	60
WT Ruler	0	0	0	0	0	0	55	45	37.5	62.5

Table 7.7 Test Stage Results for Skill 4: Measuring an Angle (%)

	Braille Paper		**Plastic Sheet**		**Thermoform Sheet**	
Tool	**Right**	**Wrong**	**Right**	**Wrong**	**Right**	**Wrong**
APH Wand Protractor	40	60	40	60	55	45
Garg Protractor	50	50	0	0	0	0
RNIB Protractor	75	25	52.5	47.5	57.5	42.5
WT Protractor	55.26316	44.73684	48.68421	51.31579	47.5	52.5

The data presented above highlights the following:

- For Skill 3, the maximum errors were for the APH Wand-inside protractor. The least number of errors occurred when using the RNIB protractor with the WT ruler.
-

- For Skill 4, overall the least errors occurred when using the RNIB protractor on braille paper TDs. Overall, across protractors, the least errors occurred when using Thermoform sheets. The least errors across sheets also were recorded for the RNIB protractor. When using Thermoform sheet TDs, the maximum errors occurred with the WT protractor; whilst using braille paper or plastic sheet TDs, the maximum errors occurred using the APH wand protractor.
- **The complicated method of the APH wand-inside protractor could be the cause of maximum errors with the same.**
- **In measuring, the raised TDs of Thermoform were useful and at the same time the slippery nature of thermoform caused errors. The sturdy nature of the RNIB protractor that caused least movement once aligned, as against the WT or APH wand protractor could be the reason for its effectiveness, along with its clear method of aligning for measurement especially on flat braille paper TDs.**

VII. Questionnaire Responses: User Experience

Having looked at individual tools for their features, this section collates the data from user experience questionnaires to provide two levels of analysis.

a. Student preferences of tools
b. Reasons for student preferences

a. Student Preferences of tools

As explained in Chapter 2 of the research process, during the course of the research in addition to the training and test phases, participants also filled a questionnaire indicating their preferences of tools as also had an open-ended game session which permitted participants to use tools of their preference. This section collates data of the same along with data on test results to provide a cross-tool analysis from user experiences. Detailed data for the same are available in Annexure L Tables 7.36- 7.37.

Table 7.8: Questionnaire response of Users for Protractors Across Skills (%)

	Easiest Protractor		Most Liked Protractor		Most Difficult Protractor		Least Liked Protractor	
Tools	**Skill 3**	**Skill 4**	**Skill 3**	**Skill 4**	**Skill 3**	**Skill 4**	**Skill 3**	**Skill 4**
APH Wand-inside Protractor	21.95122	NA	17.073	NA	19.048	NA	16.279	NA
APH Wand Protractor	31.70732	25	21.951	15	9.5238	43.90244	13.953	28.571
Garg Protractor	21.95122	27.5	29.268	37.5	30.952	21.95122	11.628	23.81

RNIB Protractor	14.63415	22.5	7.3171	30	23.81	14.63415	23.256	19.048
WT Protractor	9.756098	25	24.39	17.5	16.667	17.07317	32.558	28.571

Table 7.9: Protractors selected for Games Across Skills (%)

Tools	Skill 3	Skill 4
APH Wand-inside	10	NA
APH Wand Outside	17.5	25
Garg Protractor	35	30
RNIB Protractor	2.5	27.5
WT Protractor	35	17.5

Based on the data presented in the tables, the following observation can be drawn up:

- From the data, it is observed that for the skill of constructing an angle (Skill 3), the **APH Wand protractor was selected as the easiest protractor** (31.7%) and the **Garg protractor (29.2%) was the most-liked protractor**. However, the APH Wand protractor was the second most-liked protractor with 21.9% students selecting this protractor as the most-liked protractor.
- For the skill of measuring an angle (Skill 4), the protractors seem to be fairly equally preferred by the students. However, by a small margin of 2.5% the **Garg protractor (27.5%) was the easiest protractor**, above the WT protractor (25%) and the APH wand protractor (25%). This preference for the **Garg protractor was also reflected in the student's choice of the Garg protractor (37.5%) as the most-liked protractor for Skill 4.**
- For Skill 3, surprisingly, the Garg protractor was selected as the most-liked as well as the most difficult protractor to work with (30.9%). The WT protractor was the least-liked protractor (32.5%). If you take a closer look at the data for Skill 3, it can be seen that 24.3% of the students picked the WT protractor as the most-liked protractor. However, only 9.7% of the students picked the WT protractor as the easiest protractor. **The variation in the data regarding the choice between usability and likeability of the protractors indicates that the usability of the protractor might depend on the accuracy of the constructed angle while the likeability depends on the ease of using it**. **This might explain why the Garg protractor was considered difficult (point markers, line markers moving etc.) but the most liked protractor – the method is novel, does not require too many pins, immobilization, etc.**

- In Skill 4, the APH Wand protractor was selected as both the most difficult (43.9%) and the least-liked protractor (28.5%). The WT protractor (28.5%) was also amongst the least-liked protractors for Skill 4.
- **The Garg protractor (35%) and the WT protractor (35%) were selected for the game phase by the students for Skill 3. The Garg protractor (30%) was selected for the game phase for Skill 4.**

b. Reasons for student preferences

We have gone into some basic analysis of the reasons presented by participants whilst making their preferred choices. Due to the nature of the data, this data is more of a collation of responses, and no statistical compilation in terms of percentages has been done for the same.

Table 7.10: Reasons for Easiest and Most-liked protractor across skills

Tools	Skill 3	Skill 4
APH Wand-inside Protractor	Protractor was easy (draw/use), Can immobilize/fix the protractor easily, Easy to count/draw with the protractor after immobilization, Likes the method of using the protractor finds it easy to understand, Protractor can be used with lesser supplementary items like pins, rulers etc., It was easy to fix the wand at the measure mark on the protractor, Easy to find and read the measurement markings/grooves on the protractor, Easy to count/measure, It is quicker and faster to use this protractor, involves less work, Easy to keep the protractor straight when drawing/measuring	NA
APH Wand Protractor	It was easy to fix the wand at the measure mark on the protractor, It is quicker and faster to use this protractor, involves less work, Likes the method of using the protractor finds it easy to understand, Protractor can be used with lesser supplementary items like pins, rulers etc., Protractor was easy (draw/use), Easy to keep the protractor straight when drawing/measuring	It was easy to fix the wand at the measure mark on the protractor, Easy to count/ measure on the protractor, Protractor was easy (draw/use), Easy to keep protractor straight when drawing/measuring, Easy to align the protractor to the vertex and baseline of a given angle, It was easy to fix the wand at the measure mark on the protractor

Garg Protractor	Protractor was easy (draw/use), Can immobilize/fix the protractor easily, Likes the method of using the protractor finds it easy to understand, Liked the protractor, Easy to find and read the measurement markings/grooves on the protractor, Protractor can be used with lesser supplementary items like pins, rulers etc., Easy to keep the protractor straight when drawing/measuring	Protractor was easy (draw/use), Easy to keep the protractor straight when drawing/measuring, It was easy to work with the point markers, It was easy to work with the line marker, Easy to put the point marker pins at the exact marks on the TDs/drawings, Easy to count/measure, Easy to align the protractor to the vertex and baseline of a given angle, Liked the ability to use protractor without using the regular pins
RNIB Protractor	Protractor was easy (draw/use), Can immobilize/fix the protractor easily, Easy to count/draw with the protractor after immobilization, Likes the method of using the protractor finds it easy to understand, The RNIB knob helps to place the protractor down correctly	Protractor was easy (draw/use), Easy to find and read the measurement markings/grooves on the protractor, Easy to count/measure with the protractor, Easy to keep the protractor straight when drawing/measuring, The RNIB knob helps to place the protractor down correctly, Easy to align the protractor to the vertex and baseline of a given angle
WT Protractor	Easy to count/draw with the protractor after immobilization, Can immobilize/fix the protractor easily, Protractor was easy (draw/use), Liked the ability to use protractor without using the regular pins, Easy to find and read the measurement markings/grooves on the protractor, Easy to count/measure with the protractor, Likes the method of using the protractor finds it easy to understand, It is quicker and faster to use this protractor involves less work, Easy to keep the protractor straight when drawing/measuring	Protractor was easy (draw/use) Easy to count/draw with the protractor after immobilization, Easy to count/measure with the protractor, Easy to find and read the measurement markings/grooves on the protractor, Easy to align the protractor to the vertex and baseline of a given angle, Easy to keep the protractor straight when drawing/measuring

- The APH Wand Protractor was selected as the easiest protractor for the skill of constructing an angle. However, the Garg protractor was considered the easiest protractor for measuring an angle. It is interesting to note that the Garg protractor was selected as most-liked protractor for both constructing and measuring an angle. As seen from the data, the Garg protractor was also the most selected protractor for the game in Skill 3 and Skill 4. Therefore, the observed likeability of the Garg protractor might be related with its ease of use. The following reasons were reported by the students regarding the Garg protractor's consistent preference across skills:
  - Easy to find/read markings/measurements/grooves or ease with counting/measuring
  - Easy to keep protractor straight
- However, interestingly, the data for protractor selected for the game shows that both the WT and the Garg protractor were the most selected protractor for the game in Skill 3 and Skill 4.

Table 7.11: Reasons for Most Difficult and Least Liked Protractor across Skills

Tools	Skill 3	Skill 4
APH Wand-inside Protractor	Struggled to understand the method of using the protractor, finds it confusing/dislikes method, struggled to immobilize the protractor, The stylus would go below/under the protractor when drawing, The protractor body was too thin	NA
APH Wand Outside Protractor	The protractor wand moved causing drawing/measuring errors, It is tedious to use the protractor the steps are longer and takes longer, Difficult to keep the protractor straight when drawing/measuring, Difficulty to align the protractor to the vertex and baseline of the angle, Difficult in holding down the protractor for longer periods	The protractor wand moved causing drawing/measuring errors, Difficulty to align the protractor to the vertex and baseline of the angle, struggled to align the protractor wand to the measurement mark. Protractor was moving too much, Difficult to keep the protractor straight when drawing/measuring

Garg Protractor	The protractor slipped and moved from the point marker pins, It is tedious to use the protractor the steps are longer and takes longer, Line markers struggles (moving), Struggled to understand the method of using the protractor finds it confusing/dislikes method	It is tedious to use the protractor the steps are longer and takes longer, Difficult to keep the protractor straight when drawing/measuring, point marker struggles (moving), Line markers struggles (moving), The protractor slipped and moved from the point marker pins, Struggled with counting/measuring on the protractor
RNIB Protractor	Struggled to immobilize the protractor, It is tedious to use the protractor the steps are longer and takes longer, Difficult to keep the protractor straight when drawing/measuring, Difficult to align the protractor to the vertex and baseline of the angle, Protractor was moving too much, Difficulty in holding down the protractor for longer periods, Struggled with RNIB Knob as it came in the way of removing the RNIB pin	Difficult to keep the protractor straight when drawing/measuring, Difficult to align the protractor to the vertex and baseline of the angle, Struggled with RNIB Knob as it came in the way of removing the RNIB pin, Protractor was moving too much
WT Protractor	Difficult to align the protractor to the vertex and baseline of the angle, struggled to immobilize the protractor, Protractor was moving too much, Difficult to keep the protractor straight when drawing/measuring, Struggled to understand the method of using the protractor finds it confusing/dislikes method	Protractor was moving too much, Difficult to align the protractor to the vertex and baseline of the angle, Struggled with counting/measuring on the protractor

Most Difficult/Least Liked Protractor

- For the skill of constructing an angle, the Garg protractor was also selected as the most difficult protractor while the WT protractor was selected as the least-liked protractor.

- However, interestingly, the data for the protractor selected for the game shows that both the WT and the Garg protractors were the most selected protractor in Skill 3 and Skill 4.
- For the Garg Protractor, some of the reasons mentioned making it most difficult for Skill 3 are:
    - The protractor slipped and moved from the point marker pins,
    - It is tedious to use the protractor as the steps are longer and takes longer, Line markers struggles (moving),
    - Struggled to understand the method of using the protractor finds it confusing/dislikes method
- However, for the skill of measuring an angle, the APH Wand protractor was selected as being the most difficult and the least-liked protractor. The reasons for the struggle with using the APH wand protractor are as follows:
    - Wand moving causing issues
    - Difficult to keep protractor straight
    - Difficulty to align to vertex/baseline/angle
- The WT protractor was consistently recorded as being the least-liked protractor across Skill 3 and Skill 4 for the following reasons:
    - Protractor moving too much
    - Difficult to align to vertex/baseline/angle

CHAPTER 8. TOOL-SPECIFIC ANALYSIS: COMPASS

Continuing the tool-specific analysis, this chapter will look at the various Compasses used in the research.

This chapter is divided into a section discussing unique features for each of the four compasses, followed by a cross-tool analysis of the questionnaire responses.

I. Classmate Compass
II. APH Compass
III. Garg Compass/ Markers
IV. WT Ruler as Compass
V. Effectiveness of Tools Across Skills
VI. Questionnaire Responses: User Experience

These subsections will document the errors made when using each compass and then suggest design improvements for the same. The last two sections of the chapter are dedicated to a cross-tool analysis in effectiveness and user feedback.

I. Classmate Compass

Table 8.1: Summary of Key Issues of Classmate Compass across Relevant Skills

Skill 5: Constructing a Circle	Skill 6: Constructing/Cutting Arcs
Difficulty in maintaining radius whilst drawing: The students were not able to maintain radius i.e. the set radius of the compass changed when using it to draw the circle, the first leg of compass kept coming off the sheet when drawing the circle, compass leg moved away from the ruler mark when setting the radius.	**Difficulty in maintaining radius whilst drawing:** The students were unable to maintain the set radius on the compass when drawing arc, the students struggled with keeping the first leg at the marked point and the first leg of compass kept coming off whilst drawing the arc.
Drawing Issues: The students drew light (not tactile enough) and incomplete circles using the compass.	**Drawing Issues:** The students drew light and incomplete arcs using the compass.
Compass Knob issues: The students struggled in using the knob (tightening it) on the compass that locked the legs in place after setting the radius.	
Difficulty in setting radius measurement: The students struggled to pull the second leg of the compass to the accurate/desired measurement mark of the ruler.	

Table 8.1 above documents the errors that occurred when using the Classmate compass across relevant skills. Detailed data tables for the above summary table can be found in Annexure M Tables 8.7-8.14.

This report proposes the following design ideas/design improvements for the Classmate compass that will help to reduce the occurrence of the abovementioned errors:

- **Immobilised Legs:** It is imperative that the Classmate compass provide a **tight knob to immobilise the two legs** in place. This will prevent the radius from shifting when drawing, irrespective of how the compass is being held.
- **Inbuilt Stylus (Second Leg):** If the Classmate compass can make provisions for **a built-in stylus for drawing rather than the pen** the instances of the stylus moving and drawing light/incomplete lines will reduce.
- **Age Variation of Users**: For **the younger and older samples,** it is critical for the compass to have **immobilised legs**. Further, the first leg can be made **sharper but sturdier** and the drawing leg **(the stylus) can be inbuilt** to limit stylus movement and tearing while drawing. Medium-size rulers and rulers with grooves might be beneficial to to set radius among a younger population. While rulers with clear markings are essential to limit careless counting errors among the older sample.

II. APH Compass

Table 8.2: Summary of Key Issues of APH Compass across Relevant Skills

Skill 5: Constructing a Circle	Skill 6: Constructing/Cutting Arcs
Difficulty in maintaining radius while drawing: The students struggled with keeping the first leg fixed at the marked centre point of the circle, and thus the struggled in maintaining the radius while drawing.	**Difficulty in maintaining radius whilst drawing:** The students struggled with keeping the first leg fixed at the marked end point of the given line segments when drawing the arcs.
Drawing Issues: The students drew light (not tactile enough) and incomplete circles using the compass, the students also struggled to locate the centre point of the sheet for drawing the circle so that they did not end up drawing outside the sheet, when drawing the circle the centre point tears and braille paper folds and creases causing errors.	**Drawing errors:** The students drew light (not tactile enough) and incomplete arcs using the compass, the arcs drawn were not long enough to create intersection points, the issue with the paper folding and creasing whilst drawing, the stylus moving away from ruler when drawing the final bisector caused errors.
Measurement Errors: When using the inbuilt ruler of the compass, the students struggled to read the markings on the ruler, they made careless counting mistakes and counted 1 as 0 on the ruler.	**Mathematical skills:** The students were unable to calculate the radius to be set on the compass for bisecting the given line segment.
Difficulty in setting radius measurement: The students found it difficult to slide the moveable second leg of the compass accurately to the measurement of the inbuilt ruler.	

Table 8.2 documents the errors that occurred when using the APH compass across relevant skills. Detailed data tables for the above summary table can be found in Annexure M Tables 8.1-8.6.

This report proposes the following design ideas/design improvements for the APH compass that will help to reduce the occurrence of the abovementioned errors:

- **Sharp First Leg:** It is advisable for the first leg of the protractor to **be sharp enough to pierce the sheet and the silicon mat to mark the centre point of the circle, and sturdy enough to not cause paper tearing.**
- **Inbuilt Ruler Design:** Built-in ruler on the APH compass would be most effective if the second leg of the compass can be accompanied with **a click or an audio feedback to indicate the accurate mark** rather than a smooth slide over the ruler. The **marking on the ruler should begin with 0** rather than 1 and the 0.5 and whole number **markings along the length of this ruler must be distinguishable by touch** to further limit any counting errors.
- **Age Variation of Users**: For the younger sample, a board to keep tools centralised and straight is critical, while for the older sample, the inbuilt ruler must be required with clear markings to limit careless counting/measuring errors.

III. Garg Compass/ Markers

Table 8.3: Summary of Key Issues of Garg Compass across Relevant Skills

Skill 5: Constructing a Circle	Skill 6: Constructing/Cutting Arcs
Drawing Issues: The students struggled with using the Garg stylus i.e. they held it incorrectly and it slipped off the circle marker/caused the sheet to tear etc., the students drew light (not tactile enough) and incomplete circles using the compass, the sheet tearing, folding and creasing caused drawing errors, the students also struggled to locate the centre point of the sheet for drawing the circle so that they did not end up drawing outside the sheet.	**Drawing Issues:** The students struggled with using the Garg stylus i.e. they held it incorrectly and it slipped off the arc marker/caused the sheet to tear etc.
Braille literacy: They struggled in identifying the correct circle marker by the braille label on the marker for drawing the circle.	**Point marker struggles**: The point markers placed below the sheet to mark the end points of the given line segment moved when drawing the arcs causing errors.
	Braille literacy: They struggled in identifying the correct circle marker by the braille label on the marker for drawing the circle.
	Mathematical Skills: The students were unable to calculate the radius to be set on the compass for bisecting the given line segment.

Table 8.3 documents the errors that occurred when using the Garg compass across relevant skills. Detailed data tables for the above summary table can be found in Annexure M Tables 8.15-8.21.

This report proposes the following design ideas/design improvements for the Garg compass that will help to reduce the occurrence of the abovementioned errors:

- **Method of Using the tool**: **Aligning of tools under the sheet and drawing over the sheet are more complicated** causing unassessable drawing errors and tool movement errors and should be avoided as far as possible.
- **Arc Marker/Circle Marker Design: Solid Body:** The wheel like design of the arc marker with multiple spikes and hollow spaces can be confused with the central immobilisation hole especially by the younger sample. Therefore, **the arc markers should have a solid body.** Further, each arc marker should have **an arc of a single radius measurement.** Crowding the arc marker with multiple radii causes errors in using the correct radius when drawing over the sheet. The **arcs should be 180-degree arcs and semi-circular** to prevent difficulties in drawing long intersecting arcs and identifying the intersection points.
- **Point markers**: It is also advisable that **the magnet on the point markers be made stronger** to prevent point maker movement at the slightest touch or when immobilising the arc markers on it.
- **Garg Board:** On the Garg board the paper is immobilised at the top. Repeatedly lifting and replacing of the paper over the tools causes the paper to crease and tear. A **Garg board that allows for paper immobilisation of either side of the board for drawing might be preferable.**
- **Stylus:** It is recommended that the **stylus is made sturdier and heavier** for better hand grip over the tool. A tactile mark on the stylus can indicate the correct way of holding the stylus. Further, the design of the stylus claws needs to be the same width as the line marker for better grip over the tools placed below.
- **Braille and Mathematical Knowledge:** A **basic knowledge of braille is required to select the accurate circle markers**. Further, to effectively select an arc marker **it is required that the student is able calculate the numerical value of the** radius of the arc. These requirements might pose as a limitation for the use of the tool by a larger population. Hence, a non-braille tactile alternative could supplement the braille labels.
- **Age Variation of Users:** For the younger sample, solid circle/arc markers with one central immobilisation hole are essential for effective immobilisation and to limit drawing errors. A board design that incorporates a system to keep the tools straight and centralised is also a requirement. Further, a limited knowledge of braille and basic mathematics can be a major limitation for the use of the Garg tool among a younger audience. For both the older and younger samples, usage of tools below the sheet and working above the sheet caused multiple errors and should be avoided.

IV. WT Ruler as a Compass

Table 8.4: Summary of Key Issues of Worth Trust Ruler as Compass across Relevant Skills

Skill 5: Constructing a Circle	Skill 6: Constructing/Cutting Arcs
Drawing Issues: The students faced drawing issues as the paper folded and creased while drawing, the students drew light (not tactile enough) and incomplete circles using the compass, they struggled with using stylus as it was not attached to the compass and the sheet tore whilst drawing, the students also struggled to locate the centre point of the sheet for drawing the circle so that they did not end up drawing outside the sheet, and the board immobilisation pins/clip coming in the way of drawing the complete circle.	**Drawing Issues:** The students drew light (not tactile enough) and incomplete arcs using the compass, the sheet tore while drawing the arcs, and the board immobilization pins/clips coming in the way of drawing the arcs.
Difficulty maintaining radius whilst drawing: The students were not able to maintain radius whilst drawing circle as the unattached stylus kept shifting or falling out of the ruler/compass.	

Table 8.4 above documents the errors that occurred when using the WT compass across relevant skills. Detailed data tables for the above summary table can be found in Annexure M Tables 8.22-8.21.

This report proposes the following design ideas/design improvements for the WT compass that will help to reduce the occurrence of the abovementioned errors:

- **Compass Design:** The WT ruler finds use as both a ruler and a compass. However, given the performance errors of the tool **it might be advisable to design a tool that performs a single function**. The following design improvements can be considered**:**
- **Drawing Method:** With the present design, in order to prevent problems with the sheets tearing because of incorrect stylus use, it is critical to ideate upon **teaching the most effective angle** at which to hold the stylus when drawing. However, this issue might be nearly eliminated if the compass uses the mechanism of **immobilising the stylus on the compass** which predetermines the angle at which the stylus will be held to draw the circle. In addition, to ensure that the compass draws a dark enough line, the design of **an inbuilt stylus** can be ideated upon.
- **Immobilised Stylus:** The **stylus holes** that run along the length of the ruler need to be modified to **correspond to the size and width of the stylus being used.** This ensures that the stylus does not move when drawing or easily slide out of the accurate measurement hole.
- **Board Design and Sheet Immobilisation:** The board can provide tactile marks along its length that **aid in centralising and straightening the tools**. Further, the board design must have an **integrated, non-bulky mechanism** for **fastening the sheets** on **both or all four sides**.

- **First Leg Pin**: To prevent the issue of centre point tears the first leg pin coming off it might be advisable to **make the first leg sharper and broader.** Further, the **height of the pin** should be such that the pin can be pushed in flat against the surface of the compass and board limiting movement especially among the younger users.
- **Age Variation of Users**: The younger sample struggled primarily with drawing issues therefore; modification for a sharp, and steady first leg and an inbuilt stylus might prove useful. Further, a non-bulky sheet immobilisation mechanism for the board must also be ideated upon. For the older sample making a greater number of careless errors, the abovementioned improvements would also prove useful.

V. Effectiveness of Tools Across Skills

Having looked at tool-specific issues and design ideas before we go to analyse user feedback responses, we are presenting below the result effectiveness of the tools across the different skills. Presented below is data of test results for rulers in the skills that they were used.

Table 8.5 Test Stage Results for Skill 5: Constructing a Circle (%)

	APH Compass		Classmate Compass		Garg Compass/Arc Markers		WT ruler as a compass	
	Right	Wrong	Right	Wrong	Right	Wrong	Right	Wrong
APH Clip Ruler	0	0	10	90	0	0	0	0
NA	42.5	57.5	0	0	90	10	65	35
RNIB Ruler	0	0	22.5	77.5	0	0	0	0
Squirrel Ruler	0	0	25	75	0	0	0	0
WT Ruler	0	0	27.5	72.5	0	0	0	0

Table 8.6 Test Stage Results for Skill 6: Constructing/Cutting Arcs (%)

	Right	Wrong
APH Compass	50	50
Classmate Compass	30	70
Garg Compass/Arc Compass	43.58974	56.41026
WT Ruler Compass	30	70

The data presented above highlights the following;

- For Skill 5, the least amount of errors was recorded with the Garg Compass followed by WT ruler as a compass. Maximum errors were recorded with the Classmate compass.
- For Skill 6, maximum errors were once again recorded with Classmate compass along with WT ruler as a compass while the least were with the APH compass.

- It is critical to understand that whilst the WT ruler as a compass was effective for drawing complete circles the same was not effective for arcs. The APH compass, on the other hand, was most effective for arcs, but it had a slightly higher error rate for circles. This could be because of the first leg of the compass not being pointed enough, and hence, coming off whilst drawing a full circle.

- The point of consideration here is whether a fixed radius design such as Garg is desirable for teaching-learning or one in which the student can set their own radius. Whilst the former is more effective in results for learning, does it compromise a skill? Does it work more as a circle stencil rather than a Geometric compass?
- If students were to set their own radius, then a design like the Classmate compass without clear fixing of legs is most ineffective and to be avoided at all costs.

VI. Questionnaire Responses: User Experience

Having looked at individual tools for their features, this section collates the data from user-experience questionnaires to provide two levels of analysis.

a. Student preferences of tools
b. Reasons for student preferences

a. Student Preferences of tools

As explained in Chapter 2 of the research process, during the course of the research, in addition to the training and test phases, participants also filled a questionnaire indicating their preferences of tools as also had an open-ended game session which permitted participants to use tools of their preference. This section collates data of the same along with data on test results to provide a cross-tool analysis from user experiences. Detailed data for the same are available in Annexure M Tables 8.30- 8.31.

Table 8.7: Questionnaire response of Users for Compass across Skills (%)

	Easiest Compass		**Most Liked Compass**		**Most Difficult Compass**		**Least Liked Compass**	
Tools	**Skill 5**	**Skill 6**	**Skill 5**	**Skill 6**	**Skill 5**	**Skill 6**	**Skill 5**	**Skill 6**
APH Compass	30	45	36.585	34.884	20	12.5	12.195	22.5
Classmate Compass	10	12.5	4.878	13.953	45	37.5	53.659	35
Garg Compass(Circle and Arc Markers)	32.5	22.5	36.585	23.256	22.5	30	17.073	25
WT Ruler as a Compass	27.5	20	21.951	27.907	10	17.5	17.073	17.5

Table 8.8: Compass selected for Games Across Skills (%)

Tools	Skill 5	Skill 6
APH Compass	22.5	40
Classmate Compass	5	12.5
Garg Compass(Circle and Arc Markers)	50	32.5
WT Ruler as a Compass	22.5	15

Based on the data presented in the tables, the following observation can be drawn up:

- In the skill of constructing a circle (Skill 5), the **Garg compass (32.5%) was selected as the easiest compass followed by the APH compass (30%).** The preference for these compasses is also reflected as both the Garg (36.5%) and the APH (36.5%) were selected as the most-liked compasses.
- In the skill of constructing arcs**, the APH compass was selected as the easiest Compass (45%). This preference for the APH compass was reiterated as it was also selected as the most-liked compass (34.8%).** It is also important to note that in Skill 6, the Garg Arc markers dipped in their liking and ease of use.
- The students struggled with the **Classmate compass across Skill 5 and Skill 6. The Classmate compass was selected as both the most difficult compass (45%) and the least-liked compass (53.6%) for Skill 5**. Similarly, the Classmate compass was consistently selected as the most difficult (37.5%) and least-liked compass (35%) in Skill 6.
- In Skill 5, when selecting a compass for the game phase, **the Garg compass (50%), with its set radius, was the most preferred compass while the Classmate compass was the least preferred (5%).** In the game phase of **Skill 6, the APH compass was selected by 40% of the students, followed by the Garg compass (32.5%).**

b. Reasons for student preferences

We have gone into some basic analysis of the reasons presented by participants whilst making their choices. Due to the nature of the data, this is more of a collation of responses, and no statistical compilation in terms of percentages has been done for the same.

Table 8.9: Reasons for Easiest and Most-liked Compass across skills

Tools	**Skill 5**	**Skill 6**
APH Compass	Compass was easy (draw/use), Likes the method of using the compass finds it easy to understand, Compass can be used with lesser supplementary items like rulers etc., It is quicker and faster to use this compass involves less work, Can keep the radius fixed on the compass while drawing, Found the prescribed changing arms method of drawing easy, Easy to set the radius with the APH compass, The spur wheel on the compass makes it easier to draw, Easy to count/measure radius with the compass, Easy to find and read the measurement markings/grooves on the in-built ruler of the compass	The spur wheel on the compass makes it easier to draw, Found it easy to tighten and loosen the compass knob to fix the moveable second leg, The first leg of the compass remains fixed whilst drawing, Can keep the radius fixed on the compass while drawing, Easy to set the radius with the APH compass, Compass was easy (draw/use), Likes the method of using the compass finds it easy to understand, It is quicker and faster to use this compass involves less work, Compass was fun to use, Easy to put the compass leg at the exact mark on the TDs/drawings
Classmate Compass	Can keep radius fixed on the compass while drawing, Compass was easy (draw/use), Likes the method of using the compass finds it easy to understand	Compass was easy (draw/use), Likes the method of using the compass finds it easy to understand, The first leg of the compass remains fixed at the decided point when drawing, Easy to out the compass leg at the exact mark on TDs/drawings
Garg Compass	Easy to use the Garg compass circle markers, Likes the method of using the compass finds it easy to understand, Compass can be used with lesser supplementary items like rulers etc., It is quicker and faster to use this compass involves less work, Can keep the radius fixed on the compass while drawing, Compass was easy (draw/use), Easy to count/measure radius with the compass	Compass was easy (draw/use), Easy to use the Garg compass Arc markers, Easy working with Point Markers , Garg compass Arc markers are provided with fixed measurements, Likes the method of using the compass finds it easy to understand, It is quicker and faster to use this compass involves less work

WT Ruler as a Compass	Compass was easy (draw/use), Likes/easy method/understood method, Likes the method of using the compass finds it easy to understand, It is quicker and faster to use this compass involves less work, Can keep the radius fixed on the compass while drawing, Struggled with drawing with stylus for the WT ruler as compass as stylus is not attached to the compass, Found the prescribed changing arms method of drawing easy, Easy to set the radius with the WT ruler as a compass, Easy to count/measure radius with the compass, The first leg of the compass i.e. the WT centre pin remains fixed whilst drawing the circle	Compass was easy (draw/use), Likes/easy method/understood method, Likes the method of using the compass finds it easy to understand, The first leg of the compass remains fixed at the decided point when drawing, Easy to set the radius with the WT ruler as a compass, Easy to put the compass leg/pin at the exact mark on TDs/drawings

For the skill of constructing a circle, the Garg compass was selected as both the easiest and most-liked compass. The Garg compass was also the most preferred compass at the game stage that reiterates the students' preference. The following observations were made by the participants regarding the ease of using the Garg compass:

- Easy to use Garg Circle markers
- Likes/easy method/understood method
- Less work and its quick/fast

It is important to note that the APH compass was also highly preferred by the participants for the skill of compass for constructing a circle. However, for the skill of constructing a line bisector, the APH compass was selected as being the easiest and most-liked compass; it was the highest selected compass for the game for Skill 6. Further, given that the Garg Arc Markers dipped significantly in their liking and ease of use in Skill 6 as compared to the Circle Markers in Skill 5, it is critical to look at the reasons for preference of the APH compass for Skill 6, which are the following:

- Likes/easy method/understood method
- Less work and its quick/fast
- Can keep radius fixed while drawing
- Easy to set radius with the APH compass
- Spur wheel makes it easy to draw

Table 8.10: Reasons for Most Difficult and Least Liked Compass across Skills

Tools	Skill 5	Skill 6
APH Compass	Difficulty to find and read the measurement markings/grooves of the inbuilt ruler of the compass, Struggled with tightening and loosening the compass knob to fix the moveable second leg, Difficult to set the radius with the APH compass, The radius on the compass changed whilst drawing, The first leg of the compass come off the decided point when drawing, Struggled to understand the method of using the compass finds it confusing/dislikes method	Paper tore while drawing with the compass, The first leg of the compass came off the decided point when drawing, Struggled to understand the method of using the compass finds it confusing/dislikes method, The radius of the compass changed while drawing, Found the prescribed changing arms method of drawing difficult
Classmate Compass	Difficult to set the radius on this compass using a ruler, Paper tore while drawing with the compass, The first leg of the compass come off the decided point when drawing, The second leg of the compass coming off i.e. the pen moved, fell out, etc., The radius of the compass changed while drawing, Struggled with tightening and loosening the compass knob to fix the moveable legs, Compass was difficult (draw/use), Difficult to keep the ruler straight when setting the radius on the compass, Struggled to understand the method of using the compass finds it confusing/dislikes method	The radius of the compass changed while drawing, The first leg of the compass came off the decided point when drawing, The second leg of the compass coming off i.e. the pen moved, fell out, etc., The compass legs moved despite tightening the compass to fix them in place, Struggled to understand the method of using the compass finds it confusing/dislikes method
Garg Compass	Difficult to use the Garg compass circle markers, Struggled with stylus issues i.e. holding the stylus/using it over the tools placed below etc., Paper tore while drawing with the compass, Point marker struggles (moving), Compass was difficult (use/draw), Struggled to understand the method of using the compass finds it confusing/dislikes method, The method of placing tools below the	Point marker struggles (moving), Struggled with stylus issues i.e. holding the stylus/using it over the tools places below etc., Paper tore while drawing with the compass, Drew over the wrong arc markers/arc markers were confusing, Difficult to use the Garg compass arc markers, Compass was difficult (use/draw), The method of placing tools below the sheet but working above paper is a

	sheet but working above paper is a struggle and takes time	struggle and takes time
WT Ruler as a Compass	The radius on the compass changed whilst drawing, Difficulty drawing with stylus as the stylus in not attached to the WT compass, Compass was difficult (use/draw), Struggled with stylus issues i.e. holding the stylus/stylus falling out etc., Struggled to understand the method of using the compass finds it confusing/dislikes method	Paper tore while drawing with the compass, Difficult to put the pin through the compass to fix the first leg at the desired point, Difficulty drawing with stylus as the stylus in not attached to the WT compass, Compass was difficult (use/draw), The board immobilisation pins/clip come in the way of drawing full arcs, Struggled to understand the method of using the compass finds it confusing/dislikes method

The Classmate compass was consistently recorded as being the most difficult and least liked compass for the skills of constructing an angle and constructing a line bisector. The following difficulties were observed by the participants when using the Classmate compass:

- First leg of compass coming off whilst drawing
- Pen leg of compass coming off
- Radius changing whilst drawing
- Did not like/ /understand/d/struggled in understanding the method

The difficulties faced by the participants when using the Classmate compass are also reflected in their choice of compass for the game. The Classmate compass was consistently the lowest selected compass by the participants at the game stage.

CHAPTER 9. TOOL-SPECIFIC ANALYSIS: BASE TOOLS (Drawing Boards, Sheets, Pins, Styluses)

Chapters 6-8 have provided tool-specific analysis for the key geometry rules i.e. rulers, protractors and compasses. In addition to these, the base tools used across all skills in geometry are the drawing boards, sheets, pins and styluses/drawing tools).

Unlike the main tools, while individualised data was not possible to be recorded for the base tools in terms of key issues, it has been possible to note some of the key issues for base tools through data of the main tools. These have been reported in this chapter to enable identification of key design challenges for the base tools.

In addition, the questionnaire did cover user feedback for the base tools as well and that has been presented here and analysed.

Hence, this chapter will contain the following sections

I. Key Issues for Drawing Boards, Sheets, Pins and Styluses
II. Questionnaire Responses: User Experience: Boards
III. Questionnaire Responses: User Experience: Sheets

I. Key Issues and Design Ideas for Drawing Boards, Sheets, Pins and Styluses

During data analysis for the main tools, the following issues were recorded for the base tools:

a. Drawing Boards

- **Board Design and Paper Fastening**: The exam board design has to be ideated upon to create a comprehensive board that can be effectively used across skills. The board design must have an integrated, non-bulky mechanism for fastening the sheets. Especially for the skill of constructing an angle, the use of multiple immobilisation pins and a protruding exam board clip causes confusion and drawing challenges. The Draftsman board, on the other hand, due to the side clip mechanism not being smooth, caused difficulty in locking effectively, as also prevented from larger TDs to be loaded on the board.
- **System of locating the centre of the board/sheet:** Currently, no board has a clear system to help students locate its centre. This is critical in skills like drawing of angles or circles where you would want the student to ideally draw in the centre to ensure sufficient space for drawing.
- **Keeping tools Straight and Centralised:** Since this was a key challenge faced by most students, it is critical to ideate on a board design that enables for tools to be maintained straight and centralised, as per need.
- **Sheet immobilization mechanism:** A non-bulky sheet immobilisation mechanism for the board is a must. Currently, none of the boards tested had an effective sheet immobilization mechanism, leading to creasing of paper whilst drawing or tearing of paper whilst drawing.

Further, the immobilization method used should not interfere with size of tools or drawing methods of tools being used. e.g. pins interfering with ruler length or compass size etc.

b. **Sheets & Stylus**

- **Quality of TD: Distinct TDs:** It is more effective to have TDs that are **raised well** and on sheets which have a **non-skid surface** as far as possible. For measuring, it might also be advisable to have **TDs that are sharp but not thick** as the end points of thicker TDs might give the illusion of not being accurately aligned to the markings on tools.
- **Drawing Quality without tearing:** Depending on the sheet being used and the sharpness of tools, it is oftentimes a challenge to draw a distinct figure. Oftentimes, either the paper or plastic sheet tear if there is too much pressure applied, or the resultant drawing is too light, making it difficult to locate points or intersections on the same. A 45-degree angle of the stylus was found to be most effective in creating sharp drawings without a tear. A possible angled stylus design can be looked at for drawing purpose.
- **Effectiveness of different types of tools:** For TDs, tools with pins made the TDs not reusable after one use as the pins left holes and subsequent measurement errors on reuse.
- **Stylus Grip and Design:** For the Garg stylus, it is recommended that **the stylus is made sturdier and heavier** for better hand grip over the tool. A **tactile mark on the stylus can indicate the correct way of holding the stylus**. Further, the design of the stylus claws needs to be the same width as the line marker for better grip over the tools placed below. For the regular stylus used, a blunted yet broad tip that prevents tearing but ensures a clear tactile line along with the 45-degree inclination can be considered.

c. **Pins**

- **Height:** It is critical that the height of the pins is designed in relation to the height of the drawing board and the tools being used, in order to ensure that the entire pin fits steadily rather than wobble and make the tools loose on the sheet at the time of drawing.
- **Sharpness:** Pin edges need to be sharp enough to penetrate the board and the sheets being used.
- **Pin Box:** It is critical to have a cork box for pins to be put into when not in use for easy search and safe usage. The box should make it easy to locate and pick up a pin with one hand while the other hand might be holding down some tool.

In addition to the above, one additional element that has been identified, currently not part of any tools is the following:

- **Carrying Case and Working Tray:** In order for the student to effectively work with tools, it is important to have both a carrying case for the tools as also a working tray. Because when working with multiple materials or objects (be it craft supplies, geometry work, lab work, and so on) it is imperative that students have a defined working space and materials space, to prevent accidents and promote efficiency. Either the carrying case itself can open up to a working box, where tools can be easily identified and picked from during work, or there could be one carrying case and another working tray designed. Having fixed shape slots of tools in the carrying case, where the same can be stored, is effective.

II. Questionnaire Responses: User Experience: Boards

Having looked at individual tools for their features, this section collates the data from user-experience questionnaires to provide two levels of analysis.

a. Student preferences of tools
b. Reasons for student preferences

d. Student Preferences of tools

As explained in Chapter 2 of the research process, during the course of the research, in addition to the training and test phases, participants also filled a questionnaire indicating their preferences of tools as also had an open-ended game session which permitted participants to use tools of their preference. This section collates data of the same along with data on test results to provide a cross tool analysis from user experiences. Detailed data for the same are available in Annexure N Tables 9.3-9.4.

Table 9.1: Board Cross-Skill Questionnaire Objective Data (%)

	Easiest Board	Most Liked Board	Most Difficult Board	Least Liked Board
Tools	**Skill 1**	**Skill 1**	**Skill 1**	**Skill 1**
Draftsman Board	41.46341	48.78049	25	22.5
Exam Board	34.14634	24.39024	20	32.5
Garg Board	24.39024	26.82927	55	45

Table 9.2 Board Cross-Skill Questionnaire Selected for Game (%)

Tools	Skill 1
Draftsman Board	22.5
Exam Board	57.5
Garg Board	20

From the above table, the following observations can be made:

- **In Skill 1, the Draftsman Board was selected as both the easiest (41.4%) and the most-liked board (48.7%).** The Exam board and the Garg board were liked by 20%-35% of the students and selected as either the easiest or most-liked boards.
- The Garg board was selected as the most difficult (55%) and least-liked (45%) board in Skill 1. However, 32.5% of the students also mentioned that the Exam board was their least liked board.
- Yet, surprisingly, **the Exam board was selected by 57.5% of the students at the game phase in Skill 1. This choice of board may be related to the versatility of the Exam board. The board can be used with multiple rulers, different lines can be drawn on the board, and the board itself can be used for other purposes**.

e. Reasons for student preferences

We have gone into some basic analysis of the reasons presented by participants whilst making their choices. Due to the nature of the data, this information is more of a collation of responses and no statistical compilation in terms of percentages has been done for the same.

Table 9.3: Reasons for Easiest and Most-liked Board across skills

Tools	Skill 1
Draftsman Board	• Answer not clear/could not express • Board was easy (draw/use) • Liked using the board • The board was fun to use • Can immobilize and fix the sheet easily on the board • Can immobilize and fix the ruler easily on the board • The method for this board and the tools were different/new • Easy to keep the ruler straight on the board • Easy to push pins in to the board surface • Easy to use the stylus on this board
Exam Board	• Answer not clear/could not express • Board was easy (draw/use), Liked using the board • Liked the multiple applications of board with different rulers and for different purposes • Can immobilize and fix the sheet easily on the board • Can immobilize and fix the ruler easily on the board • Found the method of using the board easy/understood the method • Lesser number of items were needed to use the board • It is quicker and faster to use this board involves less work • Easy to keep the ruler straight on the board • Can draw all types of lines (straight or slant) on this board • Easy to push pins in to the board surface • The board was fun to use
Garg Board	• Answer not clear/could not express • Board was easy (draw/use), Liked using the board • The board was fun to use • Can immobilize and fix the sheet easily on the board • The method for this board and the tools were different/new • Easy to keep the ruler straight on the board • Easy to work with the point markers on the board • Liked the ability to work without regular pins on this board • Easy to use the Garg stylus

The questionnaire administered after Skill 1, constructing a line segment, recorded the participants' opinions on the different boards being used. The Draftsman board was recorded as being the easiest and most-liked board for the following reasons:

- Can immobilize/fix easily (sheet and ruler)
- Method/tools were different/new
- Easy to keep ruler straight
- Easy pushing pins in board
- Ease using stylus

However, it was the exam board that was the board selected for the game. Only the Draftsman ruler can be used on the Draftsman board. Therefore, the students might have preferred the Exam board which allows the use of multiple rulers.

Table 9.4: Reasons for Most Difficult and Least Liked Board across Skills

Tools	Skill 1
Draftsman Board	• Struggled with the immobilization clip on board for locking/fixing the sheet • Struggled to understand the method of using the board, finds it confusing/dislikes method • It is tedious to use the board the steps are longer and takes longer
Exam Board	• Struggled with immobilizing the sheet on the board • Difficult to keep the ruler straight on the board for counting/drawing • The ruler moved too much on the board, The paper/sheet moved too much on the board • Struggled to understand the method of using the board, finds it confusing/dislikes method
Garg Board	• Point marker struggles (moving) • Line markers struggles (moving) • It is tedious to use the board, the steps are longer and takes longer • The ruler moved too much on the board • Struggled to understand the method of using the board, finds it confusing/dislikes method • Board was difficult (use/draw)

The Garg board was selected as being the most difficult and least-liked board by the participants. The Garg board was the least selected board for the game by the participants. The following remarks about the ease of using the Garg board were recorded:

- Point marker struggles and Line Marker struggles

- Too much work/steps/long method
- Ruler moving too much
- Did not like/ /understand/ /struggled in understanding the method

III. Questionnaire Responses: User Experience: Sheets

This section collates the data from user-experience questionnaires to provide two levels of analysis.

a. Student preferences of tools
b. Reasons for student preferences

f. Student Preferences of tools

As explained in Chapter 2 of the research process, during the course of the research in addition to the training and test phases, participants also filled a questionnaire indicating their preferences of tools as also had an open ended game session which permitted participants to use tools of their preference. This section collates data of the same along with data on test results to provide a cross tool analysis from user experiences. Detailed data for the same are available in Annexure N Tables 9.1-9.2.

Table 9.5 Sheet Cross-Skill Questionnaire Objective Data (%)

	Easiest Sheet		Most Liked Sheet		Most Difficult Sheet		Least Liked Sheet	
	Skill 2	**Skill 4**	**Skill 2**	**Skill 4**	**Skill 2**	**Skill 4**	**Skill 2**	**Skill 4**
Braille Paper	21.95122	11.90476	14.28571	15	25	27.5	29.26829	29.2683
Plastic Sheet	9.756098	11.90476	11.90476	5	70	62.5	60.97561	65.8537
Thermoform Sheet	68.29268	76.19048	73.80952	80	2.5	7.5	9.756098	4.87805

Table 9.6.Sheet Cross-Skill Questionnaire Selected for Game (%)

	Skill 2	Skill 4
Braille Paper	17.5	40
Plastic Sheet	15	10
Thermoform Sheet	67.5	50

- The preference for the Thermoform sheet is unanimous. In the skill of measuring a line segment (Skill 2), 68.2% of the students considered it the easiest sheet and 73.8% of the students picked it as their most-liked sheet. 76.1% of the students considered it the easiest sheet and 80% of the students picked it as their most liked sheet.

- The dislike for the Plastic sheet is also unanimous. In the skill of measuring a line segment (Skill 2), 70% of the students considered it a difficult sheet to work with and 60.9% of the students considered it their least-liked sheet. In the skill of measuring an angle (Skill 4), 62.5% of the students considered it a difficult sheet to work and 65.8% of the students considered it their least-liked sheet.

- Unsurprisingly, 67.5% of the students in Skill 2, and 50% of the students in Skill 4 selected the Thermoform sheet for the game phase. However, 40% of the students also picked the Braille paper in Skill 4 for the game. The plastic sheet remained the least preferred for the students at the game phase.
- It is important to bear in mind that the sheet options were only given and analysed for measuring skills, and hence, are relevant to the discussion on making of TDs. As far as drawing diagrams is concerned, the sheet choice depends on the technical feasibility of generating tactile material at the user end using specific tools. Same side drawing has been consistently preferred by students, as also sharper and clear lines. Hence, for drawing it would be safe to assume that the Plastic sheet meets this need more over the braille paper given the tools. If a more effective kit for same-side drawing on paper can be developed, then paper for drawing can also be considered.

g. Reasons for student preferences

We have gone into some basic analysis of the reasons presented by participants whilst making their choices. Due to the nature of the data, this is more of a collation of responses, and no statistical compilation in terms of percentages has been done for the same

Table 9.7: Reasons for Easiest and Most-liked TD Sheets across skills

	Skill 2	**Skill 4**
Braille Paper	• Marked TDs are distinct and easily felt (measurement) • Sheet was easy (draw/use) Answer not clear/could not express	• Sheet was easy (draw/use) • Marked TDs are distinct and easily felt (measurement) • Easy to put pins at exact marks/points on TDs/drawings
Plastic Sheet	• It is quicker and faster to use this sheet involves less work • Marked TDs are distinct and easily felt (measurement) • Easy to put pins at exact marks/points on • TDs/drawings Sheet was easy (draw/use)	• Sheet was easy (draw/use) • Easy to align the protractor to the vertex and baseline of a given angle on the sheet • Protractor sits (does not slip) nicely on TD/sheet • Marked TDs are distinct and easily felt (measurement) • Easy to put pins at exact marks/points on TDs/drawings
Thermoform Sheet	• Sheet was easy (draw/use) • Easy to put pins at exact marks/points on TDs/drawings • Liked the ability to work without using regular pins on this sheet • Ruler sits (does not slip) nicely on TD/sheet	• Sheet was easy (draw/use) • It was easy to count/measure on this sheet • Easy to align the protractor to the vertex and baseline of a given angle on the sheet • Protractor sits (does not slip) nicely on TD/sheet • Marked TDs are distinct and

	• It is quicker and faster to use this sheet involves less work • Marked TDs are distinct and easily felt (measurement)	easily felt (measurement) • Easy to put pins at exact marks/points on TDs/drawings

The Thermoform sheet was considered the easiest and most-liked sheet by the participants. For Skills 2 and 4, the Thermoform sheet was the highest selected sheet by the students for the game. The reasons for its consistent preference across Skill 2 and Skill 4 are as follows:

- Ruler/Protractor sits nicely on TD/sheet/paper
- Marked TDs are distinct (measurement)
- Easy to put pins at exact marks on TDs/Drawings

Table 9.8: Reasons for Most Difficult and Least Liked Sheets across Skills

Sheets	Skill 2	Skill 4
Braille Paper	• Point marker struggles • Difficulty placing pins at exact marks on TDs/Drawings • Marked TDs not distinct enough (measurement)	• It was Difficult to align to vertex, baseline, angle • Difficulty placing pins at exact marks on TDs/Drawings • Marked TDs not distinct enough (measurement)
Plastic Sheet	• Difficulty placing pins at exact marks on TDs/Drawings • Marked TDs not distinct enough (measurement) • Struggled with counting	• It was Difficult • Did not like/method/understand/Confused/struggled in understanding the method • Difficulty placing pins at exact marks on TDs/Drawings • Protractor slips on the sheet/paper/TD • Marked TDs not distinct enough (measurement)
Thermoform Sheet	• Struggled with counting	• It was Difficult • Protractor slips on the sheet/paper/TD

The Plastic sheet was considered the most-difficult and least-liked sheet by the participants. In keeping with this data, the Plastic sheet was the lowest selected sheet for the game by the participants. Across Skill 2 and Skill 4, for the following reasons:

- Difficulty placing pins at exact marks on TDs/Drawings
- Marked TDs not distinct enough (measurement)

CHAPTER 10. WAY FORWARD: DESIGN BRIEF AND CONCLUSION

This chapter seeks to be a culmination of our two-year research journey in investigating accessible Geometry Construction Kits (GCKs) for students with blindness and low vision. The objective set out at the beginning of this research was clear – ***To research and identify the most effective design elements for building a comprehensive accessible geometry construction kit (GCK) for students with blindness and low vision.***

As an organisation directly involved in the education of students with blindness and low vision, the need for this research had stemmed from our work with students. Our Accessible STEM Education Project had kept dealing with the daily frustration of not having effective tools to teach geometry constructions to our students. We strongly believed in both the need and the ability of students with blindness and low vision to study geometry constructions. It is this belief that led us to the journey of the last two years.

Our research experience has validated our beliefs. What stood out during the research process with every group of students was their excitement with seeing with their hands new things that they had never seen before. Especially tools like the Garg Geometry Kit, the APH Draftsman kit etc., which were completely new to them. The excitement of, "Oh this is how a perfect circle can be drawn!" or "This is how a compass is used!" was palpable and expressed by many groups we worked with. Many wished to keep the sheets of the neatly and accurately drawn angles, circles or line bisectors they had constructed. Participants were excited on seeing the tactile diagrams on the Thermoform sheets. They enjoyed deducing and sharing their own methods of how the tool should be used or the modifications that were possible. All participants were just happy to be "involved" and "included" in the world of geometric constructions. Even those participants who struggled in getting the skill with accuracy just enjoyed working with their hands; creating something. As expressed by one of our participants in her own words,

"This is very new to me; I have never seen or done this before. I had never heard about this. It's new and interesting."

- *Preeti Jhadav about Skill 6*

And it is with this reaffirmation that we undertake in this chapter the mammoth task of attempting to collate all our learnings presented so far to create what this research was aimed at:

- A holistic understanding of the effectiveness and challenges of existing GCKs
- A clear understanding of useful and effective design elements of GCKs that can make geometry constructions accessible and efficient for students with blindness and low vision
- Developing a clear design brief for the production of a comprehensive accessible GCK

The first two have been delivered in our earlier chapters with discussions on the key issues followed by design suggestions for each skill as also each tool. It is the last objective, and perhaps the most crucial takeaway of this project, that we present in this chapter.

We hope that all designers, old and new, who are interested in developing universal GCKs, which even students with blindness and low vision can use, will be able to benefit by keeping in mind the ideas presented in the design brief below. And we do hope that the kits designed keeping these suggestions in mind will be able to benefit students with blindness and low vision by making this

activity that they loved so much even more enjoyable, less tedious, and more accessible than it is today, making geometry a subject that is loved rather than feared.

I. Design Brief for Comprehensive Geometry Kit

a. Rulers

Size and texture	• Medium (6-8 inches/15-20 cm) in length • Minimum 1-inch breadth • A full solid body which is not hollow and adds weight to the ruler • Matte non-skid texture better over smooth texture
Stoppers	• Non-skid stoppers at the base of the ruler flushed out to ruler surface i.e. at the same level as the ruler and not jutting out of the ruler to ensure the ruler remains flat and non-slippery with the stoppers
Design	• Use of a single measurement system either **cm**s or **inch**es • Same measurement system on both sides of the ruler with one side of the ruler having grooves (for pin method) and the other side plain/smooth for drawing/measuring without pins
Marking system and design	• Clear marking and labelling for 0 at the start of the ruler. This could either be the edge of the ruler with a clip along with the 0 marked and labelled, or it could be like print rulers; there will be some extra length of the ruler before the 0 is marked and labelled • Differentiated markings for whole and decimal numbers • Using a combination of line markings, shortcuts and grooves most easy to identify and count with • Recommended markings for a cm system: Every 0.5 cm, a groove along with an extra-short line; every 1 cm, a groove and a short line; every 5 cm, an extra-long line going across the breadth of the ruler with a groove. The 0.5 mark line to be quarter of the length of the 1 cm line being used. On the smooth side of the ruler, the same marking system can be used without grooves. All markings should be clear and distinctive and not faint. The markings to be raised and not engraved into the tool. • For an inches system: Every 0.25 inch, a groove along with an extra short line; every 0.5 inch, a groove and a short line; every 1 inch, an extra-long line going across the breadth of the ruler with a groove. The 0.25 mark line to be quarter of the length of the 0.5 line being used. On the smooth side of the ruler, the same marking system can be used without grooves. All markings should be clear and distinctive and not faint. The markings to be raised and not engraved into the tool. • For minute measurements: For cm, the minutest would be 1 mm and for inch the minutes could be 1/16. These measurements are only possible with a refreshable system such as the Squirrel ruler. Alternative non-tactile methods for minute measurements besides the refreshable system can be ideated upon. • Clear shortcut method for counting multiples as suggested above. In

	addition to the extra-long mark, a Braille label for the measurement of the extra-long mark to be placed to its right in the centre of the ruler. This will enable braille literate users with additional efficiency. • If refreshable braille is used, the dots should raise clearly. Also, in addition to braille, a neutral tactile mark refreshing will increase usability. Further, a click sound for shifting clips will also be useful. • Counting system to be kept as simple as possible. 1/16 concept might become challenging for younger users. If refreshable braille system is used, it should state the actual value itself in decimals. • Further, given that in inclusive classrooms, sighted teachers and students will be working with students with blindness and low vision, we recommend that all tool markings should also be in sighted print to aid students with blindness to work with all.
Groove design	• Deep enough for pins to rest clearly and to feel the groove clearly
Clip Design	• A clear fixed jut-out at the beginning of the ruler of not more than 1 cm in height • A movable clip created such that it will not become too loose with time, yet smooth enough to slide, and with an immobilization hole of its own • The movable clip should have a simple grip system to enable easy moving by the student. • The movable clip edge to align with the measurement mark on the ruler. The clip design could be such that both the jutting out end of the clip along with the part of the clip on the ruler both align with the measurement mark to avoid confusion.
Immobilization System	• Tool to remain flat • To have holes along the length of tool for inserting immobilization pins • Any moving part such as clips to also have holes for immobilization
Method for keeping it straight	• Having the option to fix the ruler in the drawing board • If knobs are used for the same, the knob should be bigger for better grip • A ruler with a length exactly that of the board that enables it to fit end to end on the board would also be easy to ensure that its straight • One also needs to ideate on a method to keep the ruler straight whilst trying to centralize it.
Method for centralizing	• Marking on the drawing board to locate the centre
Method of drawing & measuring	• Same side • Simple with as few steps as possible • When using the pin method, it leaves TDs redundant for use after a single use, hence, a non-pin method for measuring should be explored. • Further, it is critical that the tool enables drawing clear dark lines as the constructions drawn by the user could be later used for measurements as well.
Use with Compass	• Ruler to have small holes in the centre of its body aligned to the measurement markings on the ruler that enables for the compass leg to be inserted.

	• If this system is not possible, then the measurement side of the ruler must have deep grooves for the compass legs to rest, if a compass is being used that needs a ruler for setting the radius.
Critical For Accuracy	• Design not to have moving clips without immobilization feature • If the compass depends on the ruler for radius measurement, the ruler must have holes where the compass legs can rest. • For drawing, a medium size ruler is essential to avoid resting of ruler against wrong pins whilst drawing.
User Preferred features	• A refreshable moving clip which can read measurement rather than having to count measurement manually is preferred. • Rulers with stoppers that keep them non skid • Shortcut method and ease of reading measurements • Ease of understanding the method of using the tool • Ability to immobilize effectively • Ease in keeping tool straight

b. Protractors

Size and texture	• Medium (base length 4 inch, height 2 inch) • Matte non-skid texture better over smooth texture
Stoppers	• Non-skid stoppers at the base of the protractor flushed out to protractor surface to ensure it remains flat with the stoppers
Design	• 30-60-90 or 45-90-135 system to be used (depending on local applicability) • Ideal to have a curve one side and a flat line on the other if a semi-circle protractor is designed • Solid protractor easier to use • Along the base, to have some gaps to feel the base of the arm of the angle • If protractors are used for drawing of arms then the edge of protractor would need to be straight which might conflict with being able to feel the base arm. However, the same would depend on the method of drawing and measurement being used for the protractor. • Also, if the protractor is to be used for drawing arms, then the extreme ends of the base of the protractor to have some stop jut-outs to prevent line drawing beyond the ends. • A solid circular protractor with a hole in the centre for marking the vertex and a line jutting out or a slit at 180 degrees to draw the arms and keep the protractor straight might be worth exploring.
Marking system and design	• Clear marking for 0 at the start of the protractor. This could either be the edge of the protractor for a non-wand protractor system. For a wand protractor, it could be like a regular sighted print protractor, where there is some extra blank space below where the 0 is marked and labelled. • Recommended markings for the 30-60-90 system: Every 5 degrees, a groove along with an extra-short line; every 10 degrees, a groove and a short line with a dot at the inner end of the line; for the 30-60-90-120-150-degree marks, extra-long lines going across the breadth of the protractor

	with grooves. The 5-degree lines to be quarter of the length of the lines being used at the 10-degree mark. All markings should be clear and distinct and not faint. The markings to be raised and not engraved into the tool. • Recommended markings for the 45-90 system: Every 5 degrees, a groove along with extra-short line; every 10 degrees, a groove and short line with dot at the inner end of the line; for the 45-90-135-degree marks, extra-long lines going across the breadth of the protractor with grooves. The 5-degree lines to be quarter of length of the lines being used at the 10-degree mark. All markings should be clear and distinct and not faint. The markings to be raised and not engraved into the tool. • Clear shortcut method for counting multiples as suggested above • For minute measurements: For every degree, these measurements are only possible with a refreshable system such as the Squirrel ruler. A similar refreshable clip can be created along the body of the protractor. Alternative non-tactile methods for minute measurements besides the refreshable system can be ideated upon. • Further, given that in inclusive classrooms, sighted teachers and students will be working with students with blindness and low vision, we recommend that all tool markings should also be in sighted print to aid students with blindness to work with all.
Groove design	• Deep enough for pins to rest clearly. And to feel the groove clearly
Wand Design (if used)	• Tightening of the screw to be flat. If needed, the protractor thickness to be adjusted so that the tightening screw remains flushed inside and not jutting out at the base. • Size of the screw medium and easy to grip • The wand to be designed such that it rests immediately on the side of the selected marking and the end juts out like a clip for marking the pin. If the wand rests on top of the selected mark, it causes confusion in counting. This is provided the wand is to be aligned for marking pins. If the wand is being used like the APH wand protractor, the tip of the wand must align below the marking for fixing of the wand. • The wand itself to have an immobilization pin mark • One can also explore an innovative clip-like design for the protractor, like those on rulers, instead of a wand
Immobilization System	• Tool to remain flat • To have holes along the tool for inserting immobilization pins rather than edge grooves. Alternative immobilization methods like magnets etc. can also be explored • Any moving part such as wands to also have holes for immobilization
Method for keeping it straight	• Having a system through which a ruler could first get fixed and the protractor could sit on it as the base for getting it straightened before being immobilized might help • Circular protractor with a line jutting out (like Garg) and a way to ensure the line is straight

Method for centralizing	• Marking on the drawing board to locate the centre
Method of drawing & measuring	• One that permits the angle to be drawn by the protractor itself without needing rulers is preferred • When using the pin method, it leaves TDs redundant for use post a single use, hence, a non-pin method for measuring should be explored. • Further, it is critical that the tool enables drawing clear dark lines as the constructions drawn by the user could be later used for measurements as well
Knob Design (if used)	• Knob to fit tightly onto the pin and only one way. (If knob on pin is to be used)
Critical For Accuracy	• Sturdiness of the protractor with a solid fill and non-skid stoppers to prevent errors due to movement • Easy method for precise aligning to vertex and baseline
User Preferred features	• Ease of use without needing ruler • Ease of reading markings and measurements • Ease of keeping the protractor straight • Ease for aligning to vertex, baseline and angle

c. Compass

Size and texture	• Medium (extendable up to 5-6 inches)
Design	• If it is a two-leg compass, the knob for tightening the legs should be a medium size and easy to use and fix the legs tightly. • If it it's a two-leg compass, the legs should be solid without any removable parts. • Compass over a ruler design like the APH is ideal with the second leg to retain the wheel design as it is smoother to draw with, but change the wheel in a way that it enables same-side drawing. If this is not feasible, it could be made into a pin design. The challenge with the pin is, it creates more tears whilst drawing • The tip of the first leg needs to be sharper so that the pin stays rested well. The edge of the drawing end of the compass can be thicker and blunted to ensure darker drawing without tearing. • Sufficient holding grip on the compass that enables for a good grip whilst turning and drawing with the compass needs to be ideated upon. • If the second leg is a sliding leg on an inbuilt ruler, the knob to tighten the leg needs to be medium size and easy to turn. Further, the knob should be on top of the leg and not on the ruler so as to avoid measurement interference. • Additionally, the sliding leg to be fixed next to the marking rather than on top of it. • It would also aid to have a click sound as feedback for moving along the measurement marks of the inbuilt ruler rather than it being a silent slide.

Marking system and design	• If the compass is using an inbuilt ruler, the marking system ideas to be same as ruler marking suggestions made above. • Starting measurement to have a clear 0 marking • The marking on the sliding ruler ideally needs to be raised rather than indented. However, this might pose a technical challenge with the sliding of the leg becoming difficult. An innovative design needs to be thought for the same. Perhaps, a refreshable system like the Squirrel ruler with the leg design can be thought of.
Groove design	• If the compass is using an inbuilt ruler with the second leg sliding over it, the size of the second leg needs to lock in within clear groove marks to prevent movement. • If this has to be enabled, one needs to make a decision on the marking system possible on the compass as well as making the markings with grooves and tactile enough might be challenging
Method of drawing	• One that permits setting of radius and drawing by compass independently, without needing other tools is preferred.
Critical For Accuracy	• A sturdy grip critical for drawing arcs • Fixed radius design leads to maximum accuracy (need to keep in mind learning objective)
User Preferred features	• Quick-to-use method preferred • Ability to keep the radius fixed whilst drawing without movement • Ease of drawing with wheel rather than a point which tears sometimes • Ease to set radius

d. Drawing Board

Size	Obstruction free drawing board area 11×11 inches
Design	• Simple easy design for fixing drawing paper • Mat to be used such that the density and texture of the mat permits easy insertion and piercing of pins • A sticky yet clean texture to the mat might aid sheet immobilization • Marking for centre points of board along the edges • In line with tool design, some system on the board that enables for easy centralizing of tools and keeping them straight • If magnet systems are used for tools to be used on the boards, then magnet needs to be extremely strong to prevent movement.
Immobilization of Paper	• Effective design for immobilizing paper across the entire set of 4 edges fully flat on the mat without movement critical • A system other than clamps or clips can be thought of. • Perhaps a sliding of paper with knobs fixing an entire frame rather than clamps could be one design idea worth exploring • If clamps are used to immobilize paper, the opening-closing mechanism to be smooth and the locking system to give a clear audio or tactual feedback when being shut

User Preferred features	• Board that enables easy fixing of paper • Enables same-side drawing • Enables keeping tools straight • Easy to draw on and fix pins on

e. Pins

Size	• The insertion part to be the sum total of thickness of the tools and drawing board and mat
Design	• Size and design must complement the tools where the pin head must be easy to grip and not conflict with the tool when being inserted for immobilization or any other purpose. • The tip of the pin to be sharp enough to penetrate the sheet and drawing mat • Essential to have a cork box for keeping pins poked in whilst working to ensure easy picking up and safety, especially when the other hand is occupied.

f. Stylus

Size	• That enables easy grip
Design	• Stylus that enables to maintain a 45-degree angle whilst drawing as this prevents tearing of paper • Tip of the stylus to be broad enough as also sharp enough to enable drawing a clear line without tearing of paper • A tactile mark on the stylus to indicate the right direction to hold the stylus, if applicable

g. Working Tray

Size	• To be sized based on design of tools
Design	• Non-skid stoppers at the base to ensure it remains flat with the stoppers Based on the design of the tools, tool stencil framework in the tray that ensures that each item goes in its slot for easy pick up and placement • The stencil to be created such that the tool height is higher than the stencil to ensure easy pick up from the same

h. Carrying Case

Size	• To be sized based on design of tools
Design	• Based on the tool design to ensure easy packing up and removal • The case could be a boxed suitcase design in which the entire working tray fits along with the drawing board. This will ensure that students simply have to remove the working tray when working. • To make the case compact, the working tray can be designed such that it is not larger than the drawing board design.

i. **Tactile Diagrams and Drawing Sheets**

Measuring	• For measuring, it is essential to use sheets where the TDs are raised well, and are on a non-skid surface. • Sheets where the drawing does not become flat easily • It is also important to note that whilst making TDs, the diagrams need to be of a size and placement whereby the tools can be effectively used with them. e.g. margin for board clips, angle arms not smaller than size of protractor.
Drawing	• For drawing, it is useful to have sheets where same-side drawing is possible.

II. Conclusion and Way Forward

Having presented the overall design brief as culled out from the research, this last section aims to highlight some of the developments along the duration of this research study and some of the challenges for the future that need to be kept in mind.

- It is important to note that the Garg Geometry Kit used during this research has been its Version 1.0. The feedback from the report was given during the course of this research to the developer and incorporating some of the suggestions a Version 2.0 of the Garg Kit has been developed as well which has not been studied in this research.
- Similarly, the Squirrel Ruler used in this research is their first version. During the course of the research a Version 2 for the same with immobilisation mechanism on the moving clip as also a cm system for India without needing the 1/16 calculation has been devised.
- **The availability of the Plastic Sheet** used in the research, and currently, the only solution for effective same-side drawing, has been a challenge to procure in local markets in India. This poses a big challenge. Since the tool design depends on the drawing sheet being used, it is critical to keep the availability of drawing sheets in mind before designing any tools. Ideally, given the difficulty in organising the Plastic Sheets, **if a simpler same side paper kit can be designed it would definitely be a more desirable solution**.
- One key challenge in designing tools comes from **taking a decision on what degree of micro-measurements tactile tools can provide.** Extremely minute tactile markings have posed a challenge for students to identify. The solution for the same in the refreshable braille system, devised in the Squirrel Ruler, enables minute measurement but with the disadvantage of needing braille literacy. Can a refreshable system like the new Squirrel Ruler with refreshable neutral tactile markings along with refreshable braille or in place of refreshable braille be designed for wider use? May be two versions of the ruler – one aimed for braille users and another for non-braille users can be designed.
- The other **pedagogical debate for designing of compasses is, should the tool give students pre-defined measurements, or is setting measurements to a defined value critical to the learning of geometry?** Depending on which side of this debate the designer leans towards, the tool design would vary significantly.
- **It is critical to create a comprehensive kit rather than independent tools.** What has also been a key learning through the research is the **necessity to have a user manual/video tutorials with whichever kit is designed** with clear instructions on the tool usage method. It might also be essential to have training programmes for teachers to ensure that they learn

the methods. Whilst students would always be innovative to find their preferred methods of using the tools, it is critical to share the method as envisaged by the designer for usage to ensure efficiency and accuracy.

- **This research did not study kits for students with low vision.** The kit designed from the learnings of this report can and should supplement low visions student needs with regards the size of sighted markings on the tools, as also colour contrast on the same to enable students with low vision as well.
- **We did not test for set squares** in our research; however, any kit being designed needs to include the same for which inferences can be drawn from the results of this research.
- **We have not researched the skills of diagram labelling, drawing of arrow heads and drawing of line and angle congruency marks in this research.** Any kit being designed needs to keep in mind if a system for these can also be included in the geometry kit being designed. For labelling, currently, the system being used is that either the student's braille their labels on a sticker sheet using a Perkins Brailler, and then stick them on their diagrams. Alternatively, they also put the Plastic Sheet or Braille paper directly in the Perkins Brailler and type out the label at the right position. For drawing arrow heads, students either directly draw on plastic sheets with stylus or those who struggle are provided a small arrow head stencils and they draw with the same. Angle arcs and Line Congruency marks are drawn by students with a stylus directly.

The research has, thus, been an extremely fulfilling journey. The research has been able to re-affirm the enthusiasm, eagerness and ability to learn geometry constructions in students with blindness. It has further been able to provide the platform to start the process of designing comprehensive kits learning from the large number of tools available in the market.

Each tool study in the research has been able to throw light on a critical aspect of geometry construction in the world of students with blindness. Each tool has attempted to make the same accessible. The research has been able to take advantage of the learning and experience of all the tools designed thus far to put forward ideas to better the designing process, and thereby, the end-user experience.

This research report, therefore, needs to be seen as a continuum between the past and the future of making geometry construction an everyday aspect of school students with blindness. Learning from the past enables for setting the platform to leap forward. This research hopes that it has been able to provide this consolidated platform of work done so far in the field to stretch the imagination of designers to the next level for designing Geometry Construction Kits.

We would encourage readers of this report to think of out-of-the-box ideas for designing for the future. Harnessing technology within geometry kits has not been done so far but could hold promising alternatives. Using of audio labelling systems, drawing on refreshable electronic slates, using newer materials are all ideas that remain open for extending imagination and possibilities.

The Xavier's Resource Centre for the Visually Challenged (XRCVC) would be keen to partner with designers and will continue its journey for making STEM accessible for students with blindness and low vision.

It would only be apt to conclude this journey with our student voices, which we hope will inspire all of us to collaborate with our students with blindness more to ensure we can all grow together and fill the gaps in our understanding and their education.

"I liked all this geometry. You also taught nicely. I felt no one teaches us geometry but you taught us. Thank you very much. If you need me for any other geometry work please call me."

- Renuka Pachte, Mumbai

"No one has come and spent so much time with us to teach us a skill like this."

-Kailash, Gujarat

LIST OF ANNEXXURES

Due to the extensive length of annexures the same are available as e copy on xrcvc.org. Kindly view them there. Below are the list of annexures that are uploaded. In case you have difficulty locating the same you may contact neha@xrcvc.org. Since Annexure G related to Teaching Pedagogy used in the Research is crucial for concurrent reading to the main report the same is also published here for ease of reference.

ANNEXURE G: TEACHING PEDAGOGY USED IN THE RESEARCH

Pre-Geometry Skill Orientation Training

Before starting Skill 1 training, a basic Pre-Geometry Orientation Training was conducted. The same involved the following:

a. Orientation and Handling of Equipment
b. Using of Board
c. Learning how to Draw

a. Orientation and Handling of Equipment

Students were oriented and taught how to handle multiple tools whilst working.

- Students were given all the equipment (drawing board, rubber mat, packet of drawing sheets, etc.) in their hand one by one and asked to touch them.
- Students were also given a boxed tray with a box of pins, with the stylus placed inside, and asked to explore the same. The boxed tray ensured easy picking and using of material by preventing dropping and ensuring safety.
- Students were then oriented to the usage of each of the items given to them.
    - Drawing boards: Students were given all the boards in their hand one by one and asked to touch and explore the size and shape etc. Depending on the board given to the students, they were taught to identify the right orientation of the boards for use and the specific elements on the boards such as the clip/flaps.
    - Rubber Mat: Students were asked to touch the rubber mat with its silicon and foam surfaces. They were taught the feel of the right side of the mat with its smooth side facing up and the foam side facing downward.
    - Plastic Sheets: The students were instructed to touch the sheets.
    - Pins: Students were asked to explore the pins in the box safely through touch to ensure that they do not poke themselves with the pointed ends. Students were instructed that the pins had to be kept either in the pin box or inserted in the mat at all times, never lying on the table.
- Students were also asked to explore their workspace in front of them and asked to place the boxed tray at a place of their convenience.
- Students were also instructed to always put the material used back in its respective box to ensure easy finding and to prevent dropping.

b. Using the board

During the research, the students were taught to use three drawing boards- the Exam board, the Draftsman board and the Garg board.

- **Orientation to Board:**

Students were oriented to the right orientation of the board by touching the relevant parts of the respective boards.

- **Method used for Loading the sheet and mat in the board:**

For the Exam Board: Students were asked to align the sheet to the mat and touch to ensure that the sheet on the mat was correctly aligned within the mat's rectangular edges.

- Students were then asked to hold the sheet and mat together with one hand and slide them in the clip of the board by opening the clip with the other hand.
- After placing the sheet and mat inside the clip, the students were asked to check for gaps between the mat and the top edge of the clip. If there was any gap felt, they were asked to push the mat along with the paper all the way up.

*For the Draftsman Board***:**

Figure 1: APH Draftsman Board with the clasps

Students were asked to feel the grooves on the left and right bottom edge of the board and asked to lift the clasps outwards on the left and right edges respectively.
- They were then asked to place a sheet on the board such that it was completely aligned to the top and the bottom of the mat and had equal spill over on the left and right edge of the mat.

*For the Garg Board***:** Students were asked to lift the clip and keep it open, and use their hands to load the paper on the board, and feel the loaded paper on the board, and check that it is within the rectangular edges of the board.
- Once the paper was in position, they were asked to shut the clip. They were oriented to the tactual feedback of locking the paper in the board. The students were oriented to the magnet and hole making mechanism of the clip. This would ensure that if a paper had to be removed and put back it can be positioned in the same place.

- **Method used for immobilizing the sheet on the board:**

- *For the Exam Board:* Students were asked to push the sheet down gently with one hand from the top to the bottom of the mat to ensure that the paper is flat, and use their other hand to put three pins at the bottom of the page starting at the left edge, then mid-way and finally, at the right edge of the paper such that it now remained immobilized, straight and flat on the mat.

Figure 2: Exam board with sheet, mat and the 3 immobilizing pins.

- *For the Draftsman Board:* Once the sheet was placed, the students were asked to press down the sheet and slide their hand towards the right edge of the board, and shut the right flap. After the

sheet was immobilized on the right side, the students were again asked to slide their hands, towards the left side holding the sheet down to the mat, and then, close the left flap.
- *For the Garg Board:* With this board there was no additional immobilization of paper needed.

c. Learning how to Draw

- Students were asked to take the stylus from the boxed tray and keep the same at a 45-degree angle, and push against the immobilized sheet on the mat and for some freehand drawing practice. (They were shown this through physical demonstration). They were asked to feel the raised lines that were drawn.
- They were asked to practice drawing at that angle and with appropriate pressure till they got it right without tearing the paper or making too light a mark.

Skill 1: Constructing a Line Segment

For teaching the students the construction of a line segment, the following steps were followed:

a. Explaining the concept of a line segment
b. Orientation to the specific ruler (each different type)
c. Finding the area to draw
d. Teaching how to keep the ruler straight and centralized
e. Plotting points and measuring
f. Connecting the plotted points

a. Explaining the Concept of a Line Segment

Students were explained what a line segment is. Basic conceptual understanding of the topic was given.

b. Orientation to the Specific Ruler

- Students were given the specific ruler in their hand to explore. They were instructed to find the two ends of the ruler and feel them.
- Students were asked to explore the distinct edges of each of the rulers (e.g. the grooved side/ smooth side etc.).
- Students were to feel the markings on each of the rulers (e.g. long marks, extra-long marks, grooves, braille marks etc. and their meaning).
- Students were asked to feel any moving clips on the rulers, if applicable, and their functions were explained. In case of refreshable braille, students were explained the system.
- For the Squirrel ruler, they were explained the 16 parts and inch system of measurement.
- For the Draftsman ruler, they were oriented to the roller on the ruler and how to fix the roller on the Draftsman Board.

c. Finding the Area to Draw

- Students were asked to explore their immobilized sheet and find free space to draw on. *Free space was defined as an area with at least two finger empty space after anything tactile.* (This free space was kept for labelling, which was not covered for the research).

d. **Teaching how to keep the Ruler Straight and Centralized**

- **Keeping the ruler straight:** Students were taught two methods to keep their rulers straight.

Method 1:

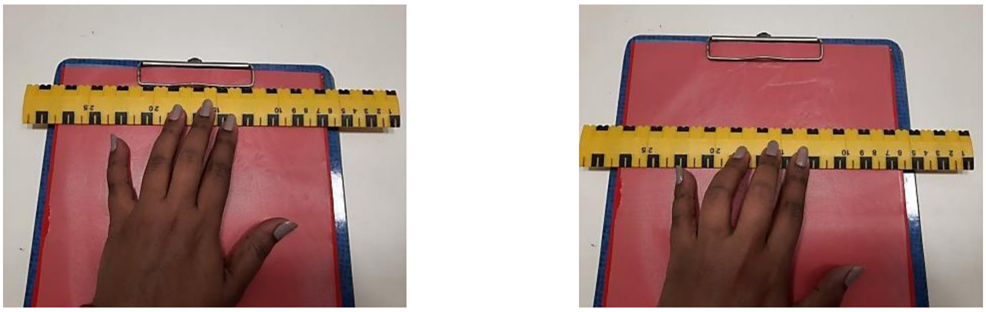

Figure 3: Method 1 of keeping the ruler straight

- Students were asked to take the ruler with the correct side (i.e. the grooved side of the RNIB ruler, and the cm side of the APH Clip ruler) towards the Exam board clip and touch it
- They were asked to re-check if the mat was fully inserted in the clip till the top edge of the board.
- They were then instructed to check if the ruler was entirely resting against the clip.
- They were then asked to bring the ruler down gradually (either with one or both hands) towards the area where they would draw. Once the ruler was placed in the drawing area, they were asked to hold the ruler down by stretching their non-dominant hand over the ruler.

Figure 4: Left hand spread out to hold the ruler in place post aligning the ruler

- For longer rulers, like the RNIB ruler and the APH Clip ruler, students could either keep the ruler aligned to the board clip in a way that equal amounts of the ruler lay outside the rubber mat on either side; or have it start at the left edge of the mat on one side with the extra part extending on the right side.

Method 2:

Figure 5: Method 2 of keeping the ruler straight

- Students were asked to take the left end of the ruler and place it in line with the left edge of the mat such that the two were in complete alignment without a gap; this could be confirmed by moving a finger along the left of the ruler and the mat.
- Once the alignment was done, they were asked to hold the ruler down by spreading their non-dominant hand over the ruler (as explained in Method 1 above).

- **Keeping the Ruler Centralized**

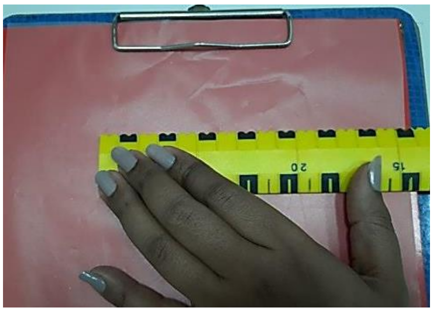

Figure 6: Ruler centralized to the page

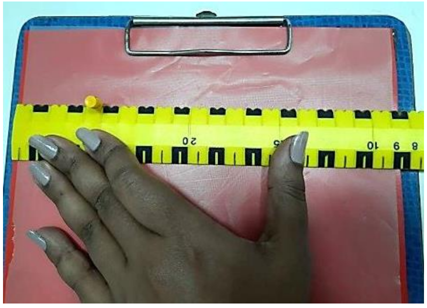

Figure 7: Position of ruler and start point pin to centralize the line segment

- Once the ruler was straight, students were asked to either push the ruler towards the centre of the page from the board clip or to leave some space from the left edge of the mat, or place a start point pin at a long mark after some space from the left edge of the mat.

Additional Points to be kept in mind.

- The Draftsman ruler was inserted in the slide grooves of the board, and the knob was tightened to keep the ruler both straight and immobilized. There was no centralization of the ruler since it covered the entire width of the board. Start points were centralized whilst plotting points.
- Given the size of the Squirrel ruler and its fixed clip on the left side, only Method 2 of aligning the ruler to the left edge of the board was useful in keeping the ruler straight.
- Similarly, since the WT ruler is smaller in length, only Method 1 of aligning as per the Board clip was advisable for keeping the ruler both straight and centralized.

e. Plotting Points and Measuring

- **Plotting the start point:**
  - Depending on the ruler being used, the students were instructed to find the appropriate long mark or extra-long mark on the ruler to mark as the start point. Since the APH Clip ruler has no distinct 0 mark, the left edge of the ruler could also be used to plot the start point.

For the Squirrel ruler, students were instructed that the left edge of the ruler would be the start point.

- Students were instructed to put a pin at the mark/groove if required and in the case of the Garg ruler, slide the point marker into the groove of the Garg ruler.

- **Measuring & plotting end point:**
  - For counting whole numbers and decimals, the students were reminded of the specific marking system of each ruler that has been provided in the section of ruler orientation. They were reoriented with the marking system of each ruler and taught to distinguish between their full and half units of measurements.
  - On counting the right measurement, they were asked to plot the end point by inserting the pin at the mark where the measurement ends whilst still continuing to hold down the ruler and resting it against the first pin whilst counting the measurement and inserting the pin for the end point.

Figure 8: Plotting of end point pin

- When using the Garg ruler, a few additional steps were involved. Unlike the others where points were marked by inserting the pins in the mats, for Garg ruler once the ruler was placed in the right position, point markers of the Garg kit were slid into the grooves of the ruler. The point markers and the ruler had magnet below making them stay in position After the students had marked both points, by sliding the point markers into positions, they were then asked to remove the ruler from the board and place the paper back on the point markers. They were instructed to gently find the point from top of the paper and press down around the point such that both points were punctured in the paper to mark the two end points of the line segment.

Figure 9: Plotting of start and end point on the Garg board

- When using the APH Clip ruler, after counting the right measurement, the students were asked to bring the clip to the mark where the measurement completed. They were instructed to keep their finger at the end point mark and bring the clip to that point with their other hand.

Figure 10: Plotting of end point with the APH clip ruler

- For the Squirrel ruler, the students simply had to drag the clip along the length of the ruler to the desired measurement while reading the measurement on the refreshable braille clip.

Figure 11: Plotting of end point with the Squirrel ruler

f. Connecting the Plotted Points

- Students were asked to turn the ruler to the smooth side when using the Draftsman and the RNIB rulers. The Draftsman ruler then had to be placed on the Draftsman board touching the plotted end point pins with the smooth side, and then fixed along the right edge of the board by tightening the screw. They were then asked to confirm if the ruler was touching the plotted end point pins, and adjust the placement, if required.

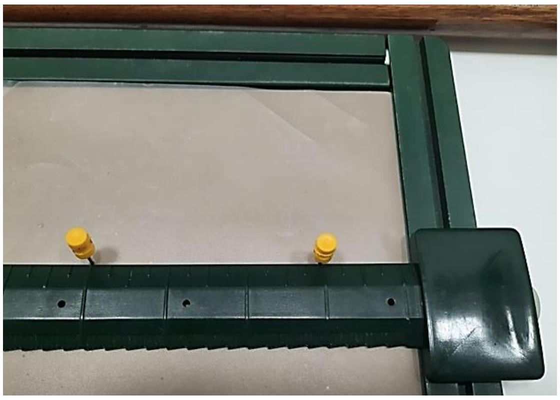

Figure 12: Smooth edge of Draftsman ruler touching plotted point pins

- They were then asked to use the stylus and draw from pin to pin .

- For the clip rulers, once the moving clip was in the place of the end point, the students were asked to draw from the start point to the end point clip whilst continuing to hold down the ruler with one hand.

Figure 13: Connecting plotted points with the Squirrel ruler

- For the Garg ruler: At this point, they were oriented to the line marker, the groove on it, as well as the bridge. They were instructed that the bridge could be removed if the line being drawn is a very short line.

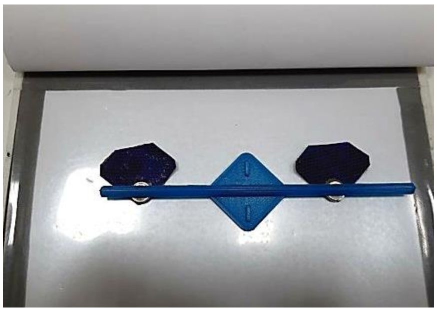

Figure 14: Connecting plotted points on the Garg board

- They were oriented to the placing of the line marker on the two points. After it was placed, they were asked to put the paper back down on the line marker resting on the point markers. With their hand placed gently on the braille paper, they were asked to lightly feel the line marker through the paper, starting from the start point to the end point.

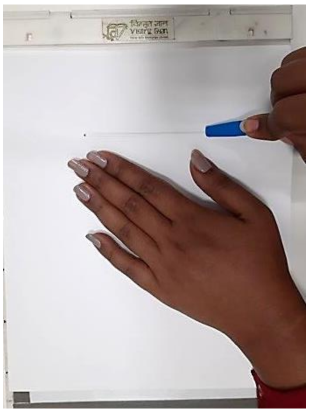

Figure 15: Drawing a line on the Garg board

- They were oriented to the **Garg** stylus and explained about the groove on the stylus. They were instructed to go to the start point and rest the groove of the stylus on the line marker from above the braille paper, and ensure a good grip at the start point. Holding the stylus face down on the line marker, they were taught to drag the stylus towards the end point to draw a line segment whilst simultaneously using the other hand to hold onto the line marker from above the paper at the start point and the end point so that it does not move when the line is being drawn.

- Some students found it easier to turn the board horizontally (and draw the line segment vertically) to have a better hold and were permitted to do so.

Skill 2: Measuring a Line Segment

For teaching measuring of a line segment, the following steps were followed

a. Revision of the concept of a line segment and introduction to the skill of measuring lines
b. Orientation to TDs and use of a ruler to measure a line segment on each type of TD, as applicable
c. Finding the two end points
d. Aligning the ruler to the line segment
e. Reading the measurement

a. Revision of the Concept of a Line Segment and Introduction to the Skill of Measuring Lines

The concept of a line segment was revised. Students were informed that in this skill, unlike drawing in the earlier one, they would be given TDs of line segments and they would have to measure the same.

b. Orientation to TDs and Use of a Ruler to Measure a Line Segment on each type of TD, as **applicable**

Students were oriented to use the Thermoform Sheet, Plastic Sheet and Braille Paper TDs with the RNIB Ruler, the APH Clip Ruler, the WT Ruler and the Squirrel Ruler and the Braille Paper TD with the Garg Ruler. The method used in orienting the student to the TDs and the use of ruler for measuring the line segment was as follows:

- **Handing over of the Board:** Students were handed over the Exam Board
- **Handing over and Orientation to TDs:**
    - Students were explained that there were 3 types of TDs that were being used for this skill – Thermoform Sheet, Plastic Sheet and Braille Paper TDs. They were informed about the sheet being handed over to them.
    - When using the Thermoform Sheet TDs and Braille Paper TDs, students were expected to immobilize the sheet only using the Exam Board clip at the top, and no pins at the bottom of the sheet, as was done with the Exam Board Drawing Kit in Skill 1.
    - For Plastic Sheet TDs, students were asked to immobilize the sheets using the Exam Board clip at the top, and also pins at the bottom, as was done in Skill 1 with the Exam Board Drawing Kit.
    - On the Garg Drawing Board, they immobilized the Braille paper, as done in Skill 1.
- **Handing over of the Ruler and Revision of the Ruler**: Students were handed over the different types of rulers and were given a quick revision of the rulers and their measurement systems.

c. Finding the Two End Points

This section details the rules for finding the two end points for when using the APH clip ruler, the RNIB ruler, the WT ruler and the Squirrel ruler in combination with the Thermoform sheet, the Plastic sheet and the Braille paper TDs.

- For Thermoform sheet TDs, students were asked to touch and locate the line segment, and identify the two end points for the same.
- For Braille paper and Plastic sheet TDs, students were asked to touch and locate the line segment, and identify the two end points for the same. They were also asked to insert pins exactly at the start point and end point as the tactile lines on the Plastic and Braille paper sheets since they were not high enough to be felt once rulers were aligned to them for measurement.
- For the Garg Kit, after students loaded their Braille paper TD on the Garg board they were asked to touch and locate the line segment and identify the two end points for the same. They were then asked to lift the paper slightly, and whilst keeping their finger at the start point, use the other hand to place a point marker underneath the paper exactly under the start point. They were asked to do the same for the end point.

Figure 16: Finding the two end points with the Garg board

- They were then asked to place the paper over the point markers, and gently touch the alignment, and only when confident punch the two holes by puncturing at the point markers.

Figure 17: Puncturing holes at the end points with the Garg board

d. Aligning the Ruler to the Line Segment

- Students were asked to place the rulers just below the line segment such that it was completely touching the line without any gap in between the ruler and the line. They were asked to align the ruler as follows: the cm side up for the APH Clip ruler, the grooved side up for the RNIB ruler, the semi-circle to the left side for WT ruler, and the moving clip side up for the Squirrel ruler.

- Students were then asked to position the ruler in the following manner for each type of ruler:
  - **For the APH Clip Ruler:** They could either place the left edge of the ruler, or any long mark of the ruler at the start point. They were to hold down the ruler with one hand and use the other hand to bring the clip of the ruler to the end point, or to measure the length of the line segment with a finger on the tactile markings itself (without the clip).

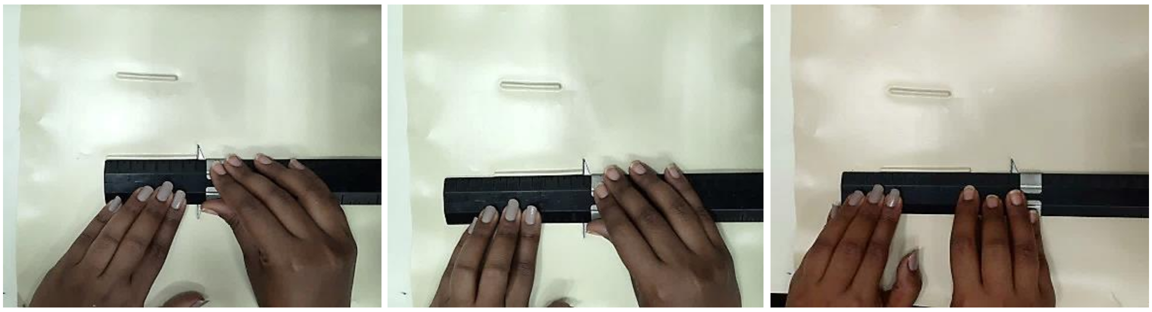

Figure 18: Aligning the APH clip Ruler to the line segment – 3 methods

  - **For the RNIB Ruler:** When using the Thermoform sheet, the students could either place the left edge of the ruler, or any long mark of the ruler at the start point. When using the Plastic and Braille paper sheets, they were asked to place one pin each at the start point and end point of the line segment. Then, they were supposed to align the ruler to the line segment such that either a groove of a long mark or an extra-long mark was at the start point. Finally, they were supposed to hold down the ruler with one hand, and measure with the other till the long mark or extra-long mark at the end point**.**
  - **For the WT Ruler:** They could either place any long mark, or the left edge of the ruler after the semi-circle at start point. They were to hold down the ruler and measure with their other hand either till the end point. Some students chose to immobilize the ruler after alignment.
  - **For the Squirrel Ruler:** Students were asked to push the moving clip to the right most end of the ruler and rest the ruler along the length of the line. They were then asked to slide the ruler to the right till the fixed clip corner fitted fully at the start point of the line. They were then asked to push the moving clip back to the left up to the end point of the line.

Figure 19: Aligning the Squirrel ruler to the line segment

  - **For the Garg Ruler:** In combination with the Braille paper TDs,
    - After puncturing the holes in the Braille paper, they were asked to lift the paper and press it down on the clip of the board.

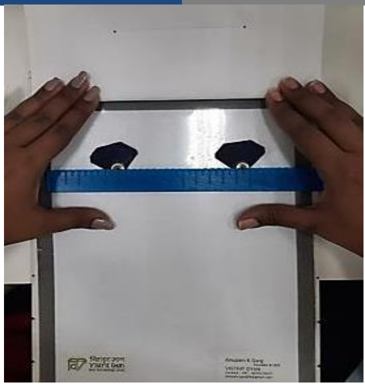

Figure 20: Paper pressed down onto the clip on the Garg board, thus making visible the point markers and ruler that were previously under the paper.

- They were asked to bring the groove side of the ruler and place the start point at either the first groove on the ruler or any long mark and after this rest the ruler against the second point marker

e. Reading the Measurement

- **For the RNIB and the WT rulers**, students were asked to use one hand to count the measurement by touching and counting the tactile markings, whilst holding down the ruler aligned to the start and end points with their other hand.
- **For the APH Clip ruler**, students were asked to either count the tactile markings, or to read the braille closest to the end point and count the remaining markings to complete their measurement.
- **For the Squirrel ruler**, students were asked to either count up to the last mark before/at the end point, or read the braille closest to the end point, followed by reading the refreshable braille for the decimal measurement following the whole number measurement they would have got by the mark/fixed braille reading.
- **For the Garg ruler**, they were asked to measure the marks between the two end points of the line segment whilst holding down the ruler to arrive at the final measurement.

Skill 3: Constructing an Angle

For teaching the construction of an angle, the following steps were followed:

a. Explaining the concept of an angle and orientation to and use of different protractors
b. Finding the area to draw
c. Drawing of the baseline
d. Finding the vertex and aligning to the vertex and baseline (RNIB, WT Protractor)
e. Reading the measurement and plotting the point and drawing the second arm (RNIB, WT Protractor)
OR
f. Drawing the angle (APH wand Protractor, APH Wand-inside Protractor, Garg Protractor)

a. Explaining the Concept of an Angle and Orientation to and Use of different Protractors

- Students were given an explanation of what an angle is with basic theory concepts to ensure that they understand the concept clearly. They were explained the concepts of rays, vertex etc.

- Students were then oriented to different protractors. For each protractor, they were shown the marking system as well as the specific component relevant to each protractor individually. They were made to explore the shape, components e.g. wands, base of the protractor, degree markings and any short cut markings if applicable.

b. Finding the Area to Draw

- Students were asked to explore their immobilized sheet and find free space to draw on. *Free space was defined as an area with at least a palm-size empty space after anything tactile.* This rule was in place to keep space for drawing the second arm.
- Students were also told to always start drawing the baseline after keeping one palm space from the left end of the board

c. Drawing of the Baseline

- **For the RNIB and the WT Protractors,** WT Ruler, APH Clip Ruler and RNIB Rulers were used to draw the baseline using the same method as drawing a line segment in Skill 1 using these rulers, except for using pins for plotting end points. The students were informed that they could draw freely along the ruler as the baseline need not have end points and they could draw it as long as they liked.

d. Finding the Vertex and Aligning to the Vertex and Baseline

- **WT Protractor:** Students were asked to locate the left end point of the base arm, i.e. the vertex, and put a pin exactly at the vertex.
    - They were then asked to keep the WT protractor straight and align the 3rd tip at the bottom-centre of the protractor exactly to the vertex pin and keep the 4th and 5th tip exactly on the base arm. They were shown, through touch, that the 3rd tip should be on top of the vertex pin and not to its left or right. They were also instructed that the 4th and 5th tips should neither be above the base arm nor overlap the base arm, but resting against the base arm.
    - They were then asked to immobilize the protractor by inserting pins in the immobilization holes. Some students chose to not immobilize the protractor, and continued to the next step.

Figure 21: Aligning the WT protractor to the vertex and baseline

- **RNIB Protractor:** Students were asked to locate the left end point of the base arm i.e. the vertex and put a pin exactly at the vertex.
    - They were then shown the RNIB knob and asked to touch the cone shape of the RNIB knob, and instructed that the broader part of the cone shaped knob is always to be placed against

the surface of the sheet. They were then shown how to insert the knob on the vertex pin and asked to place it on the vertex pin.

- They were then asked to place the protractor such that the semi-circle indent/notch at the bottom-centre of the protractor was placed exactly on the knob along with the right edge of the protractor resting on baseline and not away from the baseline or overlapping the baseline. They were also instructed that the protractor should not go underneath the knob and use their fingers to confirm that the knob is always resting on the mat.

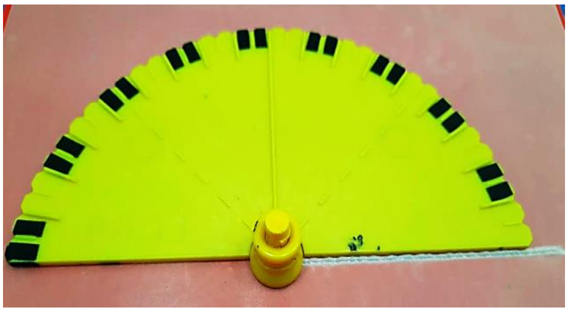

Figure 22: Aligning the RNIB protractor to the vertex and baseline

e. Reading the Measurement and Plotting the Point and Drawing the Second Arm

- Students were asked to measure the degrees starting from the right end of the protractor keeping in mind the specific measurement systems of the protractors.
- Once they had found the desired measurement the students were instructed to place a pin at the measurement mark.
- For Drawing the second arm,
    - **Worth Trust Protractor:** Before drawing the second arm the students were asked to remove the WT protractor the immobilization pins along and remove the WT protractor without removing or moving the vertex and measurement pins.

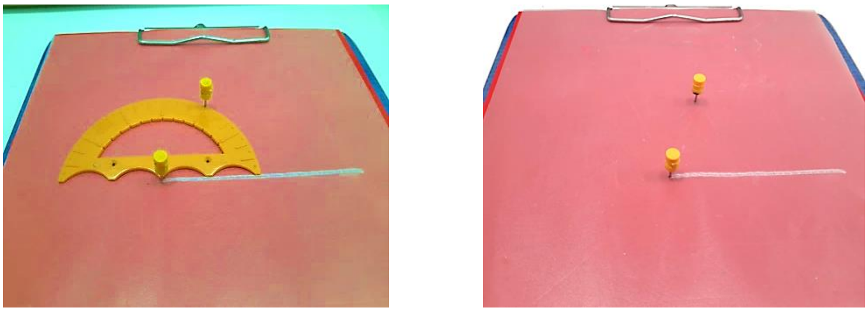

Figure 23: Plotting points for drawing the second arm with the WT protractor

- **For the RNIB protractor,** students were asked to remove the protractor and the knob from the vertex pin without removing the vertex and 45-degree measurement mark pins. Rulers were then used to draw the second arm. The method for using the ruler to draw the second arm is mentioned below:
- **WT Ruler:** The students were asked to take the WT ruler from the left side/behind the pins, and rest it against both the vertex and 45-degree measurement mark pins. After checking if the ruler was resting on both pins, they were asked to hold down the ruler with the left hand, and connect the two points by drawing a line with a stylus.

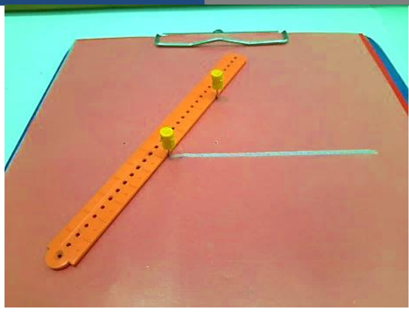

Figure 24: Drawing the second arm

- **APH Clip Ruler:** The students were asked to shift the clip on the right edge of the ruler or remove it completely. They were then asked to take the ruler and rest it on both the vertex and 45-degree measurement mark pins from the left side/behind the pins. After checking if the ruler was resting on both pins, they were asked to hold down the ruler with the left hand, and connect the two points by drawing a line with a stylus.
- **RNIB Ruler:** They were asked to take the ruler and rest its smooth edge on both the vertex and 45-degree measurement mark pins from the left side/behind the pins. After checking if the ruler was resting on both pins, they were asked to hold down the ruler with the left hand, and connect the two points by drawing a line with a stylus.

- After they completed drawing the line, they were asked to take away the ruler, remove the pins, and touch the angle drawn.

f. Drawing the Angle

- **APH Wand Protractor:** Students were asked to measure the degrees starting from the right end of the protractor and once they had found the desired measurement align the pointed end of the wand to the measurement, hold the wand down and tighten the knob.

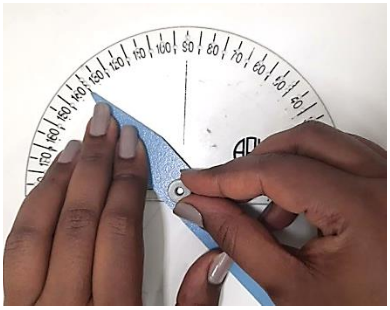

Figure 25: Setting the measurement on the APH Wand protractor

- Students were asked to keep the protractor completely upside down (such that the wand was up and the protractor down), and centralized in their drawing area.

Figure 26: Drawing the angle with the APH Wand protractor

- They were also instructed to keep the base of the protractor as straight as possible once turned upside down.
- They were then asked to hold down the protractor.
- With their hands, they were oriented to understand the angle that the protractor made to the right of the wand. If time permitted, they were explained the geometric concept of how this protractor made this angle.
- They were then asked to ensure that the wand and the protractor were held down firmly, and the angle was drawn using the stylus along the end of the wand and the base of the protractor.
- Whilst drawing, they were instructed that in order to draw a neat angle they could take the stylus from the top of the wand up to the vertex point, then, lift the stylus, and restart from vertex till the end of the base of the protractor.
- **APH Wand-inside Protractor:** Students were asked to bring the protractor to the free space, keep it straight, hold it down, and immobilize the protractor by putting one pin in each of the immobilization dents on either side of the protractor.

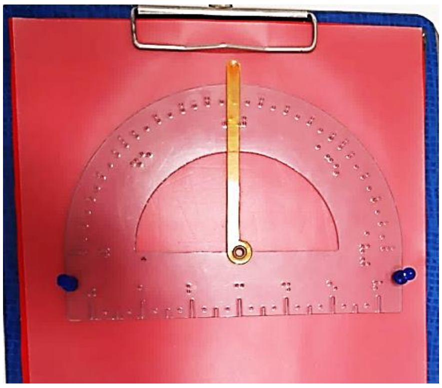

Figure 27: APH Wand-inside protractor immobilized to the sheet

- Students were asked to measure the degrees starting from the right end of the protractor, and once they had found the desired measurement, they were to align the pointed end of the wand on the appropriate tactile marking of the protractor; then, ensure the correct placement of the wand by checking the tactile markings before and after the wand.

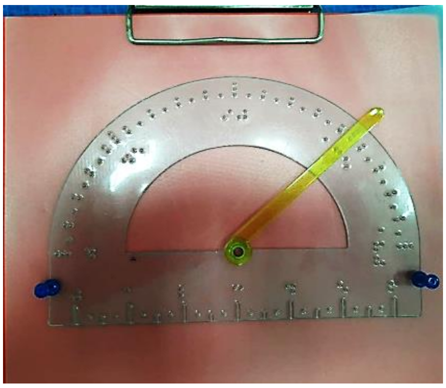

Figure 28: APH Wand-inside protractor immobilized to the sheet and set at 45 degrees

- After placing the wand on the relevant tactile marking, they were asked to immobilize it by putting a pin on the right side of the wand. Some students preferred to use two pins – one on each side of the wand.

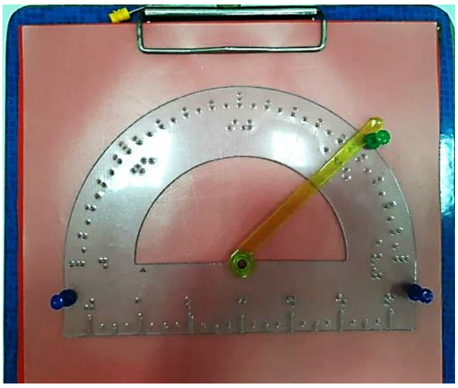

Figure 29: APH Wand-inside protractor with a pin on the right side of the wand

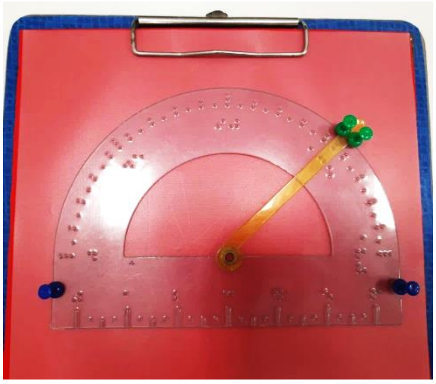

Figure 30: APH Wand-inside protractor with two pins, one on each side of the wand

- Students were asked to place three pins, one at the wand hole, one on the inside semi-circle right corner and one at the right side of the wand inside the smaller semi-circle.

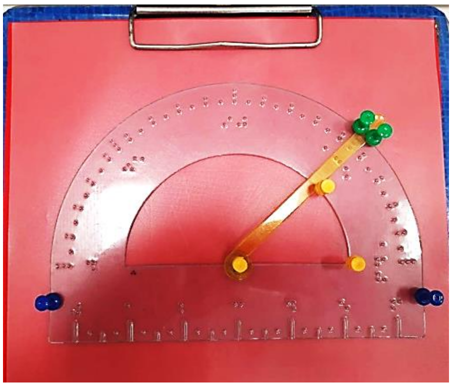

Figure 31: APH Wand-inside protractor with three more pins, marking the three points of an angle

- They were then asked to remove the protractor and the wand immobilization pins and the vertex pin at the wand hole and lift the protractor.

Figure 32: Three pins on the plastic sheet marking the three points of an angle

- They were asked to feel the vertex mark and place a pin back at the vertex. Then, they were asked to use the ruler side of the protractor and draw a line each to join the vertex to both other pins to make the angle.

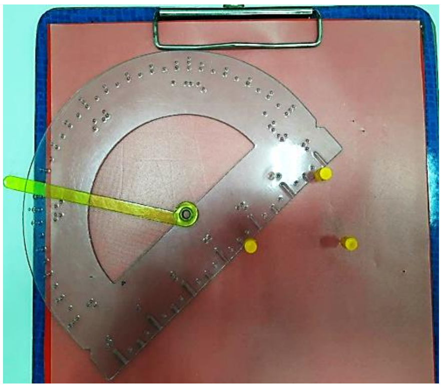

Figure 33: The ruler side of the APH Wand-inside protractor positioned to join the pins and make the angle.

- An alternate method used was that instead of lifting the protractor before drawing of lines the right side of the wand and the base of the inside semi-circle were used to draw the two arms up to the wand hole. Then the same process of lifting the protractor as per the earlier mentioned method was done and the ruler was used to extend the drawn arms up to the vertex point.

- **Garg Protractor:**
  - **Drawing of the baseline:** Students were asked to lift the Braille paper upwards, and then, place two Point Markers on the Garg board and try and keep them as straight as possible.
  - After the students had placed the point markers, they were asked to place the Braille paper back on the point markers.

Figure 34: Two Point Markers on the Garg board

- They were instructed to gently find the points through the paper and press down around both the points such that they punctured the paper.
- After the students had punctured the points, they were asked to lift the paper back.
- At this time, they were asked to place the Line Marker on the two points. After this was placed, they were asked to put the paper back on the line marker positioned on the points. They were asked to lightly feel the line marker placed underneath the paper through the sheet, beginning from the start point to the end point.

Figure 35: Two Point Markers with a Line Marker on them in the position to draw the baseline of an angle on the Garg board

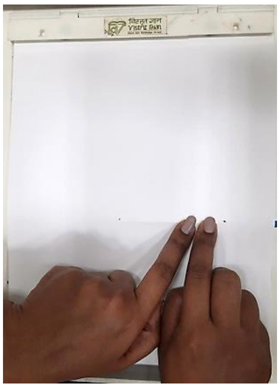

Figure 36: The student lightly feeling the line marker placed underneath the paper from the top of the sheet with their hands from the start point to the end point.

- They were instructed to place the groove of the stylus on the line marker at the start point, and check for its grip at the point, hold the stylus face down on the line marker, and then drag it till the end point to draw the line segment, whilst simultaneously holding the line marker down through the paper at the start point and end point so that it does not move when the line is being drawn.
- Some students found it easier to turn the board horizontal to have a better hold and were permitted to do so.

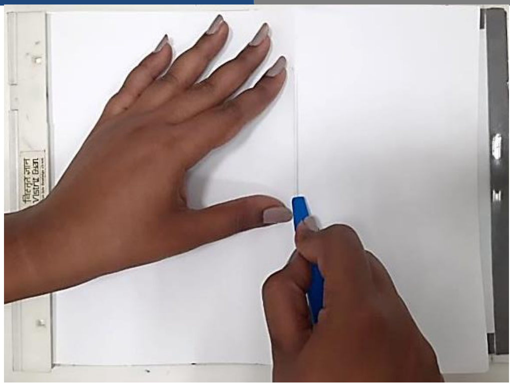

Figure 37: Drawing the baseline on the Garg board

- Finding the Vertex and Aligning to the Vertex and Baseline**:** After drawing the base arm, students were asked to lift the paper up again and asked to remove the line marker.
- They were now asked to place the protractor such that the centre hole of the protractor was placed on the vertex point marker and the fixed line marker on the protractor sat on the second point marker.

Figure 38: The Garg protractor positioned over the point markers

- Reading the Measurement and Plotting the Point: Students were asked to read the measurement starting at the fixed line marker and once the measurement was found, they were to place a second line marker such that it rested on the relevant tactile marking and the vertex point.

Figure 39: An extra line marker positioned from the 60-degree tactile marking on the Garg protractor towards the vertex

- Two line markers of varying lengths were used – a short one and a longer one. The longer line marker rested across the diameter of the protractor, marking on the opposite side of the 60-degree measurement as well.
- **Drawing the second arm:** Students were asked to place the paper back and gently feel the second line marker.
- They were asked to draw the second arm ensuring that it started at the vertex.

Skill 4: Measuring an Angle

For teaching the skill of measuring of an angle, the following steps were followed-

a. Revision of the concept of an angle
b. Introduction to the skill of measuring angles
c. Orientation to TDs and the use of a protractor to measure an angle on each type of TD, as applicable
d. Aligning the protractor to the vertex and baseline and reading the measurement

a. Revision of the Concept of an Angle

- The concept of an angle was revised, as per the teaching methods used to explain the concept of an angle in Skill 3.

b. Introduction to the Skill of Measuring Angles

- Students were informed that in this skill, unlike drawing in the earlier one, they would be given TDs of angles and they would have to measure the same.

c. Orientation to TDs and the Use of a Protractor to Measure an Angle on each type of TD, as applicable

- Students were oriented to use of the Thermoform Sheet, Plastic Sheet and Braille Paper TDs with the RNIB protractor, the APH Wand protractor, and the WT Protractor, as well as the Braille Paper TD with the Garg Protractor. The method used in orienting the student to the TDs and the use of protractors for measuring an angle was as follows:
- Handing over of the Board: Students were handed over the Exam Board
- Handing over and Orientation to TDs:Students were explained that there were 3 types of TDs that were being used for this research- Thermoform Sheet, Plastic Sheet and Braille Paper. They were informed about the sheet being handed over to them.
- When using the Thermoform Sheet TDs and Braille Paper TDs, students were expected to immobilize the sheet only in the Exam board clip and not at the bottom of the sheet as was done using the Exam Board Drawing Kit in Skill 3.
- For Plastic Sheet TDs, students were asked to immobilize the sheets using the Exam Board clip at the top, and also pins at the bottom, as was done in Skill 3 with the Exam Board Drawing Kit.
- On the Garg Drawing Board, they immobilized Braille paper as done in Skill 3.
- Handing over of the Protractor and Revision of the Protractor: Students were handed over the different types of protractors and were given a quick revision of the protractor design and its measurement system.

d. Aligning the Protractor to the Vertex and Baseline and Reading the Measurement

- Steps of the teaching method differed depending on the combination of the TD and protractor that was being taught and used. The change in the teaching methods to accommodate the varying protractor designs and TD formats is discussed below in detail.
- The students were handed over the Plastic sheet/Braille paper/Thermoform sheet TD.
- They were told to touch and locate the vertex and baseline.
- They were then asked to align the protractor to the vertex and baseline, the method for which differed for each protractor and is detailed below:
- **WT Protractor**: They were asked to place the 3rd tip, at the bottom-centre of the protractor, on top of the vertex point and place the 4th and 5th tips on the baseline.

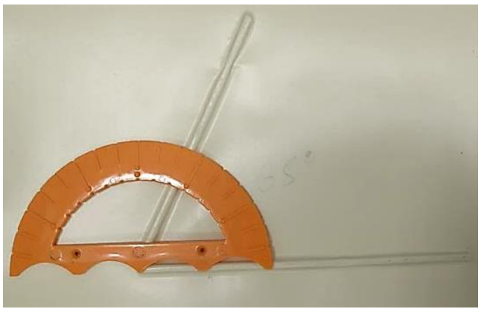

Figure 40: The WT protractor being used to measure a tactile angle on a Thermoform sheet

  - Hold the protractor down in position with one hand and read the measurement with the other hand.
  - On the Plastic sheet and Braille paper, where it is possible to plot pins on the sheets an alternative method could be used. The students either aligned the protractor to the vertex and baseline as mentioned above or they would place a pin at the vertex and then place the protractor.
  - Also, with this protractor, some students would prefer to immobilize the protractor before measuring whilst others would prefer to hold it down with their hand.
  - Once the students aligned the protractor, they were instructed to read the measurement.
- **RNIB Protractor:** Students were asked to place the RNIB pin and RNIB knob on the vertex point, and then rest the protractor on the RNIB knob and align the base of the protractor to the baseline without leaving any gaps.

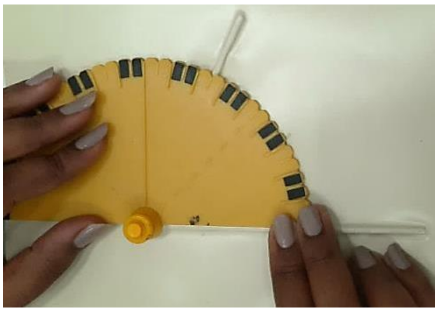

Figure 41: The RNIB protractor being used to measure a tactile angle on a Thermoform sheet

  - Once the protractor was aligned, the students were instructed to hold the protractor down in position with one hand, and read the measurement with the other.

- **APH Wand Protractor**
  - Students were asked to hold the APH Wand protractor upside down, keep the wand knob loosened, and align the base of the upturned protractor to the baseline of the TD angle.

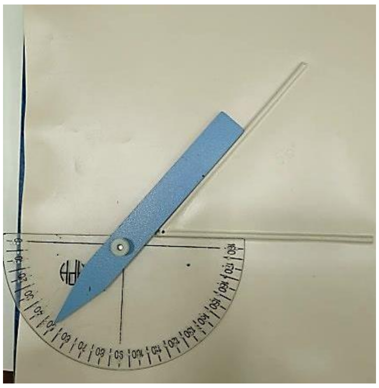

Figure 42: The APH Wand protractor being used to measure a tactile angle on a Thermoform sheet

  - They were then asked to keep sliding the protractor to the left whilst retaining the alignment of the protractor to the baseline until the wand of the protractor was resting against the second arm.
  - Once the protractor was held in position, with the base of the protractor against the baseline and the wand against the second arm, the students were asked to hold down the wand of the protractor and tighten the knob.
  - They were then asked to turn the protractor and read the measure.
  - Some students preferred to place pins on the base arm and second arm and rest the protractors against those pins whilst aligning because the lines were not clear on the plastic and braille paper sheets.
- **Garg Protractor with Braille Paper TD:** Students were handed over the paper TD.
  - They were told to touch and locate the vertex and the second arm of the angle.
  - They were then asked to place three point markers below the paper in alignment to the vertex point and a point each on the base arm and the second arm closer to the end of each arm.

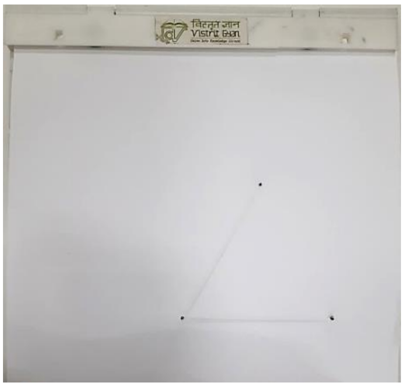

Figure 43: A tactile angle on a Braille Paper placed on the Garg Board

  - They were then asked to touch the point markers through the Braille paper and once they were sure about the points, they were to puncture the holes in the paper.

- They were then asked to remove the paper and take the Garg protractor and place the central immobilization hole on the vertex point with the fixed line marker resting on the base arm point marker.

Figure 44: The Garg protractor positioned on the point markers on the Garg Board.

- They were then asked to place another line marker from the vertex point to the point marker on the second arm.

Figure 45: The Garg protractor positioned on the point markers on the Garg Board, with an extra line marker for the second arm.

- They were then asked to read the measurement starting at the fixed line marker up to the second arm line marker. In order to be sure of the measurement, they were asked to read the markings before and after the placed line marker on the second arm.

Figure 46: The Garg protractor with a line marker set at 45 degrees hiding the relevant tactile marking under it

Skill 5: Constructing a Circle

For teaching the students the skill of constructing a circle, the following steps were followed:

a. Explaining the concept of a circle
b. Orientation to and use of each compass to construct a circle
c. Finding the area to draw
d. Setting/fixing the radius and drawing the circle

a. Explaining the Concept of a Circle:

- Students were asked if they knew what a circle was, and were encouraged to draw a circle.
- Once their circle was drawn, they were shown a perfect circle drawn by the instructor. The circle had a clearly-marked centre point and students were encouraged to see both the circles.
- They were explained the concept of a circle as being a shape with a single centre point and equidistant radius from the centre point to any point on the circumference.
- They were also explained that in this skill, they were going to learn how to draw circles of different radii and that the parts of the circle that will be worked with in this skill are the centre, the radius and the circumference of the circle.

b. Orientation to and Use of each Compass to construct a Circle

- Students were oriented to use the Classmate Compass in combination with the APH Clip Ruler, the RNIB Ruler, the WT Ruler and the Squirrel Ruler; the WT ruler as a compass, the APH Compass and the Garg Compass.
- **Classmate Compass + RNIB Ruler/APH Clip Ruler/WT Ruler/Squirrel Ruler**
    - Students were given the compass in their hands, and first orientated to the sharp pin of the first leg and instructed to always be careful when using this leg.
    - They were oriented to the two legs, one with the pin and the second leg with the pen loaded on the same. They were not instructed in loading the pen as that was pre-loaded for them to save time.
    - There were told to move the legs to see how they can be pulled apart and pushed together.
    - They were also oriented to the knob at the top where the two legs joined. They were asked to loosen and tighten the knob, and understand how the legs are immobilised when the knob is tightened.
- **WT Ruler as a Compass**
    - Students were given the WT ruler in their hand and instructed that this time we would be using this ruler as a compass.
    - In order for the ruler to be used as a compass, they were told that they semi-circle end of the ruler and the hole therein would be used as the first leg, and the holes down the middle of the ruler corresponding to the tactile markings would be used to insert the stylus which would be used as the second leg.
- **APH Compass**
    - Students were given the compass in their hands and first orientated to the sharp tip of the fixed leg and instructed to always be careful about the same.
    - They were oriented to the two legs, one with the point tip and the other with the spur wheel.

- There were told to move the legs to see how the pointed tip leg was fixed whereas the leg with the spur wheel could slide along the horizontal bar of the compass.
- They were also then oriented to the screw at the stop of the spur wheel leg. They were asked to loosen and tighten the screw, and understand how the legs are immobilised when the knob is tightened.
- They were also oriented to the measurement markings on the two sides of the horizontal bar of the compass. Both the sides had long marks and short marks, but the marks on one of the sides were more spread out, indicating it was the inches side and the other side was the cm side. For the purpose of the research, the cm side was used.

- **Garg Compass**

Figure 47: Circle markers of different sizes from the Garg Geometry Kit

- Students were given the circle markers to feel.
- They were asked to explore that each circle marker was of different size and had a braille reading of the measurement of the marker.
- They were also oriented to the central immobilisation hole on the circle marker

c. Finding the Area to Draw

- **Classmate Compass , WT Ruler as Compass, APH Compass**
  - Students were asked to explore their immobilized sheet and find free space to draw on.
  - They were asked to locate the centre of the page. Help was given to those who struggled at this stage.
- **Garg Compass**
  - Students were asked to find free space on top of the paper and the centre point on top of the paper.
  - After this students were asked to lift the paper and bend it slightly near the clip so that it would not fall back and asked for corresponding free space on the board.

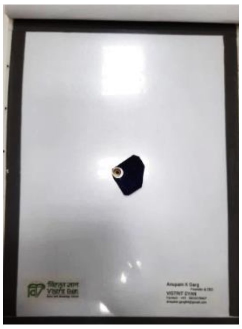

Figure 48: A point marker placed at the centre of the Garg board

d. Setting/fixing the Radius & Drawing the Circle

- **Classmate Compass + RNIB Ruler/ APH Clip Ruler/ Worth Trust Ruler/Squirrel Rulers**
    - Students were asked to rest the ruler on the immobilization pins on the bottom of the sheet. Specifically for the RNIB ruler with the groove side up and with the cm side up for the APH clip ruler.
    - The method of adjusting and resting the compass legs against the ruler markings for each ruler is detailed below:

Figure 49: The Classmate compass being aligned for a specific measurement with the RNIB ruler on the Exam board

- **For the RNIB ruler**: They were instructed to take the pin leg of the compass and place it in the groove of any extra-long mark/ other mark. They were also instructed to always press down the leg completely into the mat. They had to read on the ruler, the measurement given to them, and place the pen leg of the compass at the groove of the desired mark.
- **For the APH Clip ruler**: They were instructed to take the pin leg of the compass and place it on any long mark/ other mark of the ruler. They were also instructed to always press down the leg completely into the mat. They had to read on the ruler, the measurement given to them, and place the pen leg of the compass at that mark.

Figure 50: The Classmate compass being aligned for a specific measurement with the APH clip ruler on the Exam board

- **For the WT ruler**: They were instructed to take the pin leg of the compass and place it in the centre hole next to on any long mark/ other mark. They were also instructed to always press down the leg completely into the mat. They were then instructed to read on the ruler, the measurement given to them, and place the pen leg of the compass at the centre hole of that mark.

Figure 51: The Classmate compass being aligned for a specific measurement with the WT ruler on the Exam board

- **For the Squirrel ruler**: They were instructed to set the measurement on the ruler. Once the measurement was set, they were instructed to place the two legs of the compass at the two clip edges of the ruler, whilst holding down the ruler and ensuring that the clip did not move. They were also instructed to keep the first leg pressed fully down into the mat.

Figure 52: The Classmate compass being aligned for a specific measurement with the Squirrel ruler on the Exam board

  - They were instructed to do the above whilst holding down the ruler and the first leg.

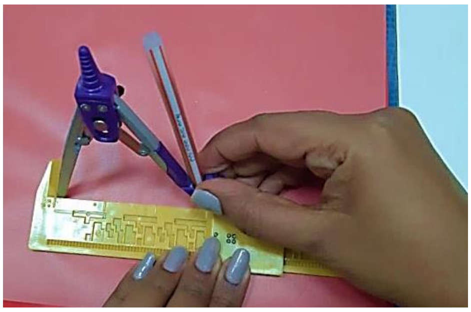

Figure 53: The Classmate compass being aligned for a specific measurement with the Squirrel ruler on the Exam board

  - After they had finished placing the compass to the right measurement, they were asked to tighten the knob by being careful to not press the legs together whilst tightening the knob.
  - For students who struggled in pulling out the compass to the right measurement with one hand, they were instructed to first keep the compass fully stretched, and after fixing the first leg to the start point, push back the compass to the right measurement mark.

- Students were asked to bring the pin leg of the compass to the centre, and press it down completely into the mat. They were instructed to ensure that they were holding the compass lightly and were not pushing/moving the legs of the compass.
- After they had pressed down the first leg, they were asked to hold the other leg of the compass from the side and not on top of the leg as the latter could lead to the leg getting pushed back towards the pin leg.
- They were then instructed to turn the mat whilst holding down the second leg of the compass on the sheet such that the pen would make the drawing on the sheet.
- As they drew, they were asked to check the sheet for the mark being drawn, and to stop when the circle was complete.

- **WT Ruler as a Compass**
    - Students were asked to place the ruler's semi-circle end at the centre of the page and immobilize the ruler by placing a pin through its hole.
    - They were then instructed to move the ruler 360 degrees, and in case the ruler clashed with either the exam board clip or the immobilization pins placed below, they were asked to remove the clip/immobilization pins.
    - They were asked to measure the radius, and place the stylus in the hole corresponding to the measurement, and draw the circle by moving the stylus along with the ruler around to make the circle.

Figure 54: The WT ruler being used as a compass to draw a circle

- They could either turn the board whilst doing this or turn the ruler whilst keeping the board straight.
- Having the centre immobilised was helpful to ensure a fixed single centre.

- **APH Compass**

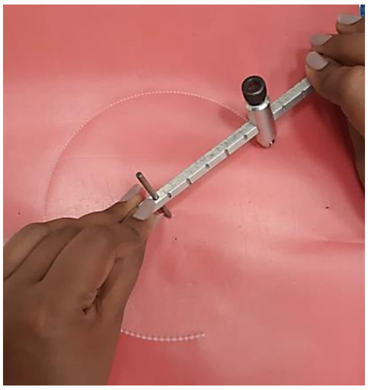

Figure 55: A circle being drawing with the APH compass

- Students were asked to fix the measurement on the compass by counting on the cm side and by bringing the spur wheel leg to the precise measurement mark. They were instructed to count the first long mark as 1. In order to do the same accurately, they were asked to keep their fingers in the dent of the final tactile mark and to bring the spur wheel leg just next to the finger.
- They were then asked to tighten the screw to immobilise the second arm.
- They were asked to bring the pointed leg of the compass to the centre and press it down completely, and keep one hand holding it down all the time.
- They were asked to hold the second leg of the compass and turn the compass whilst holding down the second leg of the compass on the sheet.
- As they turned the compass, they were also instructed to exchange their hands holding the first leg and the second leg to make drawing easy as the compass turned 360 degrees.
- Since this compass had a spur wheel the drawing happened on the reverse side.

- **Garg Compass**

Figure 56: A circle being drawing with the Garg compass/Circle marker

- Students were asked to place a point marker at the centre point on the board, corresponding to the centre point found on the paper.
- They were asked to press the paper down and puncture the hole and lift the paper back up.
- They were asked to identify a Circle Marker of the desired radius, and instructed to place it on the Point marker completely flat while ensuring that the point marker had not moved.
- They were then asked to place the paper back on the Point marker and Circle marker whilst being careful that the Point marker and Circle marker did not move under the paper.
- They were asked to gently press the paper down with their hands along the outer edge of the Circle marker.
- Then, using the Garg stylus, they were asked to draw over the Circle marker. Those who preferred to turn the board whilst drawing were allowed to do so.

Skill 6: Constructing/Cutting Arcs

For teaching them concept of arcs, the following steps were followed:

a. Explaining the concept of arcs in link with line bisection as an example
b. Orientation to and use of each compass to cut arcs for line bisection
c. Orientation to line segments and measurement
d. Fixing the compass legs to the end points of line segments and setting the radius
e. Drawing the arc
f. Finding the intersecting points and drawing the bisector

a. Explaining the concept of Arcs in link with Line Bisection as an example

- Students were given an explanation of what an arc is with line bisection as an example.
- Students were explained what an arc is. They were told that an arc is a part of the circumference of a circle, and like a circle, an arc would have a fixed point of drawing.
- They were explained that arcs are used for various functions in geometry, and in this skill, we would learn how to use the different compasses for drawing arcs for a line bisector.
- They were explained that line bisection means cutting the line segment into two equal halves.

b. Orientation to and Use of each Compass to Cut Arcs for Line Bisection

- Since the students were already oriented to the compasses in Skill 5, the same was not repeated here.
- Since the Garg Arc Markers were new, the students were oriented to them. Some students in the research used the circle markers instead.

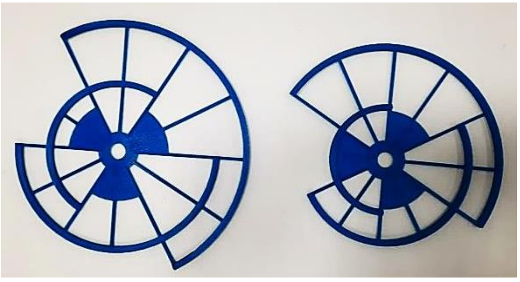

Figure 57: Arc markers of different sizes from the Garg Geometry Kit

- Students were asked to move their hands over the arc marker and find the number of arcs, the centre hole and the braille readings on the same.
- They were explained to use the braille signs and to locate the arc corresponding to that measurement.

c. Orientation to Line Segments and Measurement

- For the purpose of research in order to save time, they were not asked to draw the line segment. They were given a sheet with a pre-drawn line segment and informed of its length.
- They were also informed that in order to draw a line bisector they must set the radius of the compass to more than half but less than the full the length of the segment.

d. **Fixing the Compass Legs to the End Points of Line Segments and Setting the Radius**

- **Classmate Compass**
  - Students were asked to loosen the compass knob and bring the pin leg of the compass to either of the end points of the line segment, and press it down completely.
  - They were then asked to set the radius by judging the line length and placing the pen leg of the compass up to more than half but less than the full length of the line segment. Once they had set the radius, they were asked to tighten the compass knob and fix the compass legs to position.

Figure 58: The radius of the Classmate compass being set

- **APH Compass**
  - Students were asked to fix the measurement on the APH compass by counting on the cm side and bringing the spur wheel leg to the mark at which the measurement completes more than half but less than the full length of the line segment, or take a guess along the line segment by placing the first leg down at the end point and adjusting the second leg along the line segment.

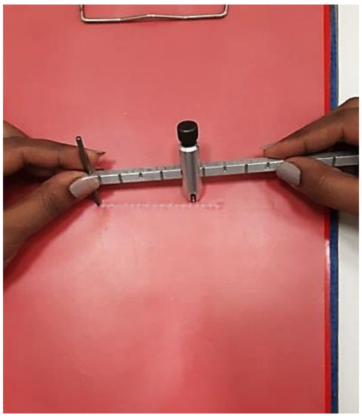

Figure 59: The radius of the APH compass being set

  - If they were using the pre-counted measurement method, they were instructed to count the first long mark as 1. In order to do the same accurately, they were asked to keep their fingers in the dent of the final tactile mark, and to bring the spur wheel leg just next to the finger.
  - They were then asked to tighten the screw to immobilise the second leg at the desired measure.

e. Drawing the Arc

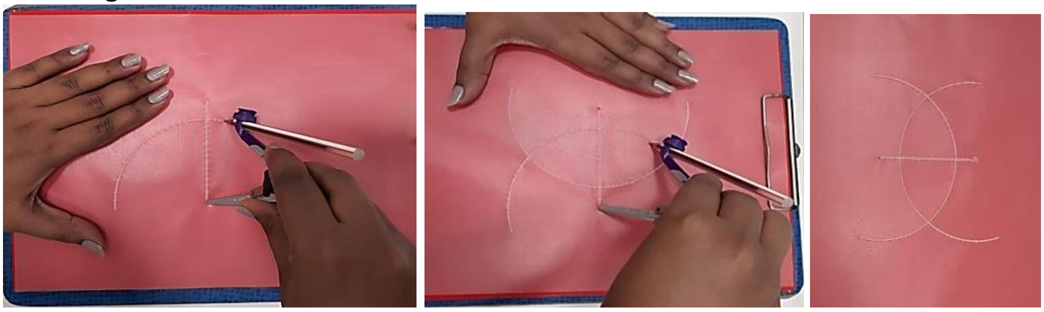

Figure 60: Cutting arcs

- Students were asked to bring the point leg of the compass to either of the end points and press it down completely, and keep one hand holding it down all the time.
- They were asked to hold the second leg of the compass, and turn the compass whilst holding down the second leg of the compass on the sheet.
- They were asked to make an extended arc on the side of the line segment such that the arc is a semi-circle passing through the line segment.
- They were asked to repeat this from the other end of the line segment as well.
- Since the APH compass had a spur wheel the drawing happened on the reverse side.

f. Finding the intersecting points and drawing the bisector

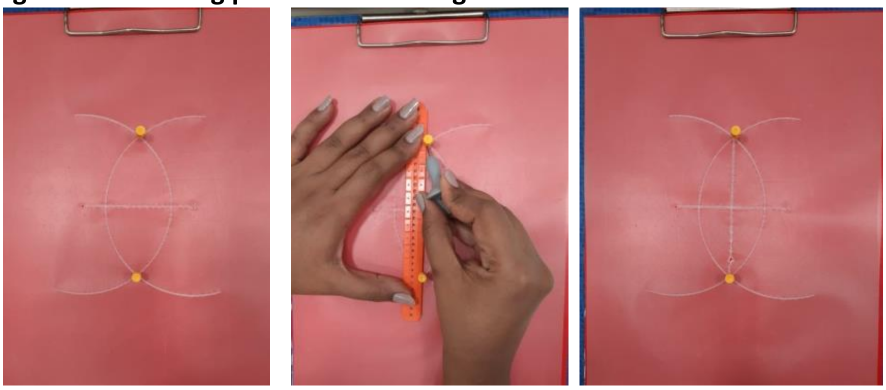

Figure 61: Line bisection on the Exam board

- Students were asked feel the entire drawing and identify the line segment, the area above and below it, the parts at which the arcs cut the line segment and the points of intersection of the arcs above and below the line segment.
- Students were asked to place a pin at the intersection points of the arcs both above and below the line segment.
- They were then asked to place the ruler resting against the two pins at the intersection points and join the points with a stylus whilst holding down the ruler.
- They were then asked to measure and see the line segment on either sides of the line bisector to check whether it was accurately bisected.
- Since the WT ruler as a compass and the Garg compass used a different system steps d, e, and f happened for them in a slightly different variation which are listed below.

- **WT Ruler as a Compass: Fixing the Compass Legs to the end points of line segments + Setting the Radius + Drawing the Arc**
    - Students were asked to place a pin in the ruler's semi-circle end, and bring the same to either of the end points, locate the exact point and immobilize the ruler by pressing down the pin.
    - They were then instructed to take a measurement on the ruler for the radius based on the length of the line segment (more than half but less than the full length of the line segment), and keep in mind the measurement.
    - They were asked to place a stylus at the hole of the selected measurement, and they were asked to make a full arc on the side of the line segment such that the arc is a proper semi-circle passing through the line segment.
    - They were asked to repeat this from the other end of the line segment as well.

- **Garg Compass: Fixing Compass Leg to end points of line segment + Setting the Radius + Drawing the Arc** :

Figure 62: Line bisection with the Garg kit

- Students were asked to place two point markers on the board corresponding to the end points found on the paper.
- They were asked to press the paper down and puncture the holes and lift the paper back.
- They were asked to identify and place the arc marker/circle marker of the desired radius and place it on the point marker fully flat ensuring that the point marker did not move.
- They were asked to select the arc marker/circle marker based on either selecting the marker of a measurement more than half but less than the full length of the line segment, or they were asked to put the arc markers/circle marker on one of the end points and make a judgement in reference to the second point marker.
- They were asked to then place the paper back on the arc/circle markers whilst being careful that the point marker and arc/circle markers did not move under the paper.
- They were asked to gently press down the paper along the outer edge of the circle marker or the desired arc circumference of the arc marker.
- Using the stylus, they were asked to draw over the same using the Garg stylus. Those who preferred turned the board whilst drawing.

- **Garg Compass: Finding the intersecting points and drawings the bisector**

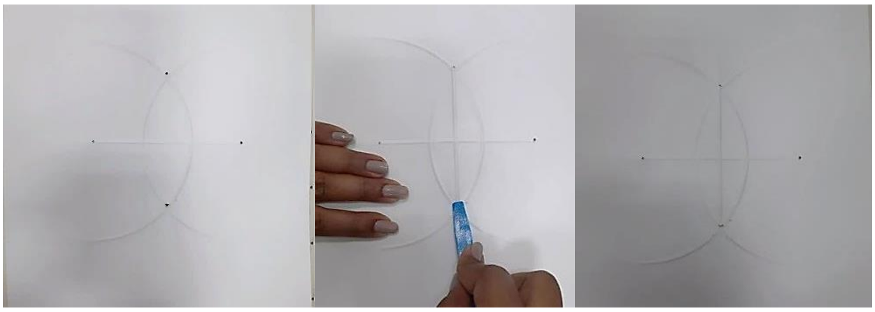

Figure 63: Line bisection with the Garg kit

  - Students were asked feel the entire drawing and identify the line segment, the area above and below it, the parts that the arcs cut the line segments and points of intersection of the arcs above and below the line segment.
  - Students were asked to place a point marker under the Braille paper corresponding to the intersection points of the arcs both above and below the line segment.
  - They were then asked to place the paper down, and puncture holes at the point makers.
  - They were asked to lift the paper, and place a line marker over the two point markers, place the paper back down, and draw over the line marker connecting the two points.

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