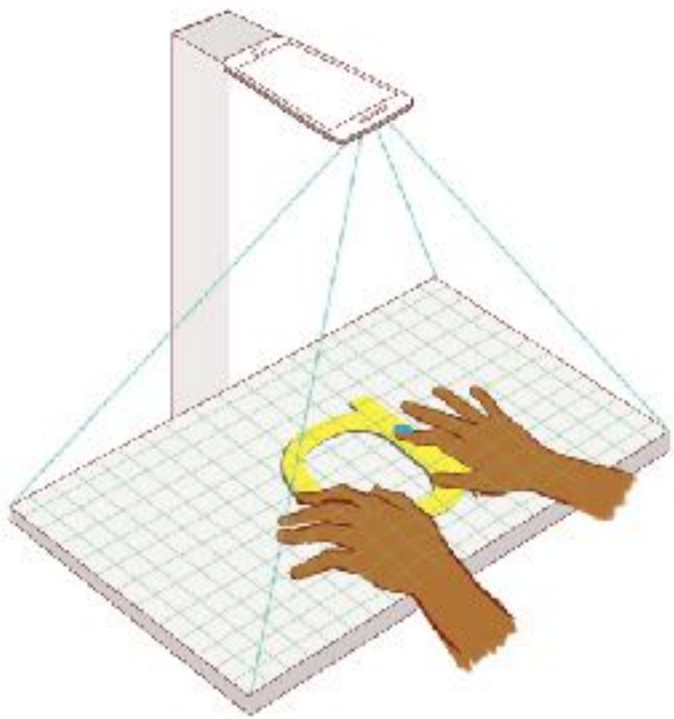

Project 2 Report:

Affordable Interactive Tactile Graphics: Design of Interaction Primitives

Chandni Rajendran
Interaction Design
M.Des (2015-17)

Guide: **Prof. Venkatesh Rajamanickam**

IDC School of Design,
Indian Institute of Technology, Bombay

Declaration

I declare that this written document represents my ideas in my own words, and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented of fabricated or falsified any idea/data.fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have this not been properly cited or from whom proper permission has not been taken when needed.

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November 2016

Approval Sheet

The Interaction Design Project II, titles "Affordable Interactive Tactile Graphics: Design of Interaction Primitives" by Chandni Rajendran, 156330001, is approved in partial fulfilment of the Master in Design in Interaction Design at IDC, Indian Institute of Technology, Bombay.

Guide:

Chairperson:

Internal Examiner:

External Examiner:

Date: 2nd November 2016

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Many people have played important roles in making this project possible. Heartfelt thanks go out to my husband, Vipin Nair, whose love and companionship keep me sane; my parents and brother, for being the supportive family that means the world to me.

I'd like to thank Prof. Venkatesh Rajamanickam for believing in an idea that must have sounded rather wishful when I first described it to him, and for guiding it through to its current state. The guidance, encouragement to explore different avenues, and the logical clarity given at every meeting are highly appreciated and valued.

The seed of the idea was found while working at Xaviers' Resource Centre for the Visually Challenged, an institution whose work in advocacy for inclusive design has inspired many like me.

For valuable feedback at various stages of the project, I'd like to thank Prof. Anirudha Joshi and Prof. Jayesh Pillai.

I'm also in awe of and grateful for Processing, a well documented open source software sketchbook, with which this project has been built.

Contents

1. Abstract

The effectiveness and necessity of interactive tactile graphics has been well established in the field of education of blind children. Developments in production technology are making tactile graphics (TGs) more affordable, but specialised hardware for interactivity is usually unaffordable for many blind students in India.

This design project uses an inexpensive webcam or a camera phone to make TGs interactive. A camera is mounted at a fixed height above the TG and the forefinger of the dominant hand is marked with a blue coloured sticker/sleeve. As a user explores the TG with their hands, the marked finger's motion is tracked, and is used to interact with the voice system.

Basic content primitives and interactions are designed based on the unique constraints, affordances and potential of this novel interactive medium, which serve as building blocks for more complex content. Usability of the medium is studied using simple tasks designed to demonstrate the possibilities.

Many examples of assistive technology developed in the past have been found to useful for a broader audience as well. Similarly, this medium of interaction can be used to enhance the learning experience for sighted children, and for children with learning disabilities.

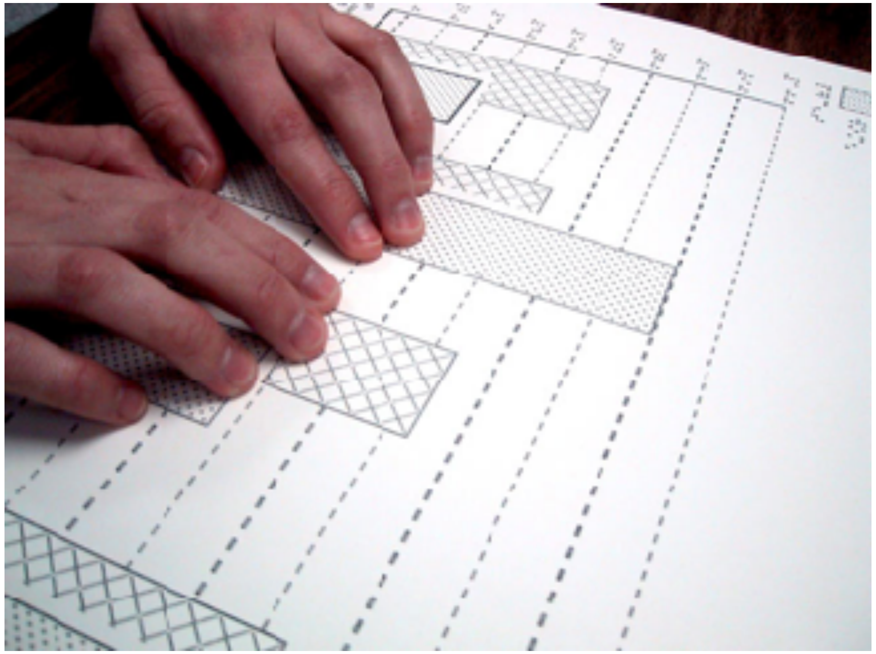


Figure1: Tactile Graphic [2]

2. Introduction

Tactile graphics (TG) are images that are formed in relief on paper or plastic sheets to represent graphics in a tangible form. As an alternative medium, it is an important part of inclusive design and have been used to make information accessible in schools, offices and public spaces. In this project, I have addressed the use of interactive tactile graphics in primary school education, although the framework described may be used in any situation where the basic equipment is available.

There are two million children (under 14) in India living with vision loss, and only 5% receive education[1]. One of the largest reasons for this is unavailability of teachers with training in special education, or even basic knowledge of handling students with special needs. Braille textbooks and special equipment can also make a blind children’s education considerably more expensive than that of a sighted child attending public school. Many public schools suffer from issues that affect even sighted children’s education, such as low funding, low teacher attendance and lack of amenities.

The primary user group for this design effort is primary school students with vision loss. However, the system can be applied used with sighted children as well, for collaborative learning where only one smart device is available.

1.1 Context

In the context of education, tactile graphics have not always been available for school children in India. Parents and schools have been importing them from Europe and US, but more recently, we see more local effort in both production and content creation. One such organisation is Xavier's Resource Centre for the Visually Challenged, whose team of volunteers regularly convert textbooks into tactile graphics for a handful of students in the city of Mumbai [3]. Each chapter, when finished, is a small booklet in itself. All text is printed in braille using a Perkin's Brailler or a braille embosser. The images are represented in relief using material, usually paper and twine, of different thicknesses and textures. These are annotated with braille labels printed separately and pasted in the right location.

These accessible textbook chapters can take days to create. They are passed on to more children who may require them, but often do not last beyond two academic cycles as they are damaged or torn easily.

Alternate methods of producing more durable tactile graphics is also being explored. AssisTech, an organisation at IIT Delhi, has developed software that convert images into 3D printed tactile graphics, which are then used as a mould for reproduction by thermoforming [4].

Considering the huge amount of effort involved in the production of tactile graphics, their utility is rather limited. This is not to say they are non-essential, but that there are many ways they could be enhanced as sources of information. A collection of interactive tactile graphics could replace entire textbooks if all the textual matter is made available in the audio channel. The size of braille textbooks could be brought down to a fraction of what they are now.

1.2 Problem space

Unlike annotated graphics in textbooks, which can be studied independently, most tactile graphics require a teacher's help in making sense of the content. After the initial lesson in a classroom, or with a teacher, the graphics can be studied and processed independently.

Several attempts have been made to create interactive tactile graphics, which will be discussed in detail in section 3.2. The problem with these solutions, be it touch sensitive surfaces, or audio pens, is that of affordability. Specialised equipment or hardware becomes an expensive investment that many students may not have access to.

Figure 2: Perkin's Brailler or Braille Typewriter [5]

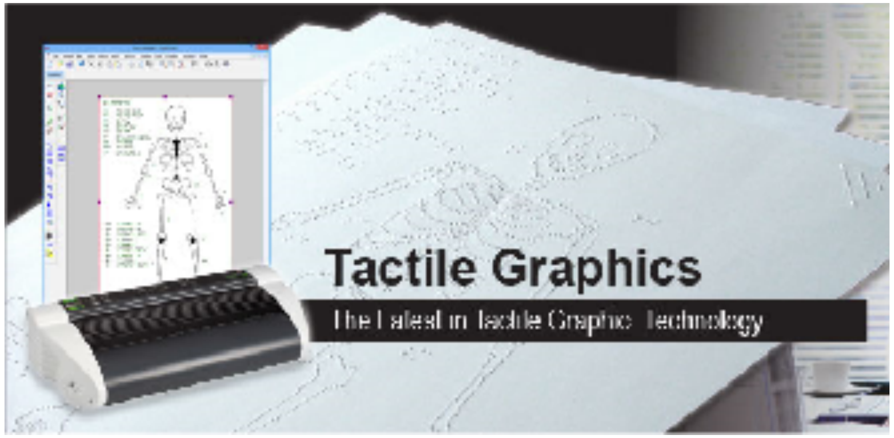


Figure 3: Tactile Graphics in braille print [6]

1.3 Objectives:

The objective of this design project is to find an inexpensive way for tactile graphics to be interactive, thus become better resources, particularly for education.

The way in which tactile graphics can have more enhanced utility and wider application is by making the otherwise static sheet interactive. Whether it is simply providing audio labels to save braille-print space, or to provide sensory substitution to enhance perception and understanding in a way that pointers and annotations cannot, interactivity can contribute in many ways to the value of a tactile graphic.

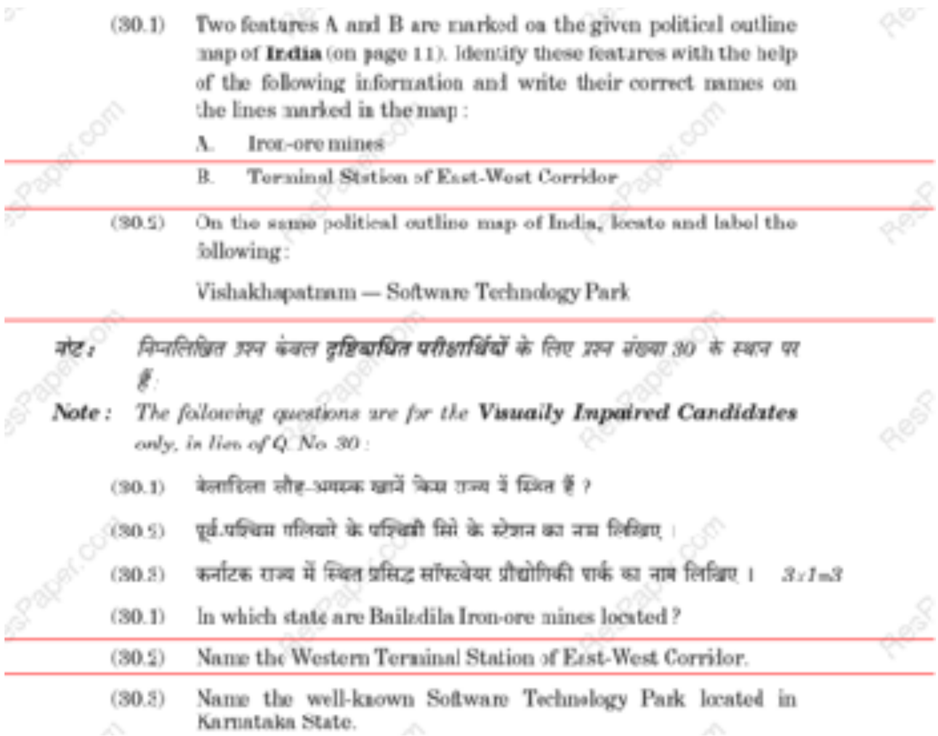
1.4 Scope:

Although the project looks to find a solution that will work in a variety of situations, there needs to be some reference content on which to base interactivity. For this, educational requirements of primary school students is taken as the content to be worked over. The reasons for this choice:

Primary school is the stage where children move from tactile playthings and learn to absorb information in the form of text and graphics in textbooks, which become essential to learning. While it is true that digital content is available to children much earlier on in their lives, the importance of tactile toys diminishes around this age. This is where the difference start and build up over the years and amount to substantial inequality in knowledge and capabilities between blind and sighted children.

For example, spatial intelligence of blind children is repeatedly disregarded and underdeveloped, as seen in these map questions (figure 4). This is not because of an actual difference in intelligence, but because we do not have effective tools to teach and test spatial concepts.

The project analyses different ways to provide this interactivity and outlines a framework for interactive elements and information units. User testing and evaluation of the same will be documented in the form of defined metrics and qualitative findings.


(30.1) Two features A and B are marked on the given political outline map of **India** (on page 11). Identify these features with the help of the following information and write their correct names on the lines marked in the map :

A. Iron-ore mines

B. Terminal Station of East-West Corridor

(30.2) On the same political outline map of India, locate and label the following :

Vishakhapatnam — Software Technology Park

*नोट : निम्नलिखित प्रश्न केवल **दृष्टिबाधित परीक्षार्थियों** के लिए प्रश्न संख्या 30 के स्थान पर हैं :*

***Note :** The following questions are for the **Visually Impaired Candidates** only, in lieu of Q. No. 30 :*

(30.1) बैलाडिला लौह-अयस्क खानें किस राज्य में स्थित हैं ?

(30.2) पूर्व-पश्चिम गलियारे के पश्चिमी सिरे के स्टेशन का नाम लिखिए ।

(30.3) कर्नाटक राज्य में स्थित प्रसिद्ध सॉफ्टवेयर प्रौद्योगिकी पार्क का नाम लिखिए । *3x1=3*

(30.1) In which state are Bailadila Iron-ore mines located ?

(30.2) Name the Western Terminal Station of East-West Corridor.

(30.3) Name the well-known Software Technology Park located in Karnataka State.

Figure 4: CBSE Board Exam Questions, Class X, 2015 [7]

Figure 5: Early conceptual model of solution.

3. Research

There are many types of TGs, using different material and production methods, which have varying capabilities and cost. This section contains

3.1. an overview of TGs,
3.2. prior work in interactive TGs,
3.3. review of relevant technology,
3.4. concept of interactive paper in general,
3.5. principles of design in voice interfaces,
3.6. and primary research conducted with XRCVC

3.1 Tactile graphics

Most of the content in a typical text book can be converted to braille, and many images can be described in text, as is the norm with web content accessibility standards. There are, however, many types of drawings an illustrations that cannot be fully grasped with a text-only description. Tactile graphics in the area of education are supplementary to text, and are essential for well rounded learning. [8]

There are several material options, and production techniques for the creation of tactile graphics:

3.1.1 Braille-embossed

This is the most affordable form of tactile graphics as it can be printed on a braille embosser on regular braille paper. Content creation is also relatively simple with the software provided with the brailler. The limitation of this method is that the drawing produced this way can only communicate distinct shapes, and fail with complex drawings. It is not possible to create many different textures or levels of embossing or size of dots.

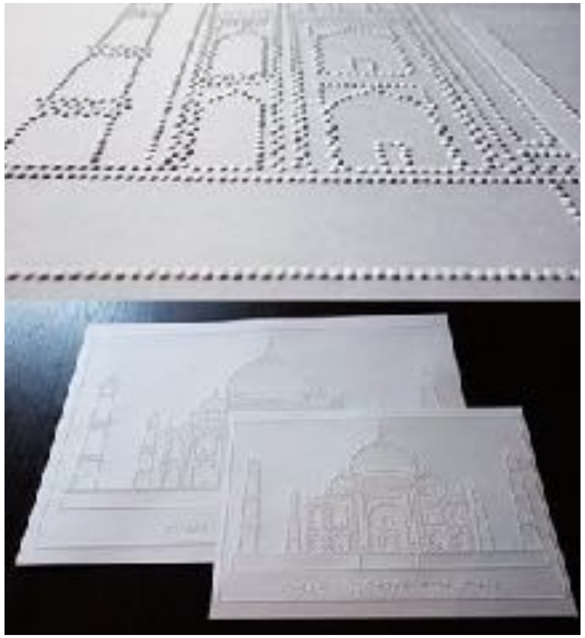


Figure 6: Braille embossed tactile graphic[9]

3.1.2 Handmade

Using papers, fabrics, velcro, etc., tactile graphics can be made with a rich variety of textures. They may be used as is, or may become base moulds for thermoforming and reproduction.

Figure 7: Handmade tactile graphic [10]

3.2.3 3D Printed

Several software packages are available for the ready conversion of images into 3D file, which can then be printed and used as a tactile graphic. These are unaffordable at present, but costs are projected to come down in the near future.

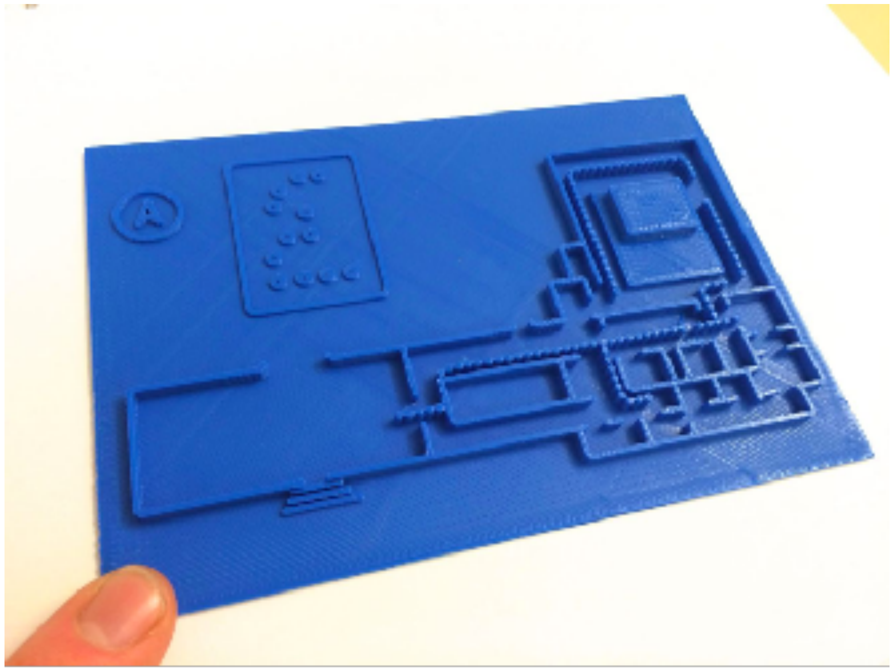


Figure 8: 3D Printed tactile graphic [11]

3.2.4 Thermoformed

Once a base mould is prepared, they can be reproduced for distribution by the industrial production process called thermoforming. It is a process that combines heat and vacuum suction to transfer relief from the mould onto a specialised sheet of vinyl or styrene.

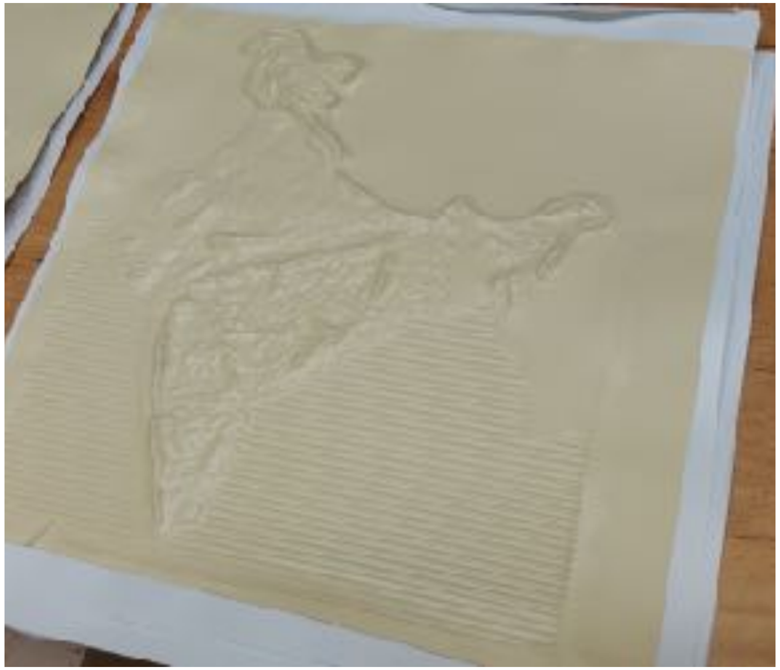


Figure 9: Thermoformed tactile graphic- Indian Topography map (design and image by author)

3.2 Interactive tactile graphics

Additional voice labels and descriptions can be added to tactile graphics through various methods. They can be broadly categorised under:

- projection mapping
- touch sensitive surface
- audio labeller

Projection Mapping

A Projection Mapping system uses a projector and camera over a tactile graphic to make the content universally accessible. While a projector casts an image on a fixed tactile graphic, a camera is used to detect position of users' hands and delivers relevant information.

Figure 9: Interactive map at Perkin's School for the Blind [13]

In this example at Perkin's School for the Blind, touch sensitive models of buildings are 3D printed to create a tactile map that can be used by everybody. Controls are provided on the sides to adjust settings, access information and even play a game with upto 4 players. [14]

Touch Sensitive surfaces

Touchgraphics, the organisation that created the installation at Perkin's School, has also developed interactive tactile graphic tools such as the Talking Tactile Tablet. More interesting applications such as Talking Tactile Head are under development.

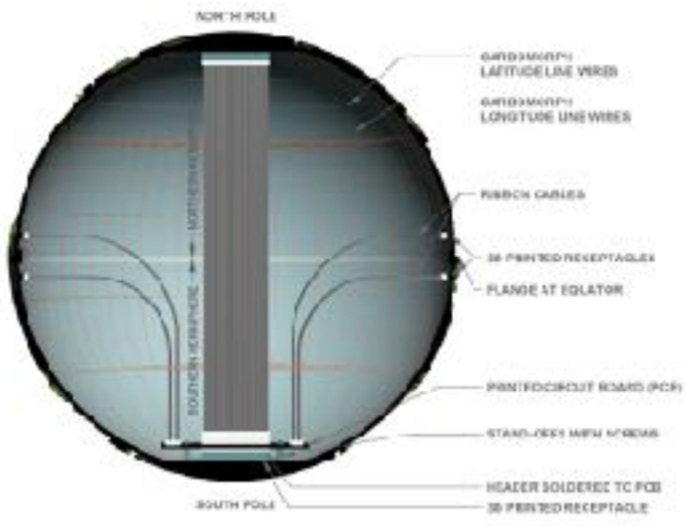


Figure 10: Interactive Globe Concept by TouchGraphics [15]

Audio Labeller

A sonic labeller or audio pen is a device that can be used in situations where custom labels are required, such as restaurant menus, and home labelling. The pen comes with a set of stickers, which have a micro-pattern printed on it. The stickers can be uniquely identified by the pen, which has both scanning technology and audio output. Out of the pack, the stickers do not contain any data, but voice messages can be recorded onto them. The stickers are then applied to relevant locations and their audio content accessed with the pen.

Figure 11: Audio Labeller [16]

Figure 12: Audio Labeller [16]

3.3 Interactive Paper

Although interactivity in paper primarily caters to sighted individuals, the technology and applications are interesting study that inform the design process with learnings. Attempts to merge the screen and paper (or any static surface) has a long history, the earliest of which tried to make the work station interactive with calculators, and most recent of which has been with a camera equipped pen that digitises notes as they are made.

Figure 13: Early example of digitised surface [17]

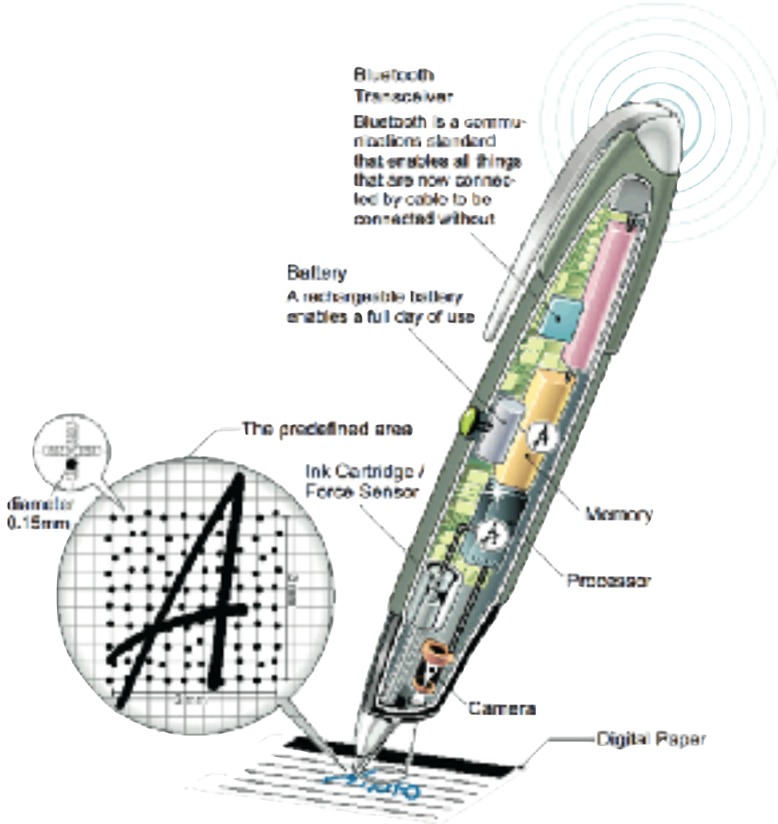
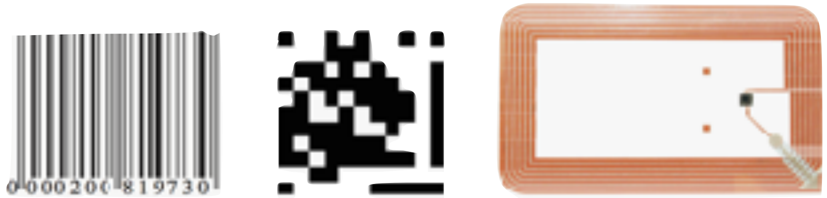


Figure 14: Anoto digital pen, on paper with non-repeating pattern [18]

As Beat Signer details in *Fundamental Concepts for Interactive Paper and Cross-Media Information Spaces* [19], There have been several attempts to integrate paper and digital media. Aspects of object identification, position tracking, writing/recording and accessing information are solved by combinations of paper and hardware.



(a) Barcode, EAN-13 (b) 2D barcode (c) RFID tag

Figure 15: Object Identifiers [17]

(a) MyPen (b) Quicktionary

Figure 16: Camera Equipped Pens [17]

(a) Seiko InkLink (b) Wacom graphics tablet

Figure 17: Position Tracking [17]

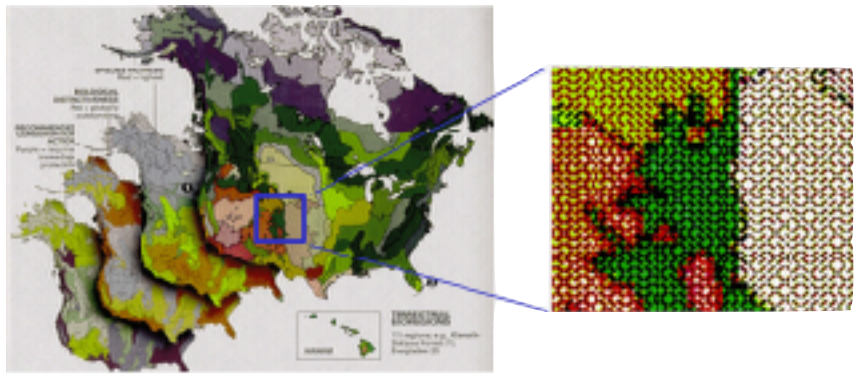


Figure 18: Information encoded in print (Xerox DataGlyph) [17]

(a) PaperClick (b) Wiziway

Figure 19: Paper based bookmarks [17]

(a) Exhibition space (b) Workplace

Figure 20: Multi-user activities (Generosa Enterprise Installation) [17]

In most of these attempts to bridge the paper-digital divide, there is specialised hardware involved, for page identification or position tracking or both.

3.4 Voice interfaces

A few key concepts for design of information in an interactive voice channel.

3.4.1 Control

Unlike text or tactile elements that can be read at will, voice content needs an element of control that is immediate or instant in nature. Without clear, easy and adequate controls to start, pause, stop, repeat audio files, accessing information in this channel could become chaotic. Additionally, users have different preferences of speaking speeds. While a new user may be comfortable at 200 words per minute, a seasoned user may be more used to accessing information at 300–400 wpm.

3.4.2 Discovery, Affordance

The clickable or interactive elements in a visual interface are buttons, links, and learned keyboard shortcuts. In the audio channel, elements that can be selected or 'clicked' need to be indicated as well. One of the popular methods employed is to play a note before or after the interactive element is spoken out. Android on talkback appends the word 'link' before a hyperlinked element.

The possible interactions or input mechanisms also need to be indicated at every relevant opportunity. Once a user is familiar with the system, these instructions can then be turned off.

3.4.3 Error Recovery

There need to be easy correction mechanisms or ways to reverse a selection or action. These do not necessarily have to be in audio channel, a standard reverse-gesture could be available and called when applicable. [20]

3.4.4. Elements of VUI:

As described in *Voice User Interface Design*[21]:

Prompts — are all the recordings or synthesised speech played to the user during the dialog.

Grammars — possible things callers can say in response to each prompt. The system can only understand those words, sentences, or phrases that are included in the grammar.

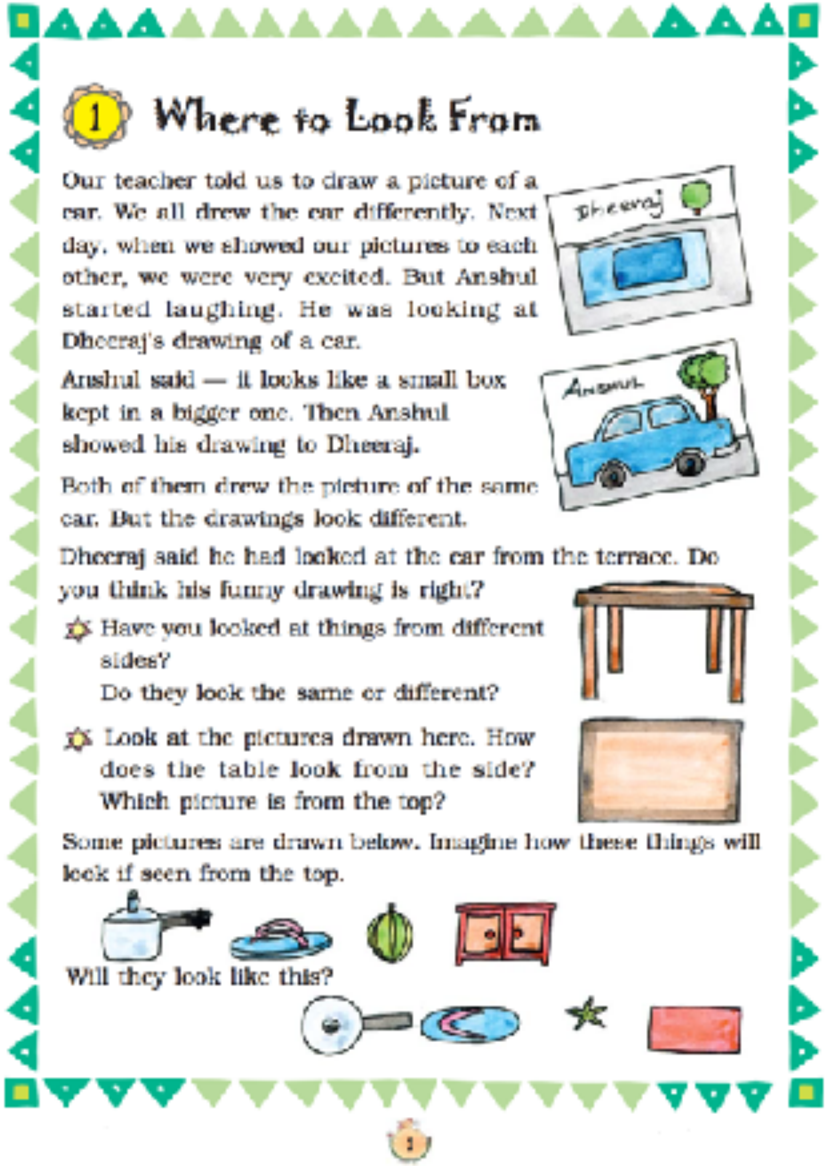
Dialog logic or call flow — defines the actions taken by the system, for example, responding to what the caller has just said or reading out information retrieved from a database.

3.5 NCERT Textbooks

The text books for class III by NCERT were analysed for the content. It is found that a typical chapter contains text, images and is also rich with exercises that are designed to make learning more activity oriented. Completion of these activities may be done independently, or involve the teacher, or even group work. Categorising activities according to nature of interaction:

- reading
- stories
- writing
- gamified worksheets
- drawing
- speaking
- discussing
- making
- observation
- field visit

In the form of stories, games, field visits and other engaging group activities, learning concepts is made easier. It is not simple access to labels that is necessary, but the ability to input answers, record data and get feedback that is required. This is an important aspect to be considered for the design of interactivity in tactile graphics.



1 Where to Look From

Our teacher told us to draw a picture of a car. We all drew the car differently. Next day, when we showed our pictures to each other, we were very excited. But Anshul started laughing. He was looking at Dheeraj's drawing of a car.

Anshul said — it looks like a small box kept in a bigger one. Then Anshul showed his drawing to Dheeraj.

Both of them drew the picture of the same car. But the drawings look different.

Dheeraj said he had looked at the car from the terrace. Do you think his funny drawing is right?

Have you looked at things from different sides?
Do they look the same or different?

Look at the pictures drawn here. How does the table look from the side? Which picture is from the top?

Some pictures are drawn below. Imagine how these things will look if seen from the top.

Will they look like this?

Figure 21: NCERT Math Textbook, Class III [22]

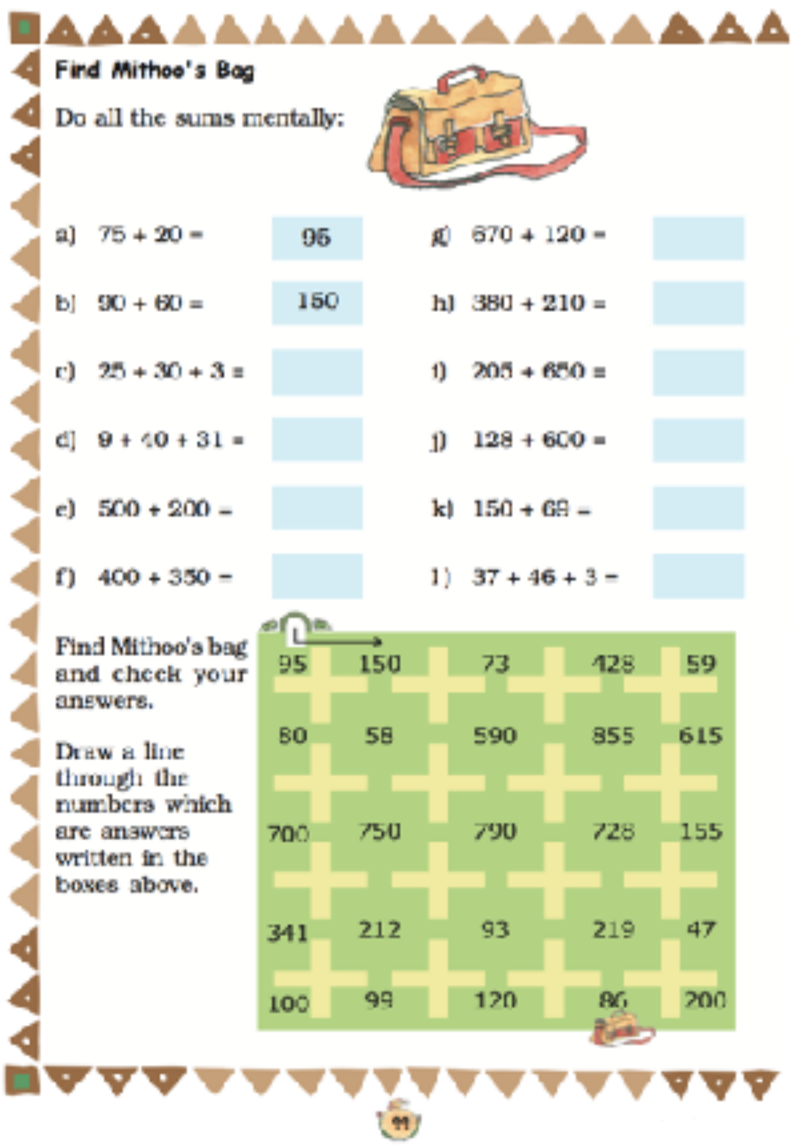


Figure 22: NCERT Math Textbook, class III [22]

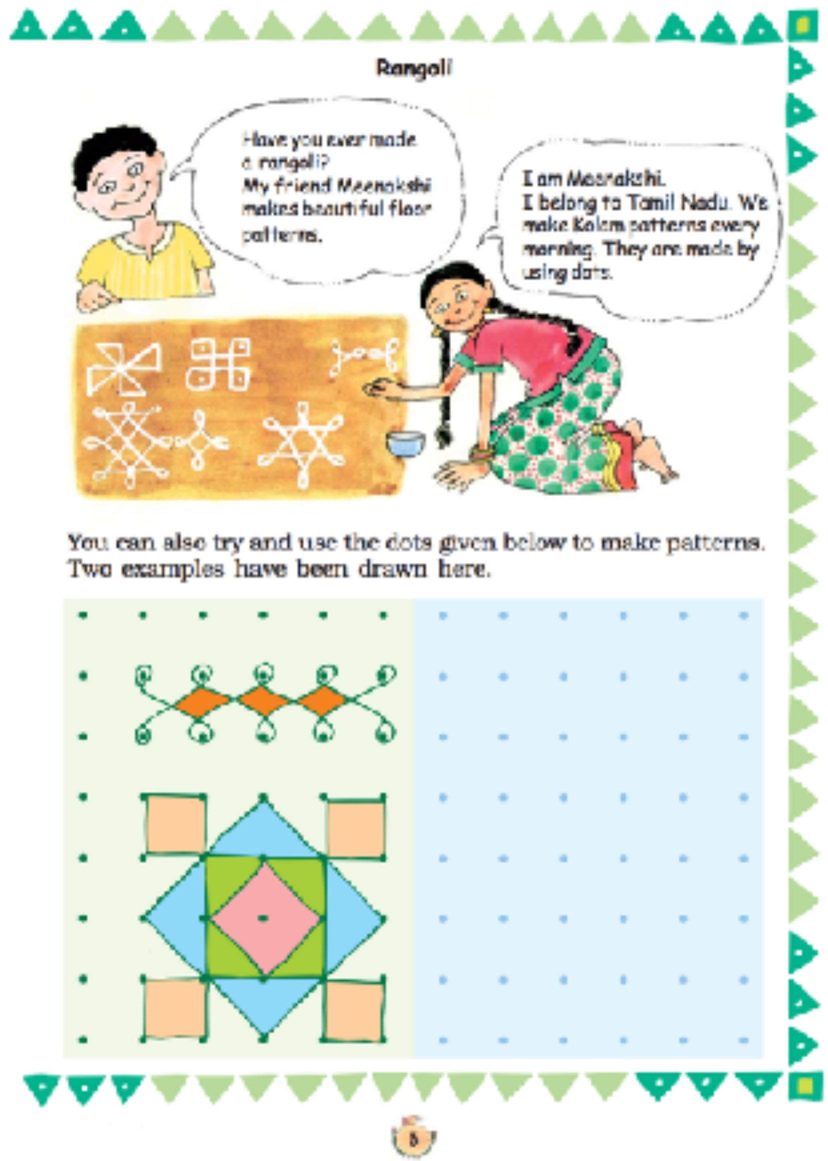


Figure 23: NCERT Math Textbook, class III [22]

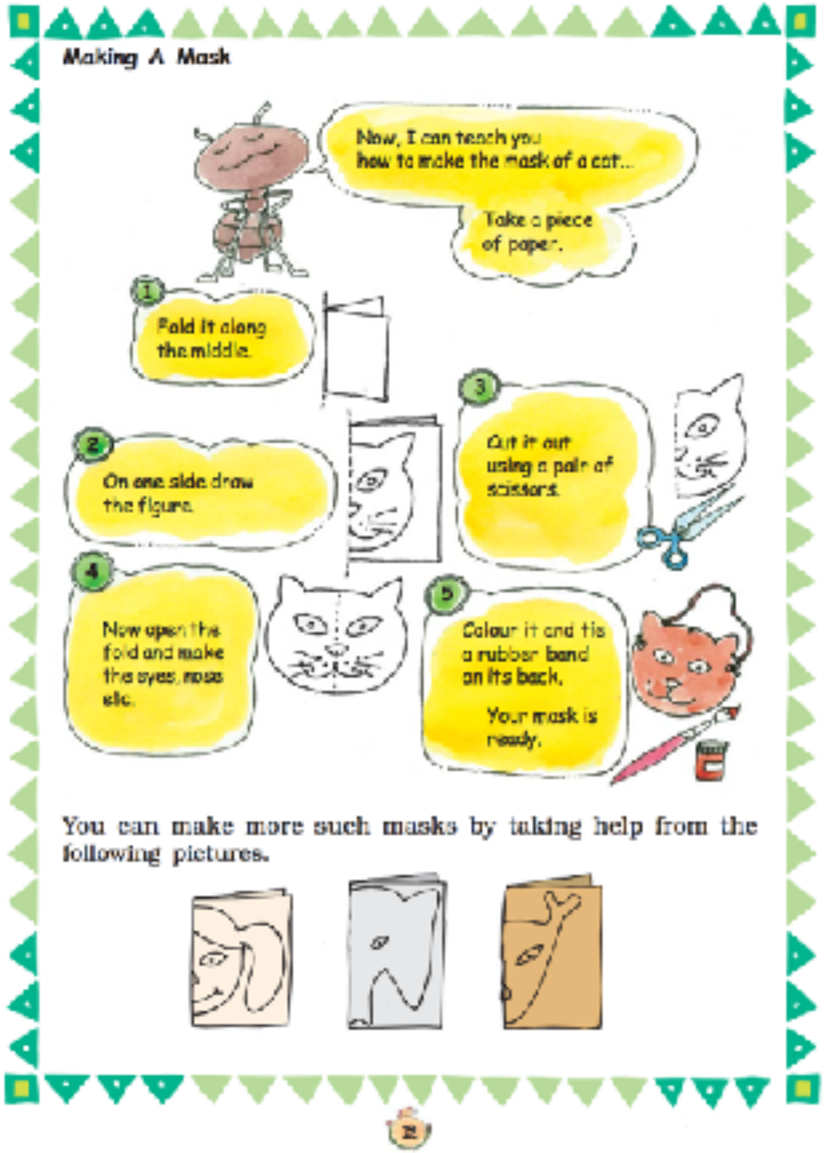


Figure 24: NCERT Math Textbook, class III [22]

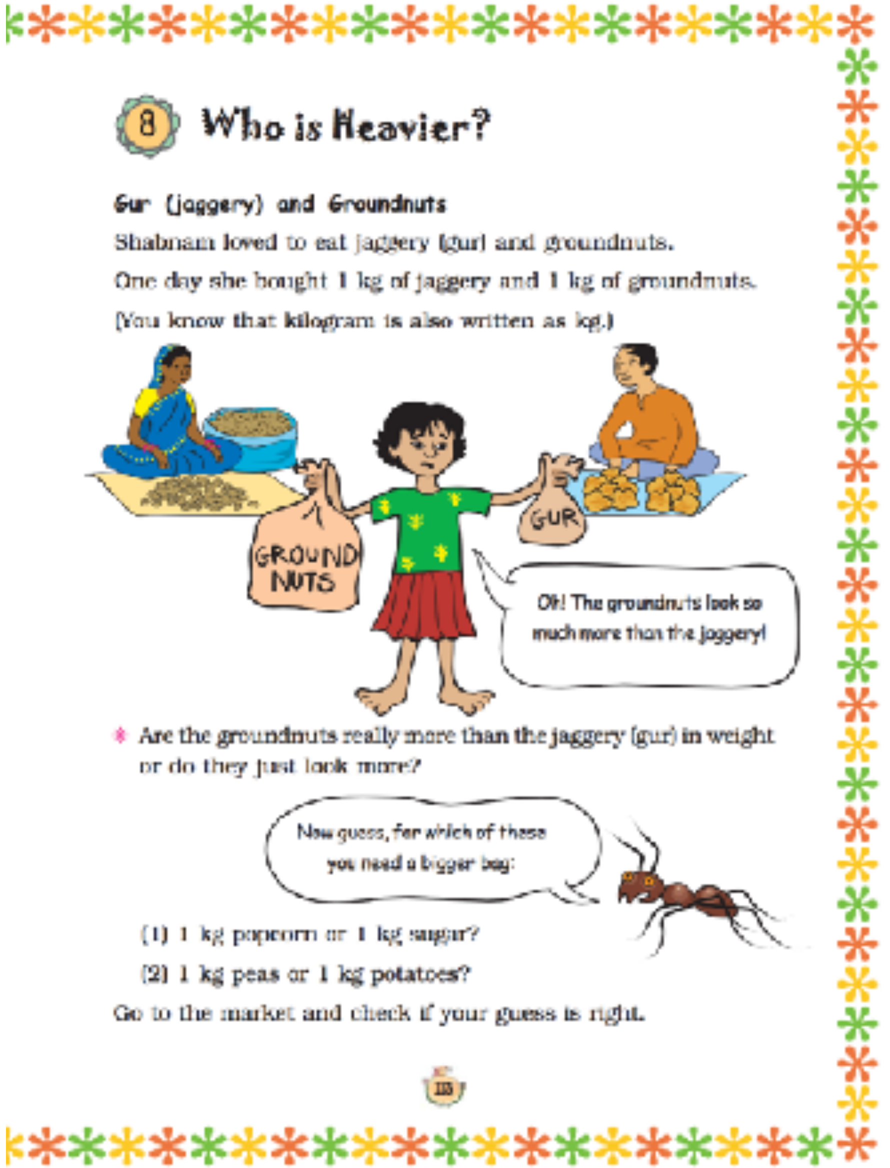


Figure 25: NCERT Math Textbook, class III [22]

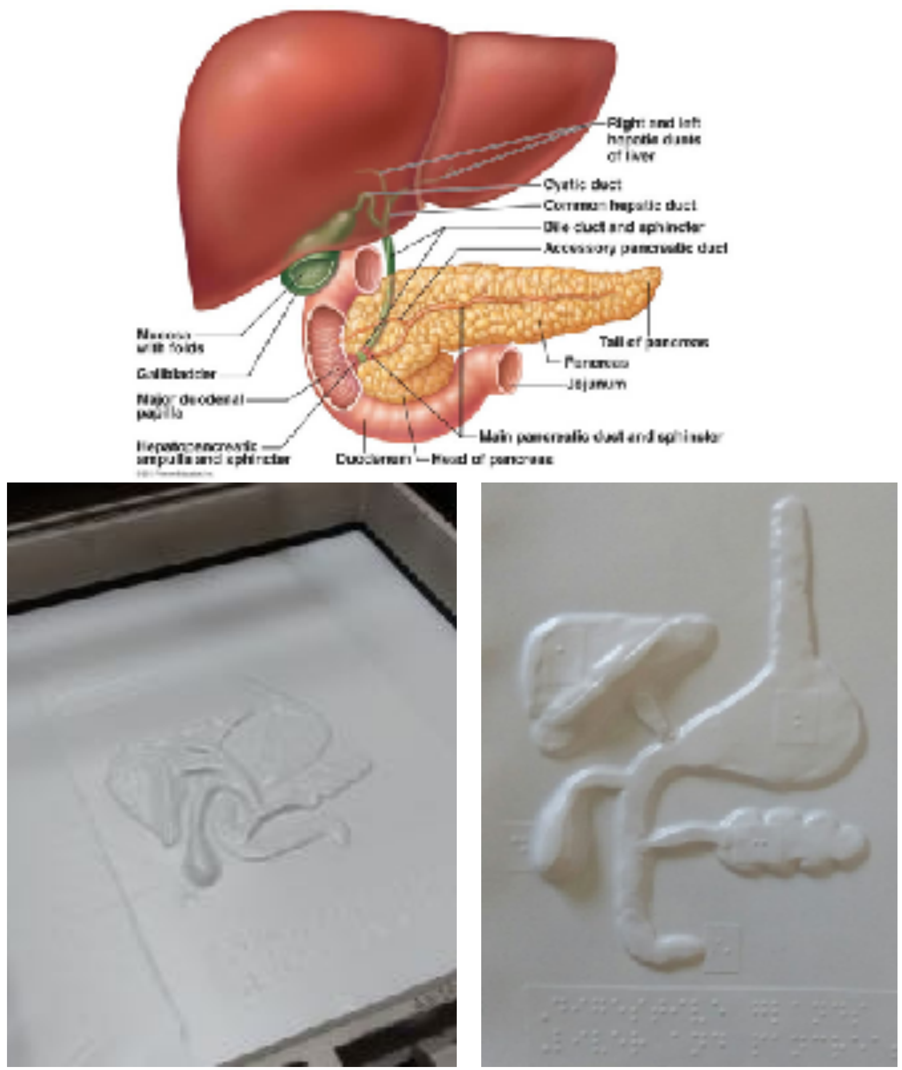


Figure 26: Iteration 1 & iteration 2, with parts separated more for clarity (image by author)

3.6 Primary Research

As part of a summer project with Xavier's Resource Centre for the Visually Challenged (XRCVC), I designed tactile graphics for production by thermoforming as it was a relatively new technique that XRCVC was trying to implement on a larger scale.

Design of TGs

Conversion of visuals in a textbook to tactile form is not a direct translation. Visual design principles need to be reevaluated for the tactile medium.

Guidelines by the Braille Authority of North America [23], a standard reference for design of tactile graphics is a good base to start with, but a many drawings require creative improvisation to be effectively translated to a tactile medium.

Overlapping elements, which may appear clear in visuals due to colour differentiation, are not very clear in the tactile form. Textbooks diagrams may needs to be modified, and this may be done in consultation with a trained special educator.

Reading TGs

Users prefer to explore the entire sheet to get an idea of its layout and contents before choosing to focus on a certain element.

The order of exploration depends on many aspects, such as level of familiarity, confidence, and an individual's learning style. While a few users prefer to read the key or annotations first before perusing the graphic, other explore the graphic before seeking the annotations as explanation.

> Design cannot assume a specific flow in which information will be accessed.

Annotations and Audio Labels

Detailed annotations must be avoided as the Braille text occupies too much space. Shortened keys is easy to miss or mistake as part of the tactile graphic. Clear bounding boxes help make it clear.

Sometimes the key or legend alone may occupy a disproportionate amount of space. TGs tend to be printed on higher grade material, which is also more expensive. This space cannot be wasted on elaborate braille labels. This is one of the basic reasons to have audio labels.

After having examined a section of the TG, users then need to find the legend, which may be on a different page, and locate the right label to access explanation to the graphic. There is a lot of friction in this process which can be solved by using audio labels, where explanatory information is available as the TG is being examined.

Learning, Discovery, Misconceptions

When a relief map of India was presented to adult users, think aloud tests revealed that they had many misconceptions about the country's terrain as they had learnt these facts through text alone. Even sighted users discovered facts that they had missed on a visual map of the terrain, emphasising the richness of the medium in effectively communicating complex data.

Many educational elements may be better experiences in 3D form if available, such as miniature animals, or anatomy of the heart. In math, however, tactile 2D medium is found to be essential. Whether it is geometry or basic arithmetic, learning is enhanced by the ability to spatially organise elements during concept-learning.

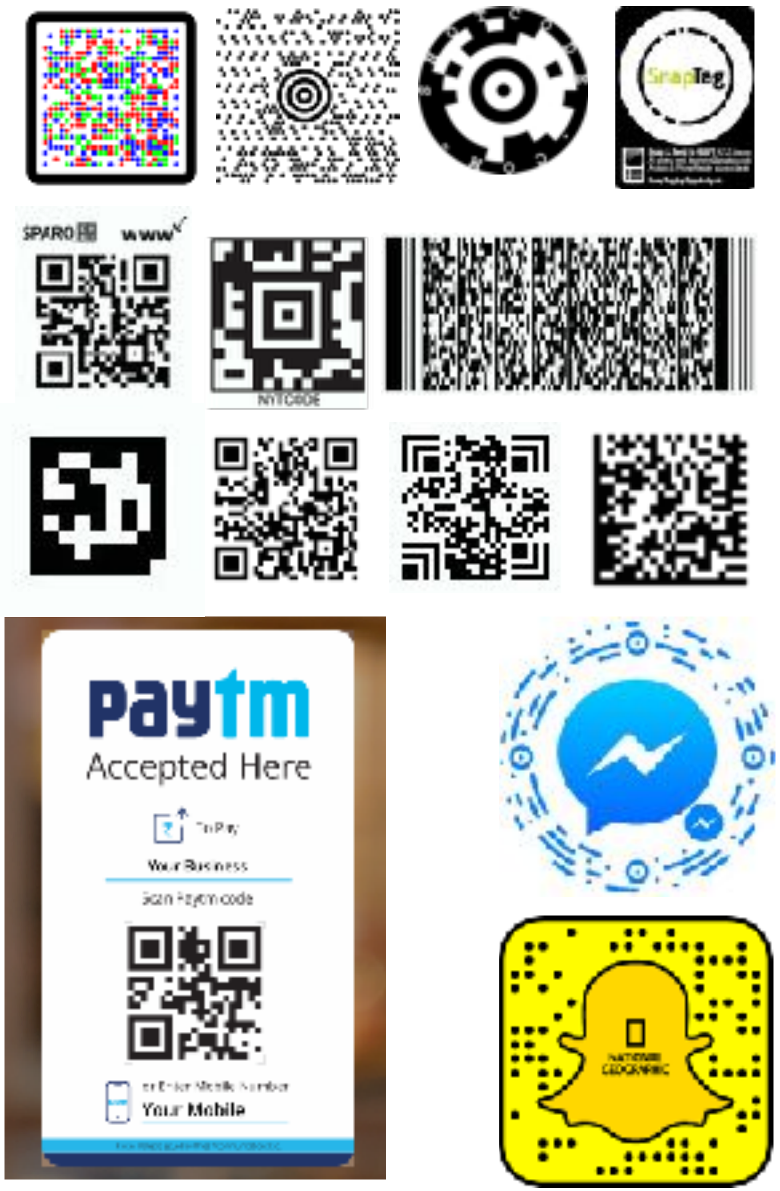


Figure 27: Different optical codes in use

4. Exploration

The objective of this design project being to add interactivity to tactile graphics in the most affordable way, all technological means are considered and evaluated in this section. Various sensors, information encoding methods and position tracking techniques may need to be combined to achieve this end. Four initial concepts have been described in detail, along with relevant literature.

Optical Codes

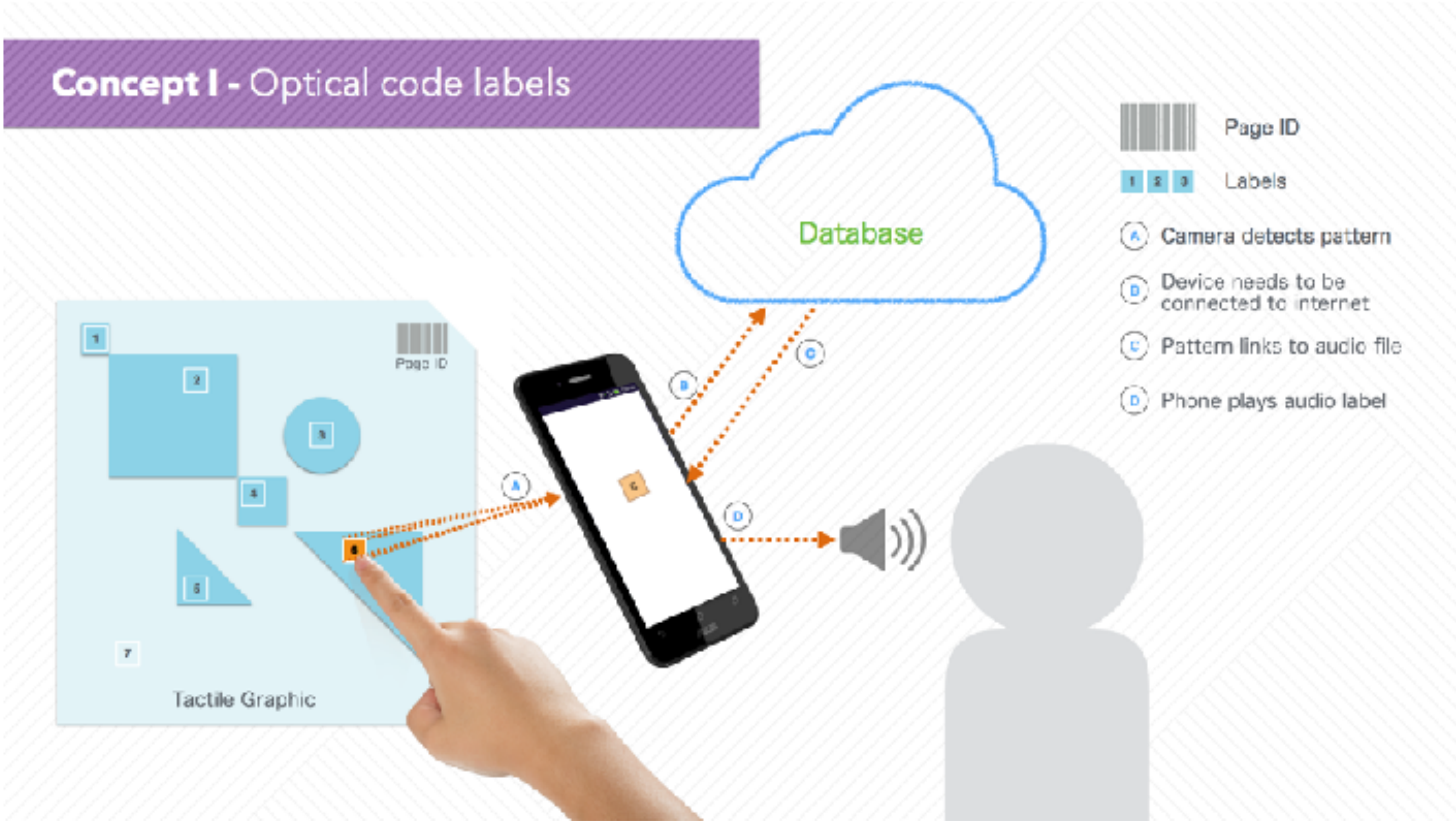
Optical codes such as QR codes can be used to encode information pertaining to different parts of tactile graphics, to be read by a phone camera. This is an affordable and practical alternative to sonic labellers with micro dot patterns, described under *3.2 Interactive Tactile Graphics*

QR codes have proven to be very useful in situations where human error can be expensive, like PayTM (mobile wallet) vendor ids. Novel applications include the use of optical identification pattern in social network applications such as Facebook and Snapchat.

With respect to application of optical encoding in tactile graphics for the blind, in a study conducted by University of Washington, it was found that this method cause a high error rate as the phone-camera cannot distinguish which QR code is selected when multiple codes occur within the same frame. Alternate solution that was not included in this study is to crop the image feed that will be processed, to narrow the range. Downside is it may cause difficulty in aiming the camera towards the intended QR code. [24]

Figure 1. The Tactile Graphics with a Voice system in use. The subject is using the finger pointing mode to select which QR code to scan.

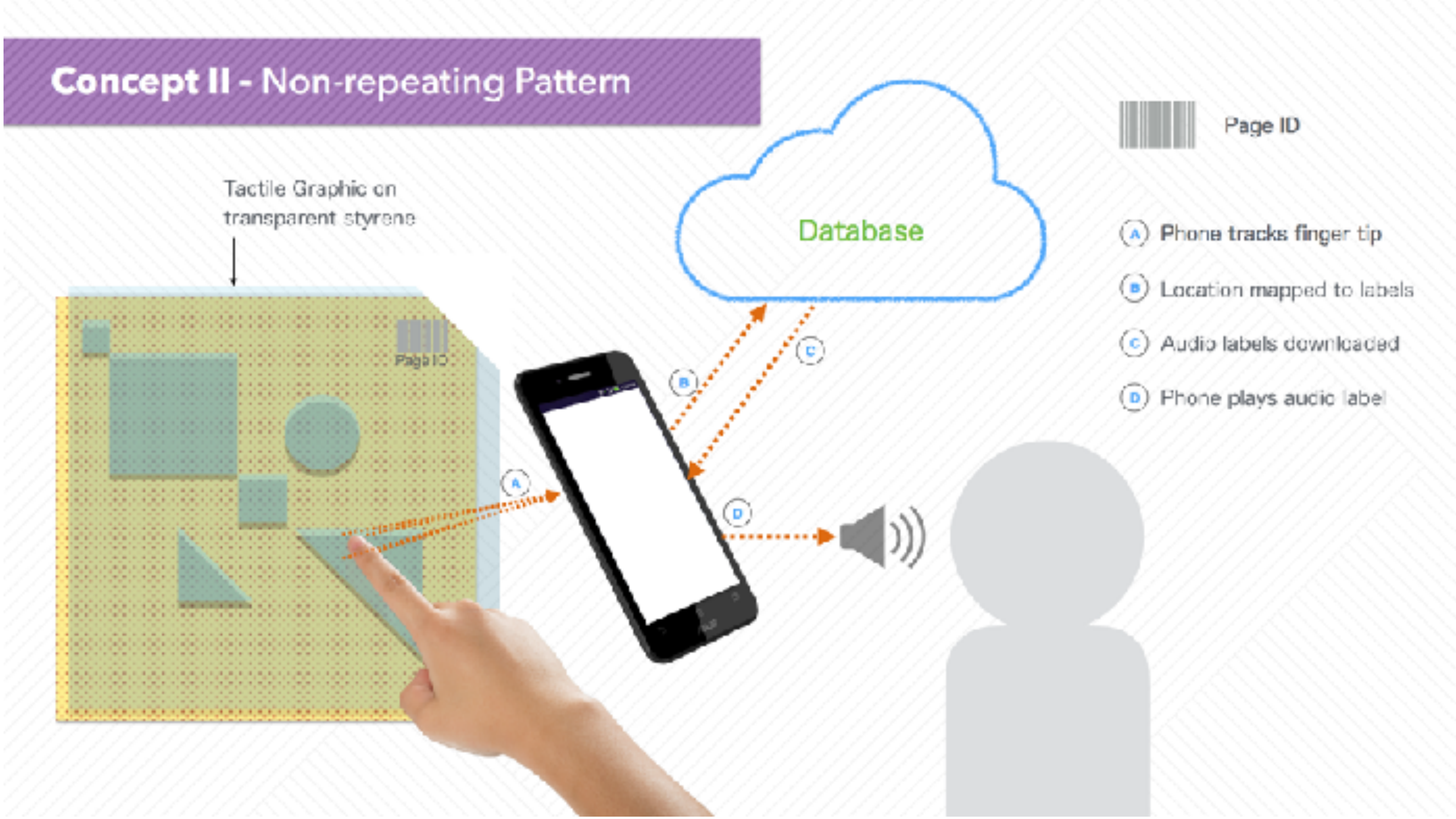
Figure 28: Tactile Graphics with a Voice: Using QR codes to access Text in Tactile Graphics [24]


Concept I - Optical code labels
Database
Page ID
Labels
Camera detects pattern
Device needs to be connected to internet
Pattern links to audio file
Phone plays audio label
Page ID
Tactile Graphic

Non-repeating pattern

Creating tactile relief on material that is pre-printed with a non-repeating pattern and using a camera to track users' hands across the graphic.

Limitations: camera needs to process the entire image from the video feed for position tracking, increasing processing load. Thermoforming or other processes of tactile graphic creation could distort the pattern.



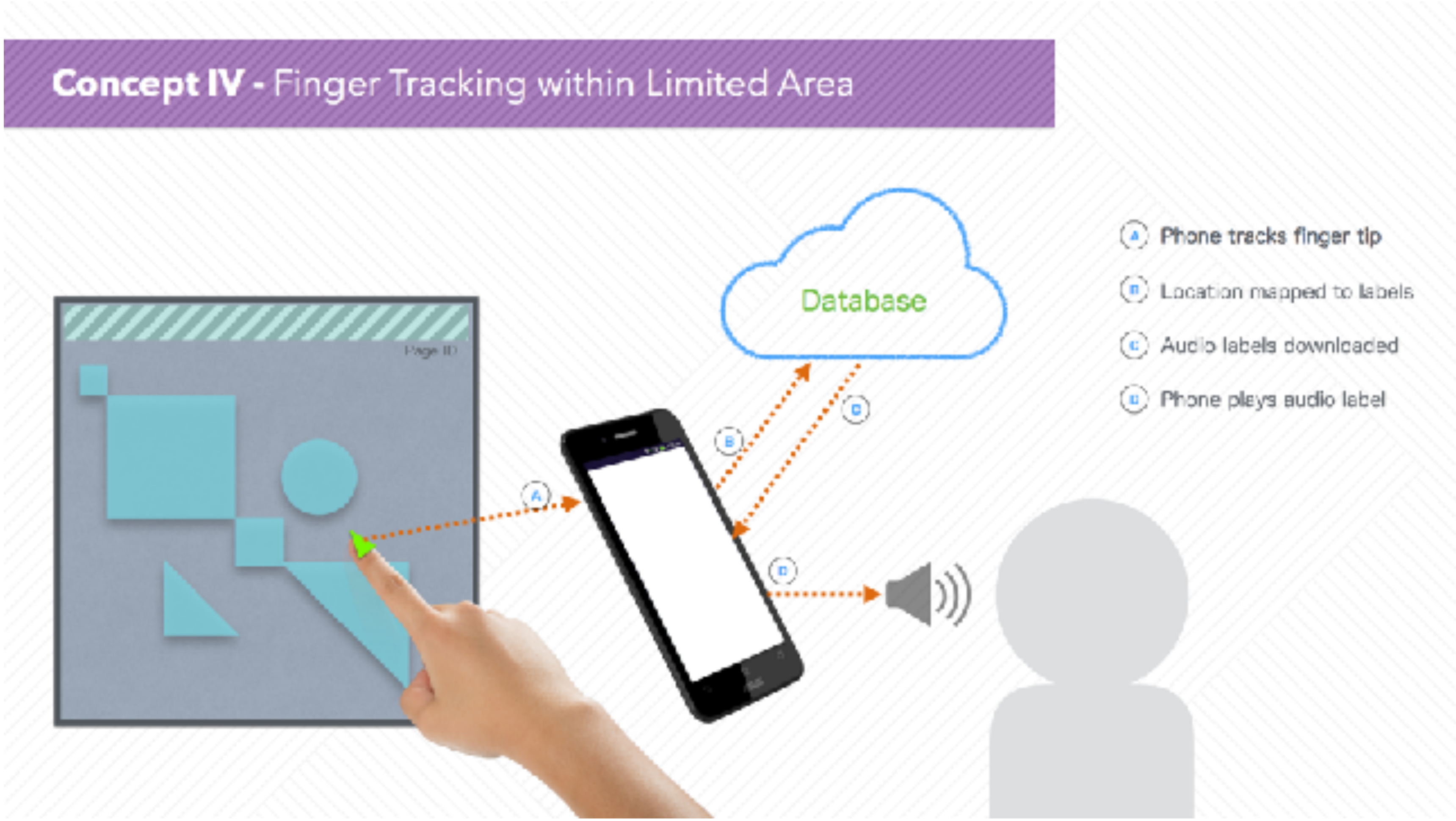
RFID Surface

Research on using battery-free RFID tags to make paper or any surface interactive illustrates considerable potential.

Figure 29: PaperID: A Technique for Drawing Functional Battery-Free Wireless Interfaces on Paper [26]

Finger tracking with fixed camera

This system uses a phone camera or a webcam attached to a computer to track finger position. The camera is mounted at a comfortable height above the tactile graphic, and the finger to be tracked needs to be marked with a specific colour. The system processes the page id in the form of a bar code of QR code, and tracks the finger tip using an HSV filter. The primary colour blue has the least interference, hence easy to detect.

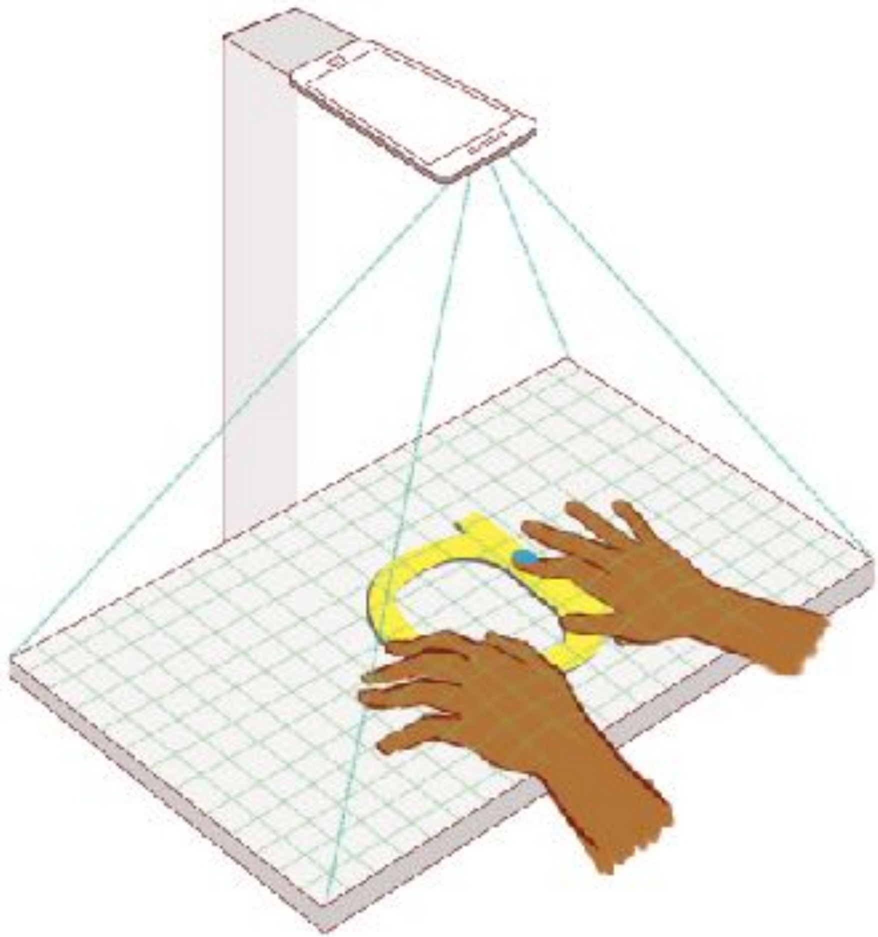


Analysis

Of the four designs discussed in this section, the fourth, namely ‘Finger Tracking with Fixed Camera’ is found to be the most affordable. It is currently conceptualised as a colour tracking system as it is essential to track the index finger as distinct from others. With advanced gesture processing, the finger marker may not be necessary if the system can identify the pointing or interacting finger directly.

To explore the possibilities of this method, I will be using Processing as a platform. Current unknowns, such as size of marker, colour that is easiest to distinguish, size of tactile graphic, height at which camera is to be mounted, size of detached elements, smallest detected movement, easy to perform gestures, etc. will be derived by trying out different configurations.

Foreseeable limitation of this method is the inability to distinguish between hover and touch. It will require a specific gesture to activate an item, as compared to the RFID system, where a direct touch would have been possible.



5. Redefining Objective & Scope With Finger Tracking Method

Components required:

- Smart phone with camera or computer with USB webcam
- Data
- Headphones
- Stickers/markers for finger
- Stand for phone with adjustable height
- Tactile Graphic

Redefined Objective:

With this system, the possibilities for interaction are far more than simply accessing labels. More educational requirements can be met by designing content in this medium. The revised objective is *to design a framework of interactivity within this novel interactive medium, by creating interaction primitives that act as building blocks for more complex applications.*

Scope:

The project started out to solve the problem of interactivity in the filed of education, but the grammar of the medium can be tested independent of content. To understand the primitives better, they can be evaluated with blind users of any age group.

6. Framework of Interactivity

Modality:

Modality of input and output are strictly defined, and use different sensory aspects. Input is by finger movement alone. Voice input is an option, but environments are not guaranteed to be conducive. Output from the phone or processing system is in the audio channel only as the tactile graphic cannot live update in response to input.

Interaction Primitives

Labelled — elements on the tactile graphic are given short labels that are spoken when touched. This interaction is henceforth referred to as *hover,* and the information it accesses is called a short *label*.

Described — apart from the short label, a longer description is made available on call. The method to access it is by an explicit action, such as a gesture. This interaction will be referred to as *expand* and the information it calls is the *description*.

Buttons — selectable elements that perform an action.

Input fields — for more complex interactions, users will be required to input data. These containers are referred to as fields. They may be numbers, text or boolean fields- checkboxes and radio buttons.

Page level controls — a standardised panel containing controls pertaining to the entire page, such as home, title, reset, start, stop, change mode, etc.

Framework of Interactive Elements, Gestures and Audio Output

Element	Description	Interaction	Output
Labelled	Elements that have only a label and no further interaction	hover	short label, less than 2 seconds
Described	Additional details available	hover	short label followed by ping
		circle gesture (expand)	start detailed description
		anticlockwise circle	stop detailed description
Button	Selectable Action	Hover	short label followed by higher pitch ping
		circle gesture (expand)	details- action that the button performs
		anticlockwise circle	stop details
		triangle	select
		anticlockwise triangle	deselect if applicable
Input (field)	Number: One digit per blank field	hover	label
		circle gesture (expand)	description + instruction on input method
		anti-circle	stop description
		triangle	engage/select
		caret ^	scroll up options
		inverted caret	scroll down options

Element	Description	Interaction	Output
		triangle when value has been selected	value accepted
	Alphabet: One character per blank field	hover	label
		circle gesture (expand)	description + instruction on input method
		anti-circle	stop description
		triangle	engage/select
		triangle	when value has been selected, "*value* accepted"
	Check Boxes and Radio Buttons	hover	label + selected(
		circle gesture (expand)	description + instruction on input method/ selection status
		anti-circle	stop description
		triangle	engage/select
		anticlockwise triangle	deselect
Home		hover	title + ping
		circle gesture (expand)	description, instructions for page
		anti-circle	stop description
Pause		hover	pause
		circle/triangle	"page paused. Reset or re-circle to resume"
		anti-circle	stop description

Element	Description	Interaction	Output
Reset		Hover	reset
		circle/triangle	“Page has been reset. You may start over”
		anti-circle	stop description

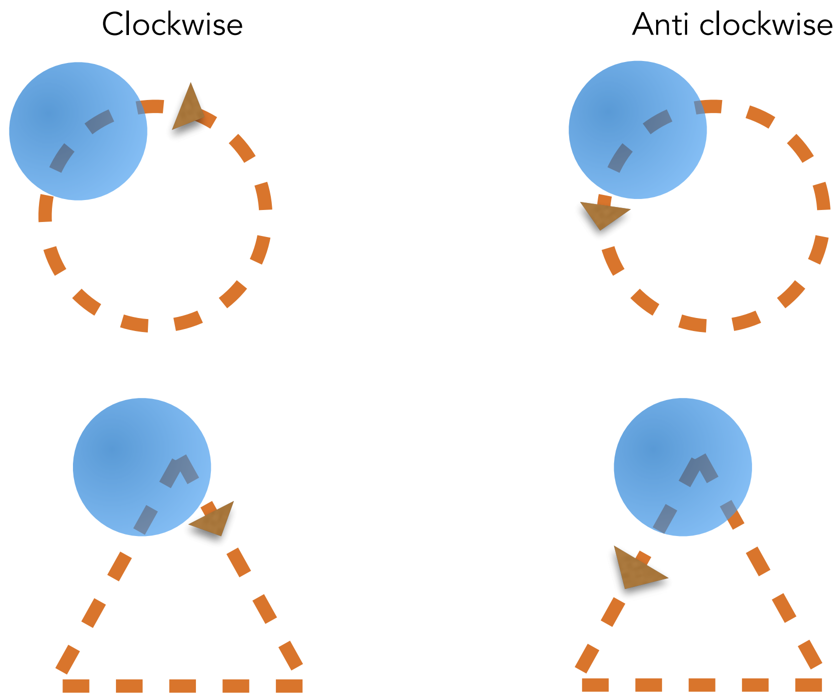


Figure 30: Basic Gestures

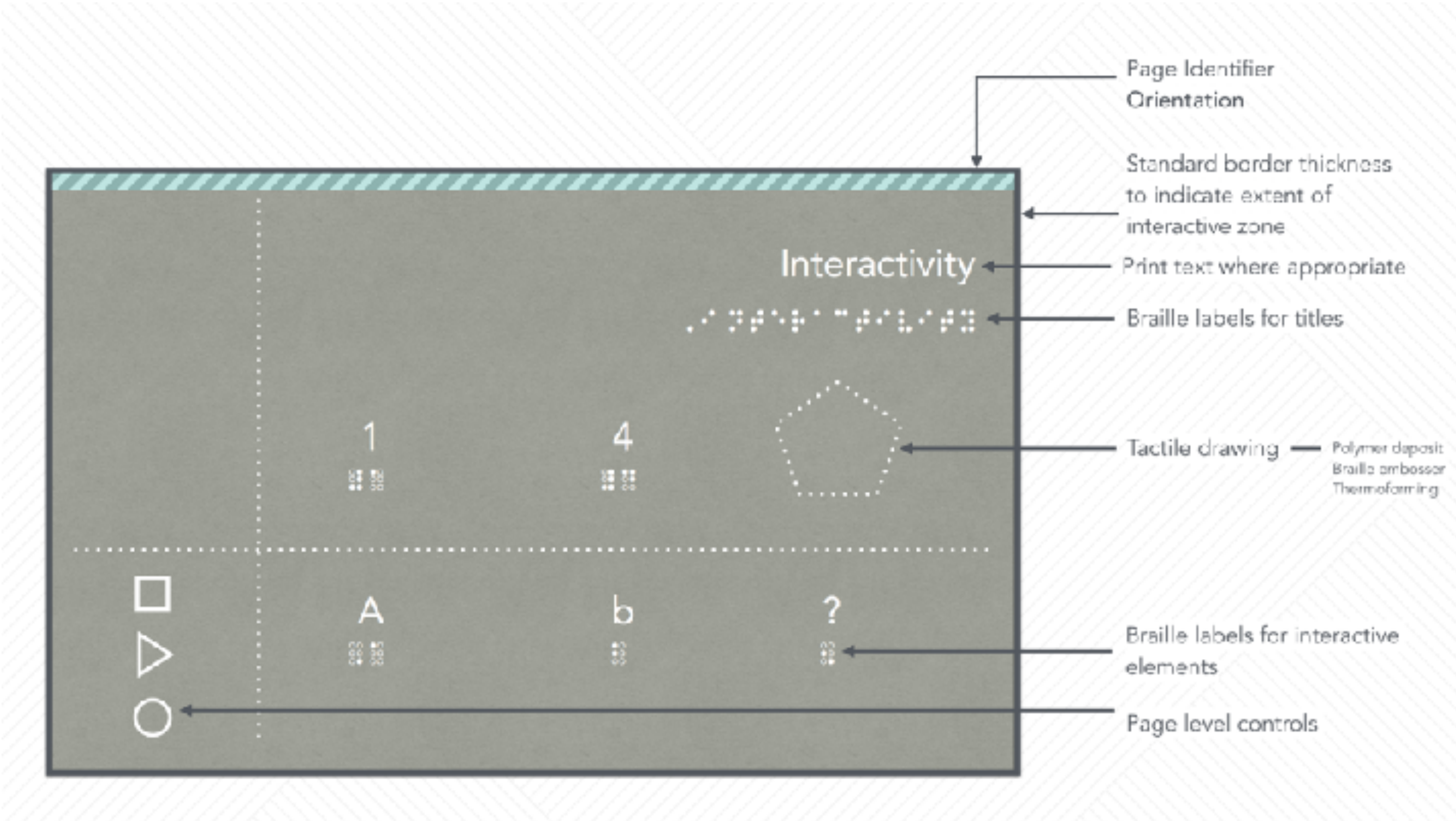


Figure 31: Typical page components

Complex Components

Using the interaction primitives, more complex elements can be created. Ex: number pad, text-keypad, multiple choice questions, etc.

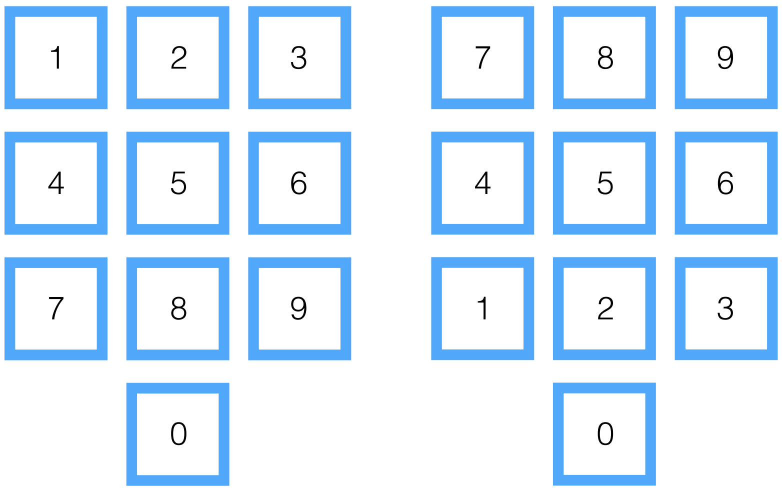


Figure 32: Number pad, phone and calculator style

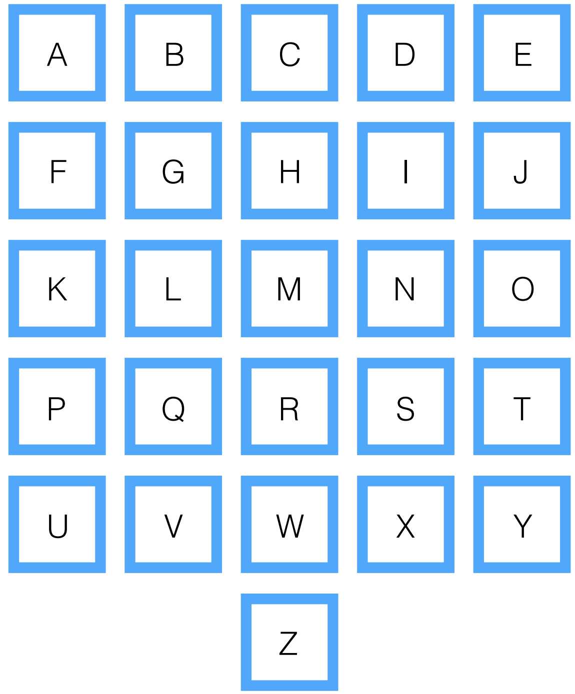


Figure 33: Alphabet pad, for early stage learning, where sequential arrangement is required.

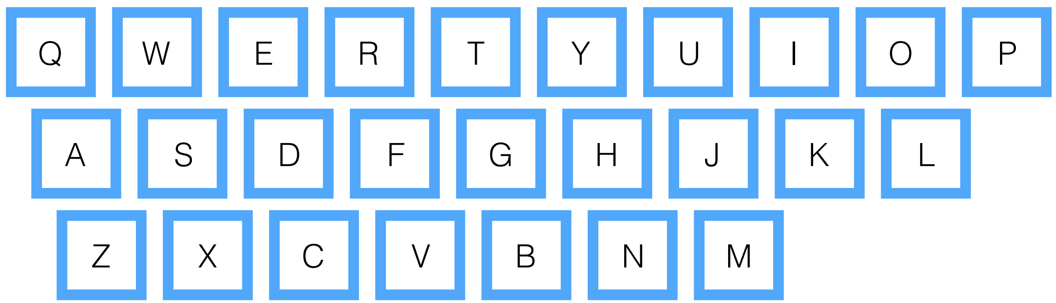


Figure 34: QWERTY layout for advanced users.

Multiple choice question set:

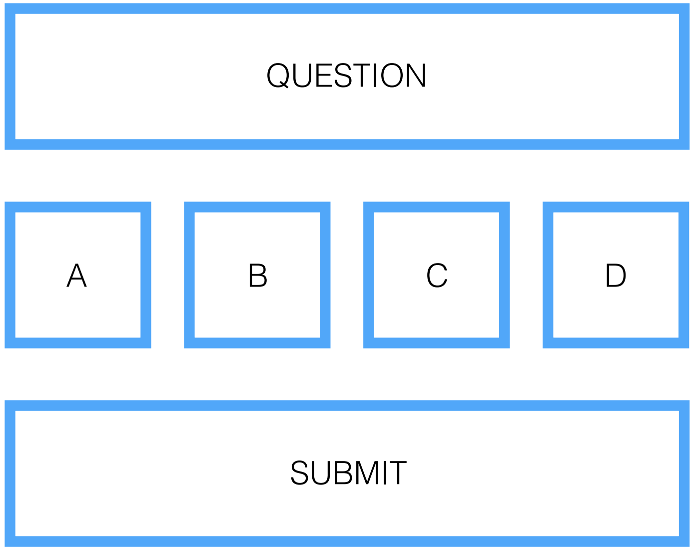


Figure 35:

In this standard format of elements for a multiple choice question, a user chooses between answer choices A, B, C and D and then selects 'submit' to enter or check answer. The same can be made with radio buttons or checkboxes depending on nature of question.

The next example illustrates an aptitude question which involves shapes, pattern recognition and visualisation to solve.

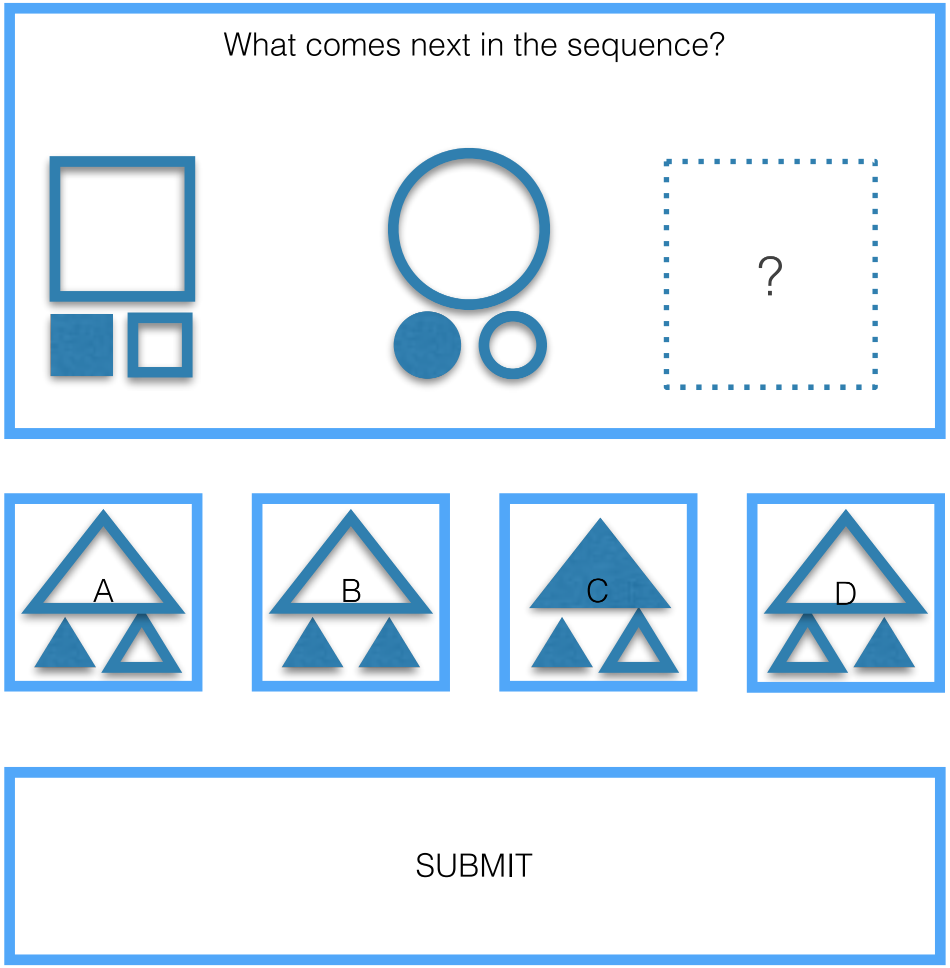
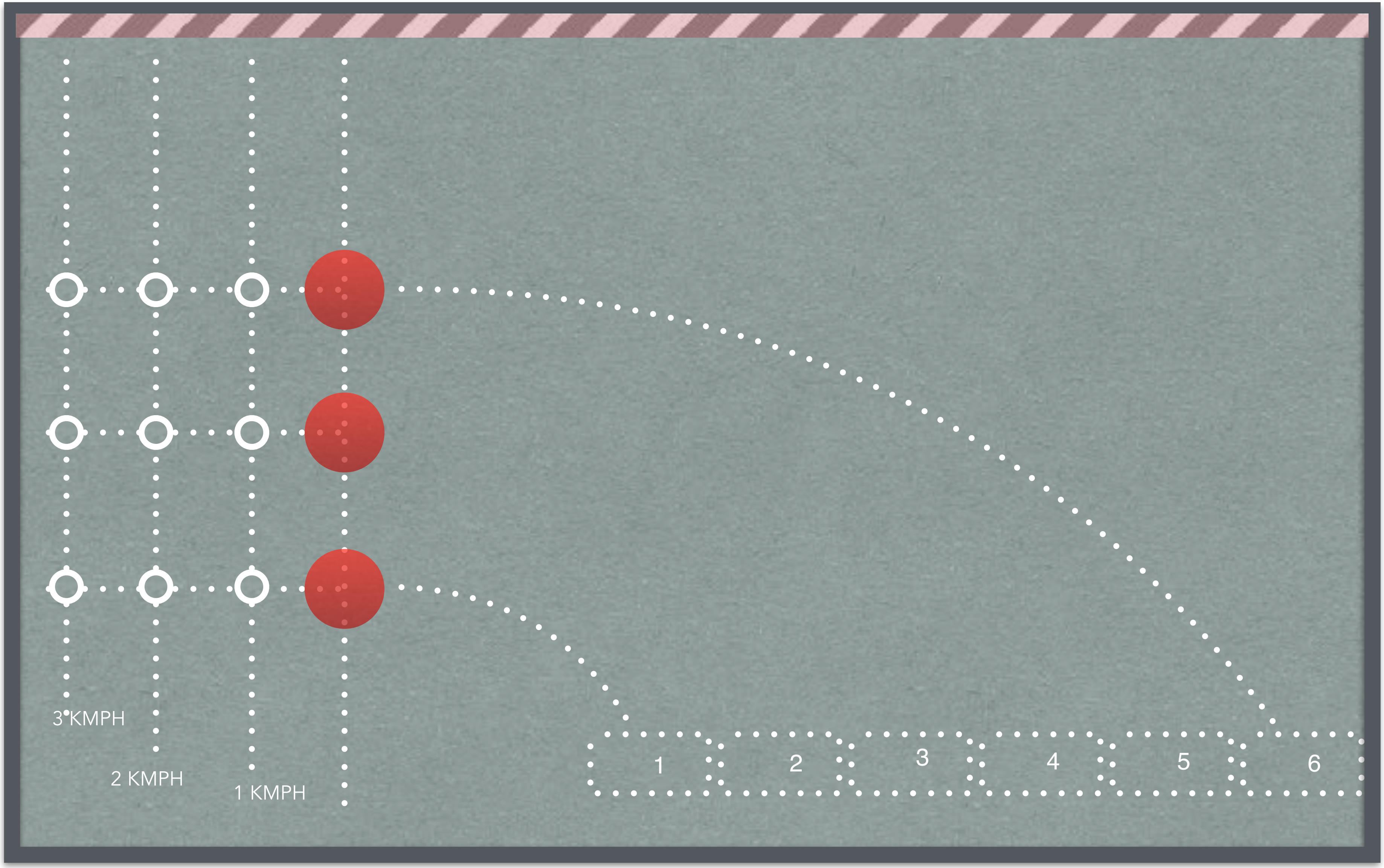
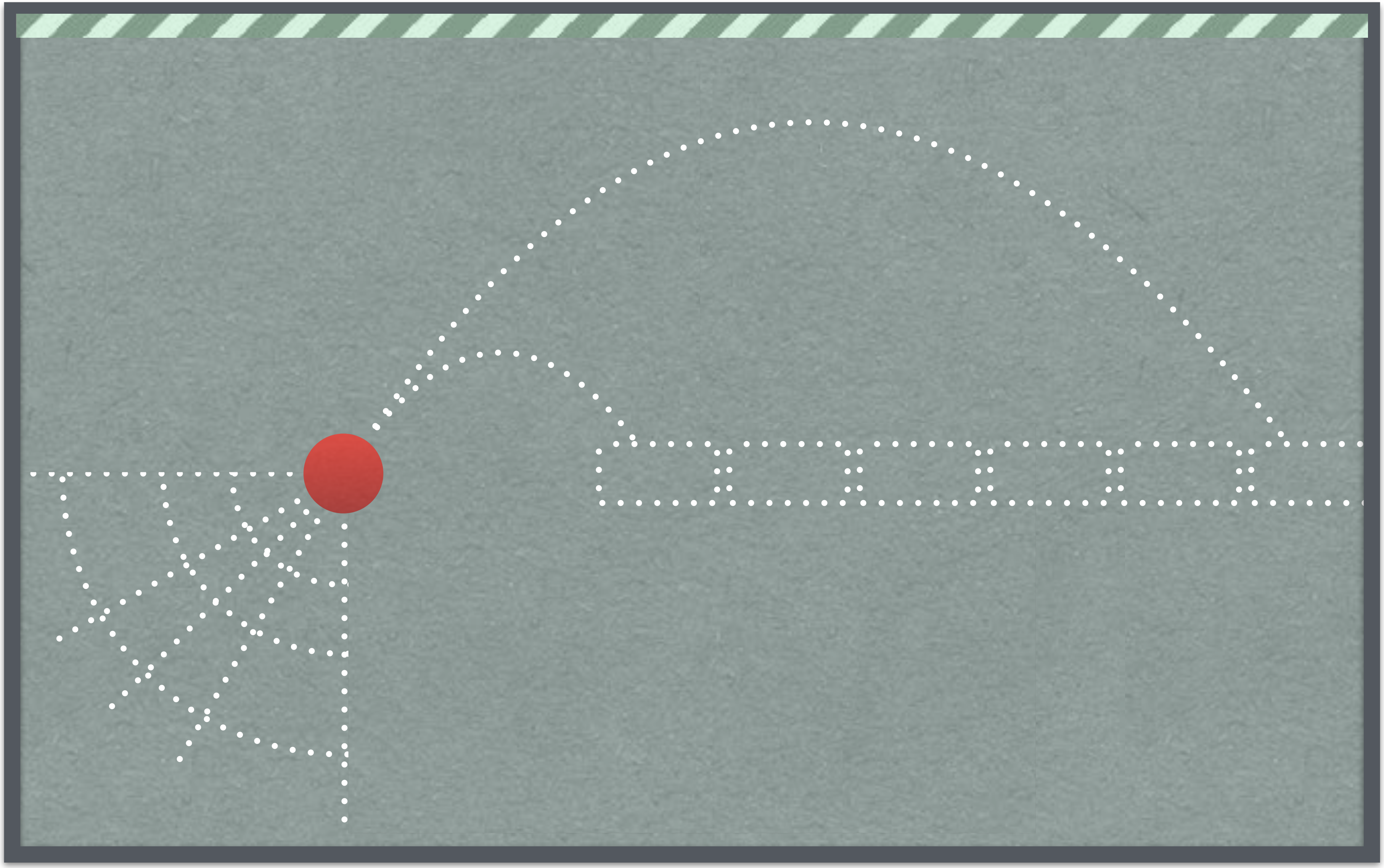


Figure 36: graphic aptitude questions



Game interaction for learning:

The concept of projectile motion can be taught experientially using this method, where users can



select the slot from which the ball is to be set off. With respect to the original location of the ball, as indicated, an audio representation of the projectile motion is generated and feedback is provided as to where the ball landed. If it was off target (specified by system) then user can retry with a different launch point. The audio representation can be derived from NASA's Mathtrax software [25], that conceptualises graphs in dramatic audio tracks, and makes for a more engaging learning experience in the absence of sight.

Whether it is in the skin of Angry Birds, or other game concepts, this medium can be adapted to create base boards on which games can be played. In larger formats, multi-player games and interactions can also be designed.

Figure 37: Projectile motion teaching aid

Figure 38: Projectile motion with angles

7. Evaluation

Simple tasks are designed using the primitives designed for this medium. Task completion and think out loud evaluation is conducted with blind users.

Lighting conditions have an impact on the quality of tracking. Calibration options are available, but it is found that when daylight is inconsistent, or if there are shadows, performance becomes erratic. Steady and uniform light makes tracking much more accurate.

Size of marker: When lighting conditions are inconsistent, a larger marker compensates the tracking errors. However, that reduces accuracy of gesture detection within smaller regions. The ideal size of marker under the right lighting conditions is found to be 10mm x 10mm, which is about the same size as a fingernail.

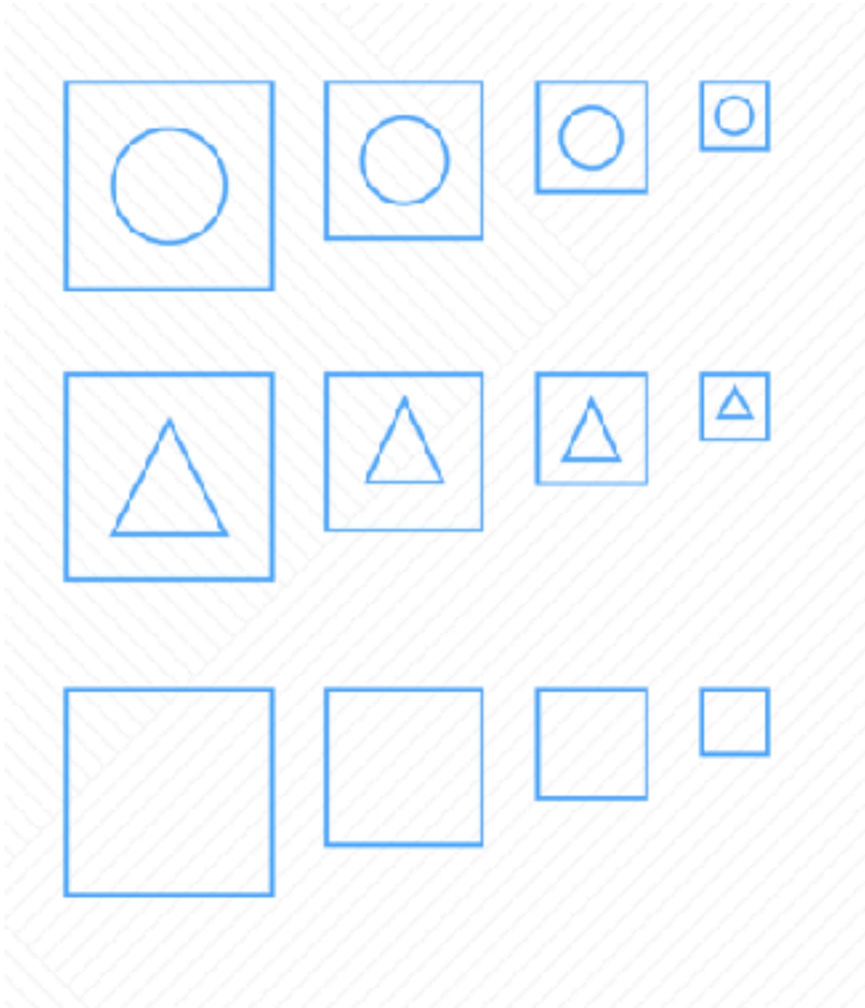
Reducing the marker size further may not deliver any benefits because the finger size is the limiting resolution.

Three tactile graphics were created for the purpose of user testing and evaluations.

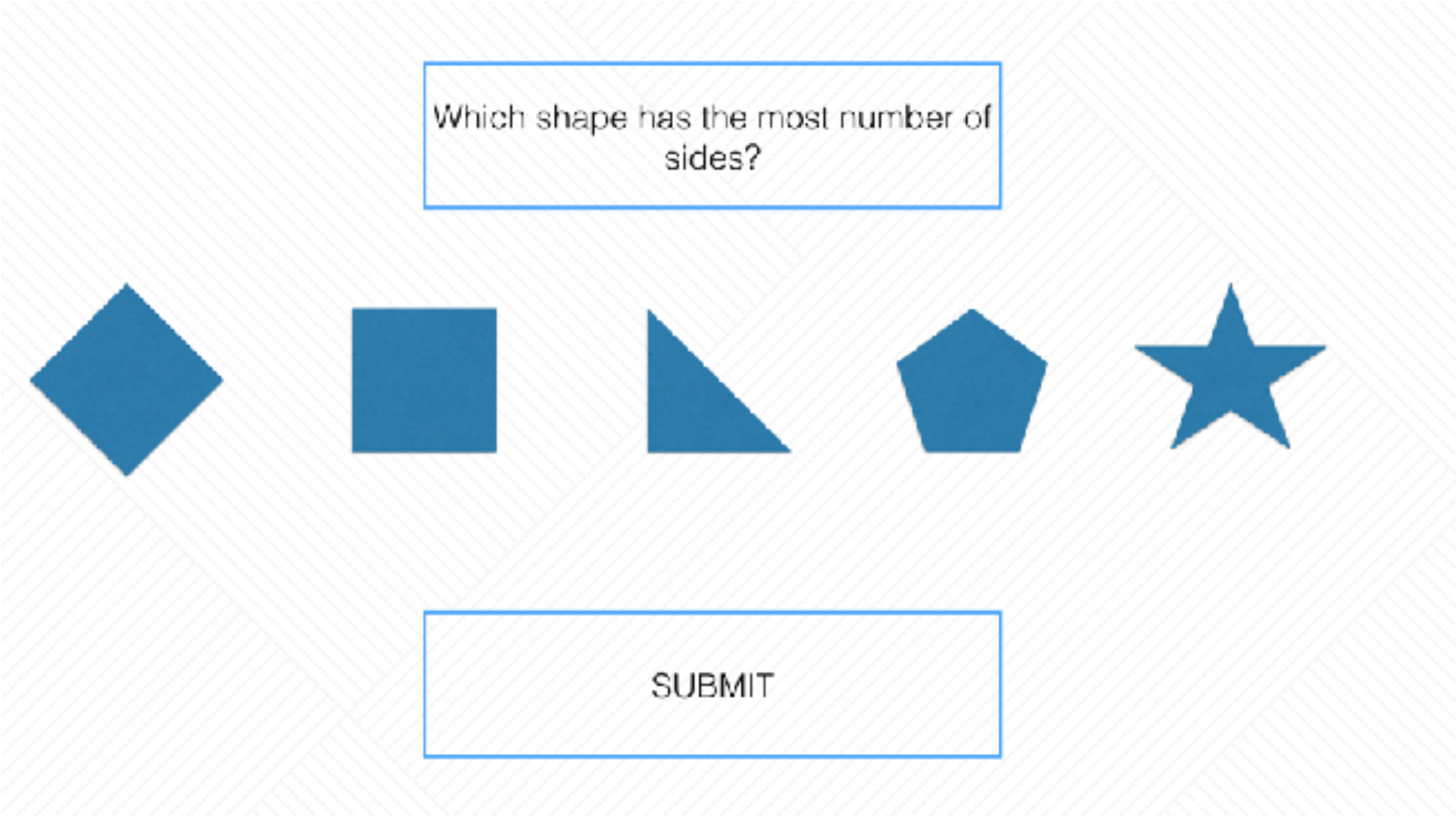
TG1: To test the ease of learning and performing the circle and triangle gestures, a TG is created with guides as well as blank boxes. The number of attempts before a user gets the gesture right is counted and recorded (table 2)

TG2: A simple multiple choice question is provided, where the learned gestures are used to read a question, select the correct answer and click submit.

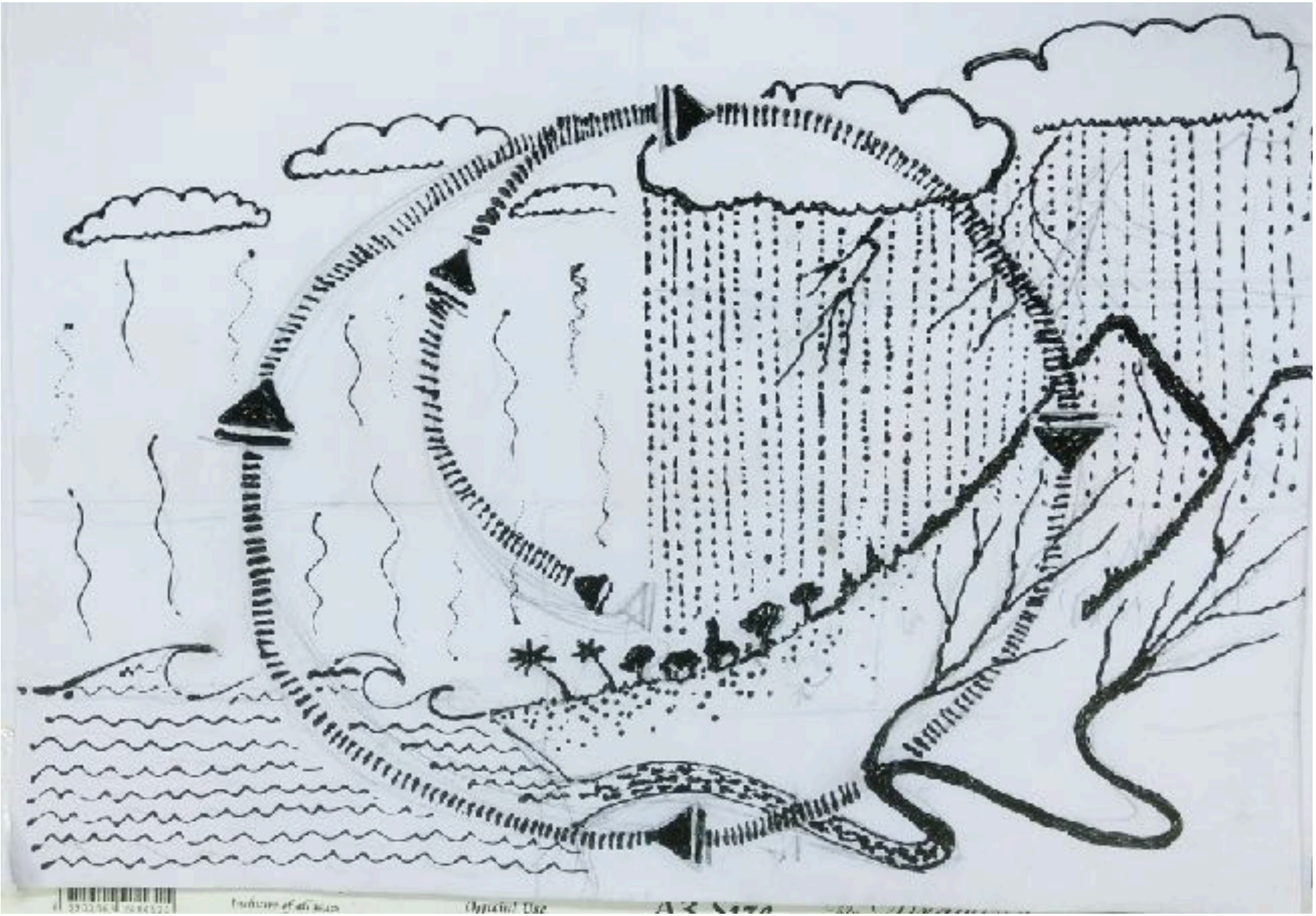
TG3: A tactile representation of the water-cycle is created with relevant audio effects and additional descriptive information.



TG1: Row 1- bounding boxes with circle guide; Row 2- bounding boxes with triangle guide; Row 3- blank boxes where users were asked to repeat circle and triangle gestures



TG2: example of question



TG3: water cycle as a tactile graphic with overlaid audio effects and audio descriptions

8. Findings

TG1- gesture evaluation and bounding box sizes

Quantitative data from TG1 are presented in table 2. Four sizes of bounding boxes were provided:

A- 60mm × 60mm

B- 45mm × 45mm

C- 30mm × 30mm

D- 15mm × 15mm

Of the four sizes, A is the most comfortable size for performing gestures, but since it was the very first time users were trying it, the number of attempts is quite high. The reason is that the instruction "*draw* a circle/triangle" makes them lift their hand and draw as if the finger tip were a pen. When the finger's lifted, the colour marker goes out of the camera's view and gestures go undetected. This is corrected with feedback by the person administering the test, in this case, author.

A noticeable drop in number of attempts is noticed in box size B, which is a result of the familiarity obtained from completing 6 gestures successfully in box size A.

In box size C, difficulty is observed due to decreased size and box D has proven too small for accurately drawing gestures.

The exact and optimal limiting dimensions can be further investigated with more box sizes in between, such as 30mm, 35mm, 40mm,… but the need for a bounding box itself can be questioned at this point, considering the large area required to draw the gesture with the human finger-tip. It might be a more effective to detect only the starting point of the gesture to provide audio feedback, and the gesture could be drawn in any size comfortable for the user.

The difference between circle and triangle or anti-clockwise gestures is not noticeable. This may be more clear after performing evaluations with more number of users.

Size of bounding box	User 1: 18, M				User 2: 14, F				User 3: 45, M				User 4: 32,M			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Trace Circle	3	2	3	6-	2	2	2	0-	5	1	7	0-	3	1	4	0-
Trace Triangle	2	0	2	4-	4	2	3	0-	4	3	3	0-	2	3	2	0-
Draw Circle or Triangle	3	0	3	0-	4	1	3	0-	5	2	5	0-	3	2	4	0-
Trace Anti-circle	1	0	2	3-	2	1	2	0-	2	2	4	0-	1	1	3	0-
Trace Anti-triangle	0	0	2	3-	1	1	2	0-	2	1	3	0-	3	2	3	0-
Draw Anti-circle or Triangle	2	0	1	0-	4	3	4	0-	3	0	4	0-	1	3	1	0-

Table 2: Number of attempts before completing the gesture within bounding boxes of sizes A, B, C and D (#- number of attempts before giving up)

TG2- multiple choice question

Users were asked to explore the tactile graphic without any instructions except that the circle gesture can be used to access a description. All instructions are available in the program, and the correct answer is also encoded.

There was relative ease in understanding the task and answering the question. In this case, the bounding box is not a raised line, but the entire surface itself.

TG3- water cycle

Touching different zones of the water cycle depiction trigger different audio effects, such as sound of running water for rivers, sound of waves for the sea, sound of thunder for rainclouds, etc. Upon drawing the circle gesture, additional descriptions are provided, detailing the process.

In this case, the bounding boxes of different zones are not actually indicated in the tactile form, but exist in code alone. This cause some amount of confusion, where the finger moves out of the zone while performing the circle gesture. This can be solved by the workaround mentioned earlier, i.e., to provide feedback based only upon the starting point of the gesture.

Findings:

Gestures: The gestures were found to be easy to perform once familiarised, and the functions of each gesture is also fairly well understood by the users.

Element size: in the current design, the area in which the gesture is performed dictates the action. Evaluation has exposed that his model could cause limitations in design of tactile graphics. This needs to be reworked to detect only the starting point. This way, typical finger-tip size of 10mm × 10mm could be the minimum element size. This still needs to be verified via testing.

Information: It was noticed that when the first word (or first few words) of the description were the same, users quickly decide that they must have accessed the same description twice. The second time the same word is heard, the audio is discontinued even though the following text is completely different. Labels and first words of descriptions need to be assigned uniquely or identified clearly to avoid confusion.

Age: In the next stage, users of age group 7-12 need to be tested with, as they are likely to behave very differently from the adults who participated in the first round of evaluations.

9. Future Work and Development

If all of the NCERT educational content is designed in this medium using a fixed camera and inexpensively produced tactile graphics, cost of educational material for blind children could be brought down by simply reducing the amount of braille printed textbooks to be purchased.

The next task to take this forward is the content creation interface for special educators. Massive amounts of content needs to be converted from visual to interactive-tactile form.

When simple concepts are presented in an enriched, multi-media format, it becomes appealing and more engaging for sighted children as well. Keeping with principles of universal and inclusive design, content must be developed for a wider user group in the long run.

Applications of this system extend beyond education and can be applied in public spaces, transit locations, offices, restaurants, etc. where information access is currently a challenge.

Data visualisations is another area that has been developed highly for sight, but not many alternatives exist for other senses. Complex data sets may find novel expressions in this medium that enrich the experience for sighted users as well.

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