Situating assistive technology for sustained diagram comprehension in learning spaces: Case study of Iris-Antara solution for children with visual impairments

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Abstract

Children with visual impairment in India face significant challenges while studying STEM subjects. Mainly, teaching and learning concepts that involve visual materials have been a matter of challenge for teachers and students. This paper reports preliminary insights from the design, development, and implementation of a solution that augments the physical tactile picture or model with digital auditory inputs for the children along with a scalable cloud-based content management system. The Iris-Antara assistive technology solution for diagram comprehension makes self-paced, independent, diagram comprehension in their preferred language possible for CVI. Teachers can integrate Iris into their lesson plans by uploading diagram descriptions on the cloud platform. Together, this solution provides a powerful tool for teachers, students, and caregivers to engage in sustained learning in various spaces that can build their confidence to choose STEM subjects in higher classes as well. Our preliminary findings show an enthusiastic and positive response from both teachers and students for more physical tactile materials and curated audio content. This solution also highlights the need and potential for the convergence of members of industry, academia, and grassroots-level organizations in creating impactful innovations for the challenges in the accessibility domain.

CCS Concepts

• **Human-centered computing** → **Accessibility**.

Keywords

children with visual impairments, diagram comprehension, assistive technology

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1 Introduction

India has over 1.1 million school-age children (5-19 years) who are visually impaired (CVI). However, only 68% of these children are enrolled in school [5]. As a signatory to the UN Convention on the Rights of Persons with Disabilities, India is committed to Sustainable Development Goal 4, which promotes inclusive and quality education [15]. Policy efforts like Section 31 of the 2016 Rights of People with Disabilities (RPWD) Act mandate education for children with disabilities [10]. Additionally, the 2020 National Education Policy (NEP) recommends reasonable accommodations, such as audio textbooks, to support visually impaired students. [14].

Despite many initiatives, a gap remains between policy and practice, especially in providing accessible resources like textbooks. For children with visual impairments, textbooks need to be available in Braille. However, books for sighted children cannot be fully converted into Braille. While text and tables can be printed in Braille, elements like labeled pictures, equations, graphs, and exercises are difficult to reproduce with standard Braille embossers. As a result, much of the curriculum remains inaccessible to children with visual impairments. As an alternative to Braille, leveraging the audio based learning and recognizing the need for accessible textbook content, the government of India launched Digital Infrastructure for Knowledge Sharing (DIKSHA) - an online WCAG-compliant portal that provided textbook content in various accessible formats such as EPUB, PDF, and HTML5. The DIKSHA platform hosts over 3400+ audio textbook chapters, enabling effective learning for CVI using assistive technology solutions such as screen readers and DAISY audio players [16]. However visual components of the curriculum, such as diagrams, graphs, and figures still remain inaccessible [22]. The alternative texts provided as a part of the description of scientific diagrams and graphs are necessary but not sufficient for learning. The inaccessibility of textbooks disproportionately affects STEM learning as the instructional strategies for science and maths subjects heavily rely on visual media such as charts, graphs, and diagrams [12]. In the absence of appropriate accommodations, students with visual impairment find it challenging to learn scientific concepts [7].

Some of the recent advances in technology offer a promising solution in the form of a remediated textbook with tactile diagrams. For example, the Department of Education in Science and Mathematics (DESM) of the National Council of Educational Research and Training (NCERT) collaborated with the Raised Line Foundation (RLF), a non-profit organization to develop additional tactile diagram books for school students with visual impairment [21]. The tactile books thus produced have curricular diagrams with thermal embossing and Braille Labels following the BANA guidelines. While these tactile diagram books are a huge step in the positive direction, the impact of such textbook-based interventions may be limited due to other constraints. Besides the revisions in the textbooks may render previous versions outdated, and the need for integrating different languages makes it a high-cost affair. Thus, there is a need to develop interventions that augment textbook-based learning with other solutions in the context of diverse linguistic settings such as that of India.

While sole textbook-based learning is fraught with challenges, teachers have been using alternate approaches for teaching visual diagrams involving tactile graphics. This includes the use of 2.5D, 3D diagrams, Do-It-Yourself (DIY) tactile models. Prior research has explored the use of such tactile graphics in classroom settings. Aldrich and Sheppard [1] conducted multiple studies to uncover the perception of students and teachers towards tactile graphics. The finding revealed that, while the young learners enjoyed learning math concepts (such as geometry) through tactile diagrams and models [1]; teachers were overwhelmed by the time-consuming process of tactile diagram creation and the ensuing instructional practice of repeating long descriptions related to the concepts to the students [18]. Additionally, in the case of special schools for the CVI, a vast majority of educators themselves are visually impaired and are unable to leverage such processes for teaching.

Another potential solution to augment teachers' instruction practices is through the use of audio information. Voice is an effective medium in substituting vision. Prior studies have explored technology solutions that use audio to understand tactile graphics [2, 11, 19, 20]. Baker et. al [2] developed a software application that scanned QR codes to guide visually impaired users to aim the camera as they navigate the textbook figures and read-aloud audio descriptions of the figures. Extending this beyond the textbooks, Li et. al [19, 20], developed prototypes to augment the 3D printed models with audio annotations using an application through gestures and voice commands.

While these solutions offer promising prospects for the task of tactile graphics comprehension. The socio-technical context of special schools in India is in stark contrast to that in the Global North, where many such solutions have been emergent. Firstly, despite the rapid uptake of digital technologies and online use, the penetration in rural India remains slow with online learning being unpopular among rural India [6]. When the pandemic impacted physical learning, educators of CVI had to be provided special training to orient them to use digital tools for teaching online to keep learning sustained [4]. The idea of using the internet and digital resources for classroom learning is a fairly recent phenomenon in special schools whose infrastructure is marked by limited internet connectivity [9]. In the absence of the internet, teachers and students have limited exposure to accessible teaching and learning materials [5]. Additionally, special educators who have experience teaching through tactile diagrams and models are overworked and underpaid [3, 13]. The process of learning is also highly individualized with different students having distinct learning paces and language preferences.

With such unique constraints shaping special education in India, there is an urgent need for solutions that ease the workload of the teachers and enable and strengthen self-learning by the students. Individuals from an academic institution, a Non-Governmental Organization (NGO), and an assistive technology startup collaborated to address this need in the context of diagram comprehension for STEM subjects for children with Visual Impairments. Their work was motivated by the following research question:

How can we substitute vision to facilitate self-paced, tactile diagram comprehension for students with visual impairment in India?

To address this, we examine the Iris-Antara solution, an assistive technology solution iteratively co-designed and created by a partnership from academia, industry, and an organization working with the teachers and students. We report here the evolution of the solution shaped by multi-stakeholder discussions, iterative development, test pilots, and feedback from the end-users. We find this solution a case that proves not only the possibilities of expanding learning horizons with multi-sensory inputs but also the necessity and power of collaboration among technologists, academicians, and implementors to make meaningful technology innovations in low-resource settings such as India. We discuss the implications for sustainable design of assistive technology in the Global South and outline some of the future work around the deployment of this emerging solution.

2 Convergence of efforts by partners

Vision Empower, a not-for-profit organization committed to making STEM education accessible, has been working to create accessible resources, inclusive pedagogies, and a strong eco-system for the CVI, leveraging technological solutions wherever needed [17].

In the context of making printed materials accessible, both digital and non-digital interventions are used by VE field personnel according to the resource contexts. To make textbooks digitally accessible, a pipeline for remediation is followed (First, using OCR to make the textual content digital, next, manual and AI-based interventions to provide alternate text for the visual aspects, lastly, publishing in DOC, PDF, HTML, BRF and EPUB formats). Apart from alternate text, hand-made tactile representations of pictures, maps, graphs, and diagrams are also used. 2D, 2.5D and 3D models available in the market are made more tactile by adding textural highlights for CVI. When the RLF materials became available, they were introduced to the students. From their engagements, VE found that creating accessible resources alone does not solve the challenge of addressing the learning gap among the CVI as they need facilitators to help the students explore the tactile properly and understand the lessons unambiguously.

Recognizing the need for building assistive technologies for equitable and joyful learning experiences for children with visual impairment in low-resource settings, Vembi Technologies, an assistive technology startup, was incubated at IIIT Bangalore based on the experiences gathered from Vision Empower engagements. Their first award-winning product Hexis, a refreshable Braille display, addresses the issue of book famine for children with visual impairment by making digital content available in Braille script.

The Centre for Accessibility in the Global South (CAGS) is a research-based multidisciplinary centre for disability studies, with a focus on the Global South. The research initiatives of CAGS have informed the design and development of many products and programs amongst its partners.

To find an innovative solution to the challenge of self-paced, independent diagram comprehension by students with VI, CAGS@IIITB, Vembi Technologies, and Vision Empower came together as the research partner, technology partner, and implementation partner respectively. The rich expertise of these three partners shaped the development of the Iris-Antara solution, which we now describe in the next section.

3 Iris-Antara solution

The needs of teachers and students to meet the challenge of diagram comprehension were identified as follows : a) Physical tactiles with labels should be introduced to the students in a proper manner such that the concept is conveyed without ambiguity. b) Once introduced, students should be able to explore and understand the tactile as well as the sighted children do. c) Teachers should be able to manage this across many children in the classroom. d) Each child should be able to learn at their own pace, in the language of their choice. e) The tools given to children should not create any information overload or unnecessary distractions. f) The solution should be usable in the low-resource context of Indian special schools for the blind, preferably without high demands on digital infrastructure or the literacy of users.

Recognizing the pitfalls of the contemporary approaches to diagram comprehension (such as cost, fragile setup, and inaccurate design), the solution was developed as described below:

a) Iris device (Figure 1) - a novel TV remote-sized product designed for visually impaired children to explain the tactiles in audio format. It has 12 Braille embossed keys (0-9 number keys, Enter and Clear keys) and a speaker/headphone. It operates on a battery and gets charged with a USB-C cable. b) A cloud-based content management platform “Antara", that can convert text to audio descriptions. c) To integrate audio content with the physical tactile (that could be a handmade one, a 2D RLF printed sheet, or a 3D model), they can be organized as books of tactiles. Each such book is to be allocated a book id. The tactiles in a book each have a tactile id and numbered labels.

Every content creator (teachers, VE team etc.) can have their access credentials in Antara to create content. Once logged in, they can choose a book id, and create labels and audio descriptions for any tactile that has been correspondingly labeled with Braille numbers. Fig 2 shows a snapshot of the Antara dashboard.

A typical learning session with Iris is tabulated in Table 1:

Thus, the student can complete the exploration of the tactile at their own pace, in their language of choice, as many times as they want to get a complete understanding. Learning can now happen in various spaces - classrooms or outside without any additional efforts by the facilitator, but in the way they would like. The teachers can themselves create content in Iris for tactiles of their choice, thus democratizing the use of the device beyond device vendors (unlike other solutions).

4 Methodology

To design, develop, and test the solution - a Participatory Action Research (PAR) approach [8] was employed where student and teacher needs were identified, and multiple iterations of engagement were undertaken. Once developed, the solution was piloted in two regions by the VE implementation team and the Iris technology team.

First pilot study (P1) was geared towards understanding the curriculum to identify schema of different types of tactile diagrams and potential information flow. P1 was a contextual inquiry conducted with four visually impaired (VI) students from grade 8 involving an orientation to the device and identifying the scope of integration of Iris with their curriculum. Based on feedback from P1, the product team iterated over the design of Iris and shared insights to improve the tactile diagram book to partner organization, Raised Lines Foundation (RLF).

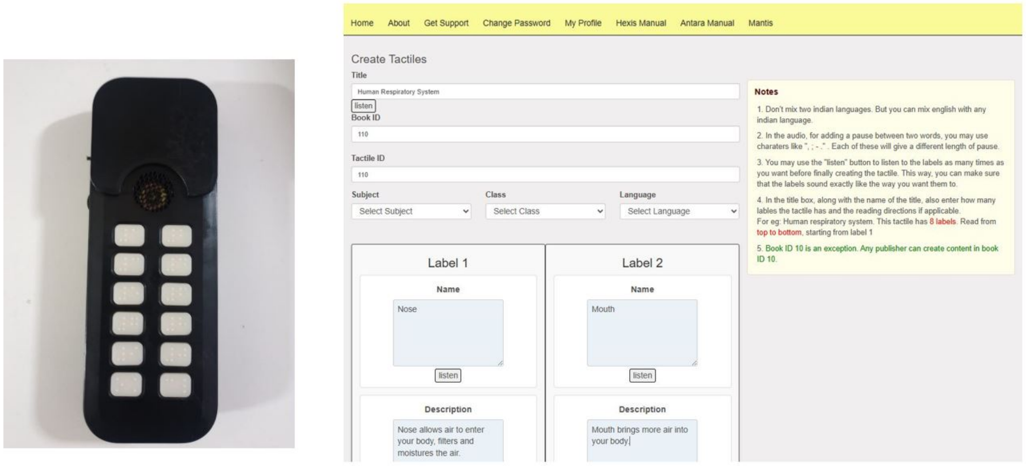
After refining the design of the solution, the research team conducted a follow-up pilot study (P2) to evaluate the potential of Iris for diagram comprehension. P2 was conducted with 28 VI students (15 - Grade 6, 13 - Grade 7). During P2, students were divided into two groups to explore the tactile diagram wherein only one group was provided with Iris. A total of 5 Iris and earphones were provided to the students with the audio content loaded with the label explanations. After a lesson plan covering the tactile diagram, groups were asked to articulate their understanding of the tactile diagram.

Post the pilot studies, VE designed program implementations for Iris and trained the students and teachers about the same. For this study, teachers and students were interviewed to assess the utility, value, and integration of Iris in classroom settings. This paper presents the findings from the pilots and the interviews.

5 Findings

During P1, the team found that there is indeed a need and value for the integrated multi-sensory solution that tactile-Iris-Antara together provide that individually they cannot. Reflecting on the potential of Iris for self-learning by the students, Iris designer shares his observations from the pilot study:

"One thing I found in the pilots is that students need time to understand a tactile and they do exploration multiple times, listen to the description and create a mental model. In a school setting, special teacher time is less, and learning scope is reduced. Iris lets them to do self-learning, reinforcing of learning and helps to learn concepts better."



(a)   (b)

Figure 1: Iris-Antara solution: (a) Iris device ; (b) Antara dashboard

Table 1: Typical Learning Session with Iris-Antara configuration

Action	Iris-Antara Response
Content creator logs in to Antara to create the descriptions	Content is saved in Antara
Student picks the physical tactile they want to explore (with the Book ID and tactile ID) and switches on the Iris device and presses 2 for downloading the tactile	Tactile diagram descriptions are downloaded on the Iris device
Student presses 1	"Read" mode configured
Student enters Book ID	Book details loaded
Student enters the tactile ID	Title of the tactile and the orientation information is read out
Student explores the tactile part labeled 1 and then short presses 1	Label name read out
Student long presses 1	Detailed label description read out

(a)   (b)   (c)

Figure 2: Iris-Antara solution in use: (a) Tactiles coded with Braille number labels ; (b)Teacher guides the student to explore the tactile and listen to Iris (c) Student learning independently

5.1 Design considerations identified during pilots

We now outline the design considerations that emerged from the pilot: **Types of tactiles:** All tactiles are not the same in terms of information flow. Some patterns found were (a) cyclic flows (e.g. water cycle) ; (b) progressive changes (where the sequence of labels conveyed sequential progression in the concept, e.g. germination of a seed); (c) ordered lists (where the label numbers should be ordinal, e.g. periodic table); (d) unordered lists (e.g. parts of a system), (e) hierarchical structures (e.g. food chain). Each of these entails a different method of exploration that needs to be informed to the student in the beginning.

Ensuring complete diagram exploration: Students were not aware of the total number of labels in a tactile diagram. As a result, many students missed reading a few labels in a complex tactile diagram. Students needed help in navigating across the labels sequentially with audio cues.

Spatial orientation of labels Numeric labels spread across the tactile were not intuitive and a structured labeling approach is needed.

5.2 Post-pilot design iteration and testimonials

Inputs from this pilot study were shared with RLF who made revisions to the structure and layout of the tactile diagram with labels contiguously structured thereby maintaining spatial consistency. The dotted lines leading from the part to the label were also refined to improve tactile perception. Audio cues were also added to make the learning experience seamless and intuitive. Upon confirming the tactile diagram to be read aloud, Iris also announced the number of tactile labels and their spatial positioning (cyclic, left to right etc.) at the outset to orient the students to the content of the tactile diagram.

These improvements enhanced the solution as was evident in the follow-up study wherein groups that were given Iris orientation showed a stronger grasp of the diagram. Beyond mere identification of individual labels, students were able to make connections across different labels to understand the process as a whole. Assesssment of their diagram comprehension showed their ability to share what they learnt in their own language and the audio cues had significantly reduced errors in navigation.

Beyond the pilot studies, VE's teacher and student training programs ensured appropriate scaffolding in integrating Iris. Teachers appreciated the introduction of Iris as this brought about a notable improvement in their instructional practice. One of the teachers contrasted the 2D and 3D models and remarked that Iris facilitated a thorough understanding of complex concepts such as water cycle and respiratory system in a holistic manner. Another teacher from Bagalkote shared his experience of implementing Iris for teaching water cycle as follows,

"I was introduced to Iris during teacher training session. After that I used it in my life science class to teach water cycle concept. The students were very happy as there was audio in Kannada and tactile diagram. They even requested for more diagrams. It took them about 10 minutes to learn the device, but after orientation, they repeatedly listened to the description and correctly answered all my questions."

Yet another teacher reflected how Iris eased teachers' workload:

Figure 3: Iris being introduced in a teacher training session

"Iris is an amazing device. I was wanting something like this for a long time. Our children find it difficult to understand the diagrams and in the classrooms it is not possible to repeat the diagram details again and again. This will be very useful for children to learn and understand diagrams on their own." (Teacher, Telangana)

Students expressed interest in possessing personal devices for themselves:

"The device is nice and useful...If each one of us have one device of our own then we will be able to take to hostel and listen." (Student, West Bengal)

6 Limitations and Future Work

This study reports the findings from the conception to pilot and initial trials by the students and the teachers of the Iris-Antara solution. In the intial phase, the upload of content in Antara and the usage of Iris has been closely facilitated by VE staff to introduce the solution and its possibilities. Once trained, the teachers are expected to independently upload content and the students, to explore the tactiles. Such routinized, self-paced, tactile comprehension moments are yet to be observed to make a concrete conclusion about the sustainable use of the solution and consequently, a marked shift in the pedagogical approach and learning of STEM subjects. These in-situ usages may also demand feature enhancements in the hardware and software components of the solution. Thus, the value perception, adoption trajectory, and consequent evolution of the solution will be the topic of our future research.

7 Conclusion

Beyond the confines of the classroom, Iris has also been integrated with life-sized models (like the skeleton in a science lab) and infovisuals such as posters. This multi-sensory approach that brings together the physical and digital promises to be a useful design template for making information accessible to everyone. This innovative solution was possible only due to the research-backed design and development followed up by context-specific programmatic interventions. The multi-stakeholder partnership that made this happen is also a template for future assistive technology development in this space to create a sustainable impact for the beneficiaries in all the spaces they reside.

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