Theme: ICT, Assistive Technology and Assistive Devices for facilitating curriculum transactions

Tactile Diagrams for Science and Mathematics: Design, Production and Experiences of Students with Blindness

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Abstract

Lack of access to diagrams has been a key challenge in education for children with Blindness especially in subjects like Science and Mathematics. Centre of Excellence in Tactile Graphics (CoETG) at Indian Institute of Technology Delhi was set up with the vision of addressing this challenge. CoETG has developed end-to-end a cost-effective mass-production techniques for making affordable tactile diagrams. It uses 3-D printing technology for mould making, developed a high speed thermoforming machine for mass production and software tools for automating production of tactile diagrams compliant with guidelines. Over the last couple of years, centre has developed several books in tactile form in collaboration with NCERT and several other agencies.

This paper discusses the development cycle of NCERT Class 9 Science and Mathematics. The visual diagrams were converted to embossed representations adapted for the sense of touch. They were simplified, magnified, decomposed into parts whenever required, based on international tactile design guidelines. The master copies were then created using 3D printing process and mass produced using high speed thermoforming machine.

Books were given to several students from different Inclusive as well as Special schools for feedback and evaluation during the academic year. The systematic feedback was collected over the entire year through multiple classroom observation sessions. Detailed questionnaire were administered with the students as well as their teachers. The questionnaire comprised of a mix of close and open ended questions aimed at capturing the difficulties faced by the children in understanding the diagrams as well as difficulties faced by teachers in explaining the diagrams to the children.

Paper discusses the experiences of children and their teachers from Inclusive as well as special schools. It also discusses the challenges faced in learning and how they were handled.

Introduction

Diagrams or pictures provide an effective way of human communication. They are often used for representation as well as reasoning of certain types and hence play a vital role in subjects like Science and Mathematics (Stanford Encyclopedia of Philosophy, 2013). In the absence of vision, access of diagrams becomes a serious challenge for persons with blindness especially in subjects like Science and Mathematics where majority of concepts are conveyed through diagrams. It often leads to exclusion of a student in an inclusive classrooms where sighted students easily learn concepts through diagrams and a student with blindness is left with no option expect to image the diagram by listening or reading the related text. As a result, majority of students have to drop Science and Mathematics subjects in higher classes.

This challenge can be addressed by making tactile diagrams available to the persons with blindness. Tactile diagrams are the raised representations of a visual image which is adopted for the sense of touch as shown in figure 1. Over the decades, special educators have played a vital role of creating tactile diagrams. Diagrams are often created using art and craft materials and are extremely helpful in classroom setting for explaining various concepts to students with blindness. Creation of handmade tactile diagrams requires significant effort and time. Moreover, this method is not scalable especially when diagrams need to be created for thousands of books from different state boards across the country.

Figure 1 An example of tactile diagram

To create multiple copies of tactile diagrams, several organizations working for the blind often use handmade tactile diagrams as master copies and then replicate those on plastic sheets (often referred to as Brailon sheet) using the thermoforming process. However, with handmade master copies of tactile diagrams, only limited accuracy and resolution can be achieved. Moreover, the materials like glue, thread etc. that are used for creation of such diagrams must be heat resistant to withstand heat produced during thermoforming process.

To address this challenge, Centre of Excellence in Tactile Graphics (CoETG) was setup at IIT Delhi in 2013 with the support of Ministry of Electronics and Information Technology, Government of India. It aimed at developing affordable and scalable solutions for the design and production of effective and meaningful tactile diagrams at a mass level. Over the last couple of years centre has developed several tactile books in collaboration with NCERT and many other organizations.

This paper mainly focusses on the design and production cycle of tactile diagrams of NCERT class IX Science and Mathematics textbooks as well as experiences of students and teachers who used these books during the last academic year. The design process followed for the end to end creation of tactile version of both the textbooks is illustrated in figure 2.

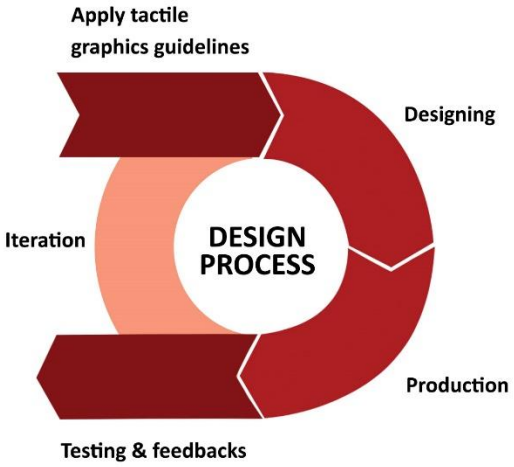

Figure 2 Design Process

Design of Tactile Diagrams

Tactile diagram is not a direct conversion of visual image to raised representation. The perception bandwidth of our sense of touch is much lower than sense of vision. With vision, a lot of information can be captured in a glance wherein through sense of touch, information is sequentially gathered and then integrated to form final image in mind.

Organizations like Braille Authority of North American and Royal National Institute for the Blind, UK have formulated international guidelines for the design of tactile diagrams. BANA guidelines and standards for tactile graphics (BANA Guidelines and Standards for Tactile Graphics, 2010)

are quite comprehensive and clearly explain the various points to be considered for conversion of a visual image to a tactile image.

These guidelines were followed during the design of Tactile Diagrams. Some of the key considerations during the design process were:

1. Simplification of diagram to reduce spatial clutter.
2. Resizing (enlarging) of diagram to ensure adjacent lines, textures are easily distinguishable by touch.
3. Elimination of elements that didn't convey any meaningful information like decorative elements.
4. Decomposition of complex diagrams into two parts where first diagram represented the whole picture with the minimum labeling and key representative elements along with clear reference line along which the diagrams is decomposed into parts. The successive tactile diagrams represented the magnified and detailed views of the divided parts.
5. Tactile representations were not created for images that can be well explained through text descriptions.
6. 3D views were converted to simplified 2D representations.
7. Adjacent tactile textures and lines were made clearly distinguishable for clear perception.
8. Braille code used in the labels was made consistent with Braille code used in the accompanying text.
9. Appropriate keys were used when space was insufficient to place Braille labels in the diagram.
10. Changes made in the tactile image as compared to visual image were documented and added as a transcriber note for facilitating better understanding.

An example of simplified diagram created from the corresponding print image, based on above considerations is shown in figure 3.

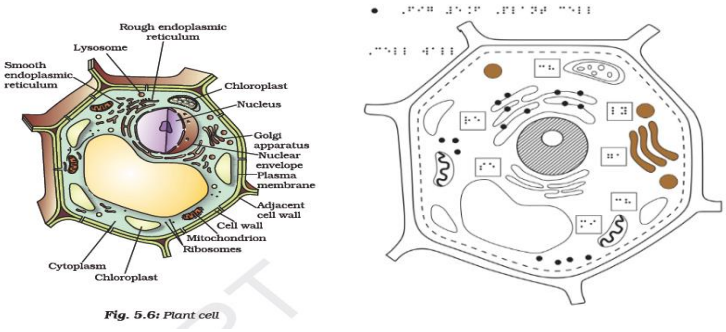

Figure 3 Print graphics and its tactile equivalent

The original textbook images were in pdf format. The diagrams were redesigned using the professional graphic design software CorelDRAW (CorelDraw, n.d.). The images were recreated in Scalable Vector Graphics (SVG) format using tracing and other tools. SVG format is a vector format. It allows images to be scaled to any size while retaining the quality of the image, making it an ideal choice for tactile diagrams.

For simple line drawings, even software tools like Microsoft Word and Power Point can also be used. But they are typically not suited for creation of complex tactile images which require use of multiple textures and line styles.

Production of Tactile Diagrams

There can be multiple ways of producing tactile diagrams from the print ready tactile images created on computer software as shown in figure 4. The simplest way is to print them using tactile embossers like ViewPlus Premier (VIEWPLUS Premier, n.d.) or Index Everest D (INDEX Braille, n.d.). The diagrams can be printed on normal Braille paper and therefore, cost of printing/ diagram is very low. This method of production is not well suited for complex diagrams because of limited resolution of tactile printers. Moreover, the shelf life of diagrams printed through this technique is limited and diagrams are prone to tearing.

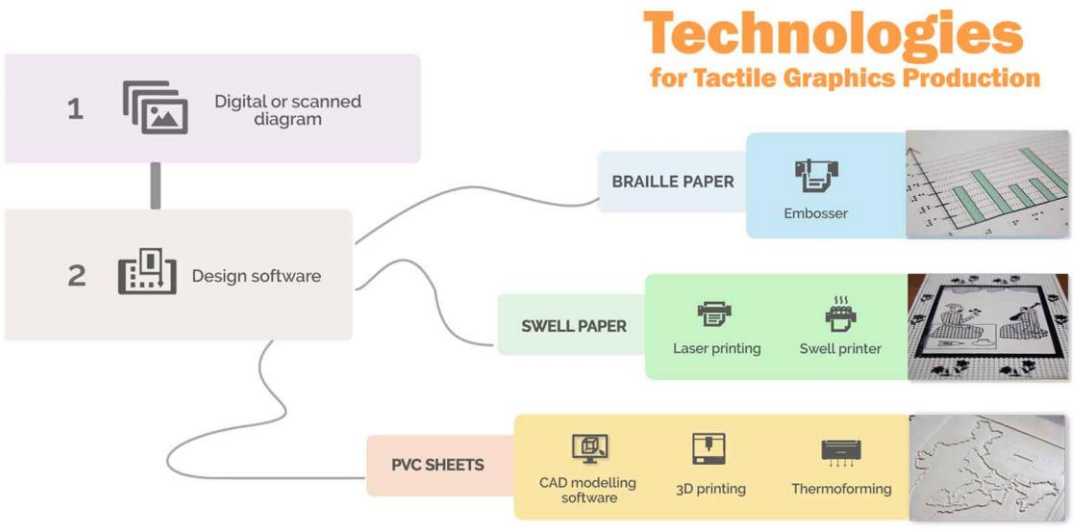

Figure 4 Technologies for Tactile Graphics Production

Another method of production of tactile diagrams is to print diagrams on heat sensitive swell paper. This method of production is simple and fast. The diagrams can be printed in very high resolution. It is two-step process. The diagram is first printed on swell paper using standard Laser printer. It is then passed through a special heating machine (PIAF (HARPO, n.d.)). On heating, the printed black sections of the diagram get embossed. The high paper costs limit (typically INR 60-70/ sheet) limits the use of this production method in developing countries.

Both the above methods were not suited for mass production of tactile diagrams. We followed the third approach for production of tactile diagrams in which master copies were created using 3D printing technology and then multiple copies were created using automated thermoforming machine. This method requires exporting of 2D vector images designed in Corel Draw to CAD (Computer Aided Design) modelling software like Blender as shown in figure 5. This is done to add height element. The output of this stage is an image in STL (STereo Lithography) format that can be printed using a 3D printer for generation of master copy. The 3D printed tactile diagram is then used for printing of multiple diagrams on Brailon sheets using thermoforming process as shown in figure 6. Traditionally, manual thermoforming machines have been used for production, however, to scale up the production, centre has developed an automated thermoforming machine which is capable of printing more than 200 diagrams in an hour.

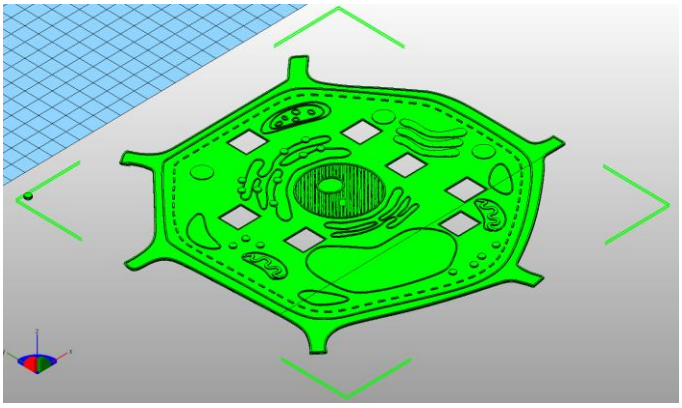

Figure 5 CAD modelled diagram

Figure 6 Thermoformed diagram

Experiences of Students and Teachers

To evaluate the effectiveness and usability of produced tactile diagrams, the tactile books were given with 30 students from 3 schools for the blind and 5 inclusive schools. Testing sessions were conducted periodically throughout the academic year (2015-2016), in close association with students and teachers to monitor their progress. Feedback was collected through the following mechanisms. Team members periodically attended classes at various schools and observed the students in the real classroom setting when teachers were using the diagrams for explaining various concepts to the students. Questionnaires were created to access the quality of diagrams as well as capture the suggestions for improvements. Combination of multiple choice and open ended questions was used to capture both quantitative and qualitative inputs. Apart from this, a 3-day workshop was conducted by NCERT, Delhi where a large group of participants including special educators, subject experts, students and CoETG team members gathered to assess the correctness and effectiveness science and mathematics tactile books.

Figure 7: Special educator giving an overview of the concepts

Figure 8: Classmate explaining concept using tactile diagram

Key findings

It was found that the students had very limited exposure to tactile diagrams. As a result, they faced difficulties the diagrams on their own. But once they got acquainted, they were able to understand and infer information given in the diagrams. Some of the key findings were:

1. Students found diagrams really helpful and were able to understand the concepts explained through diagrams. Majority of students highlighted that they had read several concepts earlier, but tactile diagrams helped them really understand those concepts.
2. Students took time to get acquainted with some of the complex diagrams. Verbal assistance from the teachers helped in understanding.
3. Students, teachers as well as special educators highlighted the need of similar books in early stages of learning to faster and better perception on information conveyed through the diagrams.
4. In inclusive schools, teachers were less equipped with teaching resources for blind, these tactile diagrams proved to be highly beneficial and effective but larger number of students relatively took more time to get use to the diagrams as they had no previous exposure to the tactile diagrams
5. In schools for the blind and resource centres, special educators were already using learning conventional resources like tactile board, 3D models and hand-made tactile diagrams for explaining several concepts, the availability of tactile books provided them an opportunity to combine the two. This really helped students in faster understanding and learning of wider variety of concepts.

6. Several conceptual and design errors were identified by the special educators and students, which provided an opportunity to further refine and improve the diagrams.

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