Edutactile - A tool for rapid generation of accurate guideline-compliant tactile graphics for science and mathematics

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Abstract

In this paper the authors have presented the design and implementation of Edutactile, a cross-platform software which automates the process of creation of tactile diagrams. Edutactile provides for automated application of guidelines or presets as well as Braille translation and thus abstracts away the production related issues. This relieves special educators for the visually challenged from having to learn the workings of the graphics editing software (Photoshop, CorelDraw) which are currently being used to produced tactile graphics and instead focus on the content of the diagram.

1 Introduction

According to WHO about 39 million people are estimated to be blind worldwide, 90% of whom live in the developing world. Out of these, 2 million are children under the age of 15 years [1]. Teaching and learning of science and mathematics is particularly challenging due to the graphical and diagrammatic content (chemical equations, mathematical graphs etc). Increasingly, embossed tactile representations are playing a significant role in assisting special educators in conveying concepts for diagram comprehension and practice.

Tactile representation requires certain guidelines to be followed for comprehension and perceptibility of the diagrams. These guidelines (BANA[1], RNIB[2]) recommend/constrain the use of line types, line thicknesses and texture types.

Former, existing software solutions are general purpose graphics software (CorelDraw, Adobe Photoshop). They have a high learning curve and are more sophisticated than what's required. Furthermore these software are proprietary with high licensing costs and are tied to a specific output method or product like braille embossing, thermoforming or swell. Additionally, current solutions mostly cater to a specific category of diagram and do not holistically address the needs of a typical special educator.

Hence, there is a need for a software that relieves the special educators from the workload of conforming to guidelines, braille labelling and layouts for production and hence allows them to concentrate on the quality and the expression of the diagram.

This paper presents the design and implementation of Edutactile, a cross-platform Java-based software which facilitates the creation of tactile graphics specialised for scientific and mathematical content. It automatically handles layout and formatting thus relieving special educators and enabling them to

[1] http://www.brailleauthority.org
[2] http://www.rnib.org.uk

concentrate on the content of the diagrams. During the development, feedback was taken from special educators as well as visually impaired students. Initial feedback has been positive regarding both the software as well as the quality of diagrams produced using it.

2 Related Work

There are commercially available software like TactileView [2] , TGD-Pro [3] etc aimed at the creation of tactile graphics but limitations arise due to their generic nature with them being tied to a specific output method. Further drawbacks include their proprietary nature and a high learning curve. R.E. Ladner et. al. [4] from the University of Washington present a system for automation of the graphics creation process. Drawbacks arise as this system only converts pre-existing printed images and does not generate new tactile diagrams. This does not guarantee the accuracy of many of the diagrams, as the original images might have errors.

3 System

3.1 Software Design Aspects

Edutactile is built on a Java framework with the front-end GUI being implemented using Java Swing and images being rendered using the Java class Graphics2D. Tactile diagrams are input/generated in the .svg (Scalable Vector Graphic) format. Input .svg files are preprocessed by first parsing them using SVGSalamander[3] and then by converting them to a table-like *Shape* data structure. Braille translation (in multiple languages) is done by an open source braille translator BrailleTrans [4].

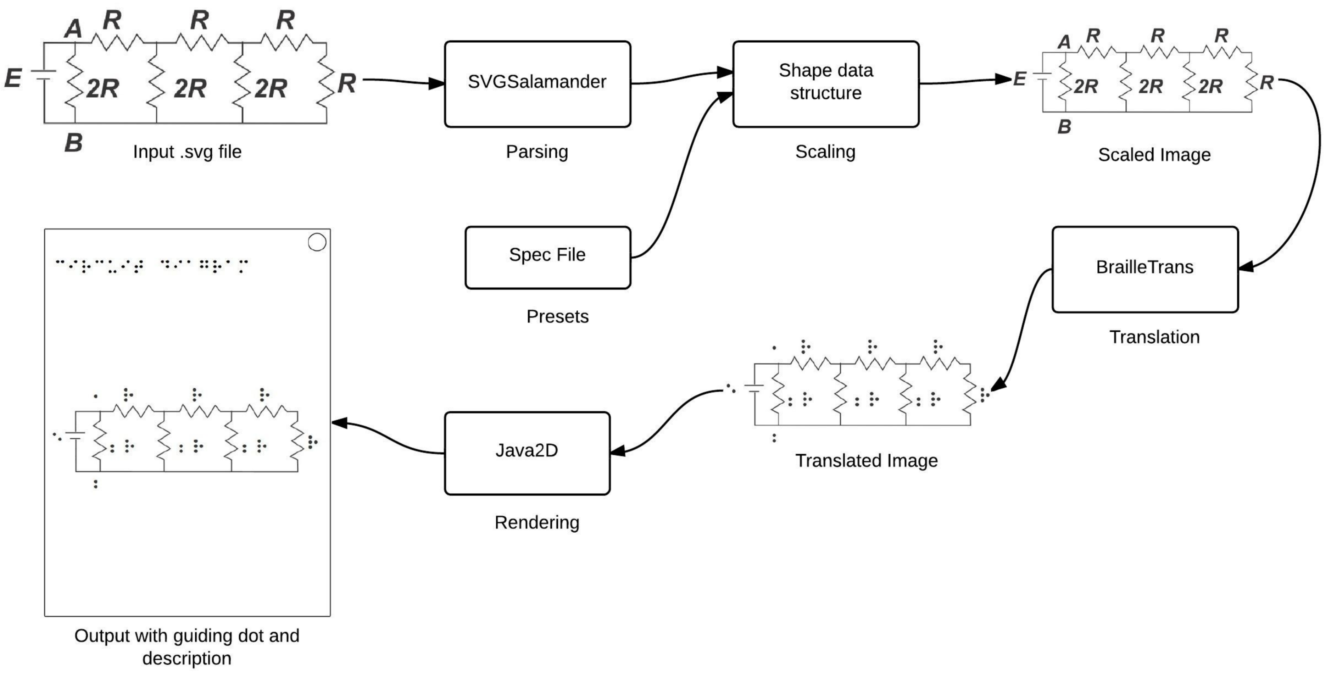


Figure 1: Process of conversion for a standard image into a tactile graphic suited for a production method and conforming to guidelines

[3]`https://svgsalamander.java.net/`

[4]`http://alasdairking.me.uk/brailletrans/`

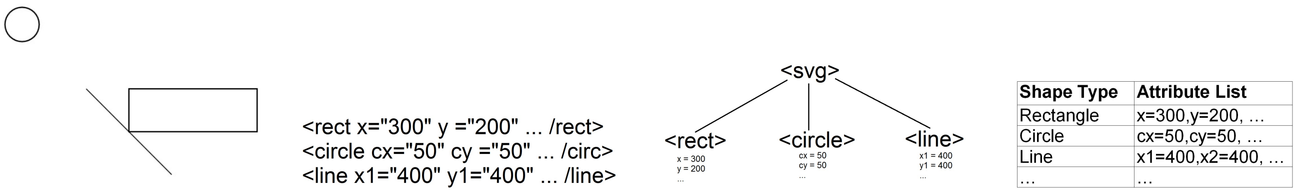
Focus groups were formed during the design and development process of the system. Constant feedback was taken from users and special educators throughout to know their needs. Keeping these specifications in mind, three modules have been incorporated into the system.

1. **Image Converter Module** - Automates the translation of a standard textbook figure into a tactile version conforming to guidelines with descriptions and accessible labeling
2. **Chemical Equations Module** - Generates chemical equations with the help of a drag and drop library of commonly used chemical symbols
3. **Mathematical Functions Module** - Provides entry, parsing and plotting of complex mathematical functions

3.2 Image Converter Module

The image converter module takes as input a basic .svg figure and applies guidelines as well as does transformations like scaling, spatial decluttering, occlusion removal, braille conversion, changing edge thicknesses/textures, marking and positioning to create a better diagram. The system allows for specifications for guidelines. Specification files can be imported and applied to a class of diagrams. Furthermore, the special educator can add annotations.

The input .svg file is parsed and the component shapes (embedded in XML tags) are converted into a *Shape* data structure which is a table where each entry corresponds to a particular shape and it's attributes (radius, length, breadth etc).



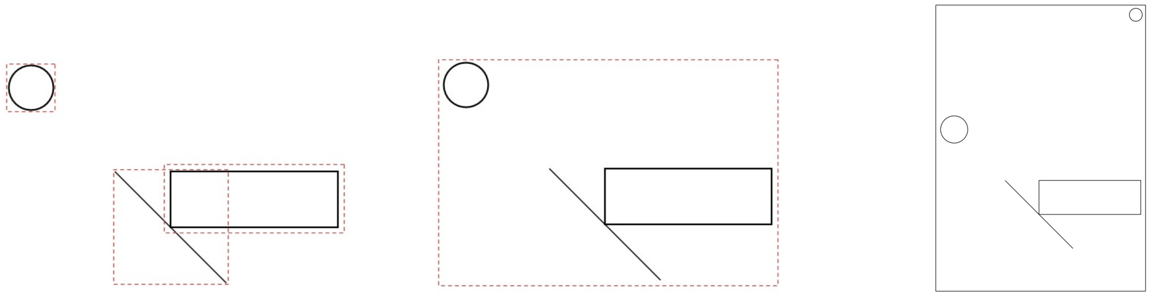
(a) Input .svg file (b) Shapes in XML tags (c) Parsed Tree (d) Shape data structure

Figure 2: **Parsing of an input .svg file** - **(a)** Input image in the form of a .svg file **(b)** Component shapes and attributes embedded in XML tags **(c)** File parsed using SVGSalamander to create parsed tree **(d)** Tree is converted into table-like *Shape* data structure for easier processing

Scaling is done by finding the bounding boxes for all the shapes (done with the help of the *Shape* data structure) in the image. Then a maximal bounding box is found using all the individual bounding boxes. The dimensions of this maximal bounding box is compared with the page dimensions (on which the image is to be printed) and all the shapes are appropriately scaled.

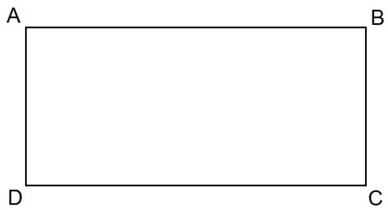
To facilitate the changing of line thicknesses, shapes are decomposed into their constituent lines/arcs via modifying their entries in the *Shape* data structure. The entry corresponding to the shape being decomposed is replaced by entries corresponding to it's constituent parts. This enables a user to click and change the thickness/nature of a particular line/arc.

Textures can be changed via the click of a mouse button. To simplify this process the regions bounded by the various components of the image are calculated. The system also warns a user if adjacent textures are too similar.



(a) Individual bounding boxes (b) Maximal bounding box (c) Scaled image

Figure 3: **Scaling of image** - **(a)** Individual bounding boxes drawn over all shape components **(b)** Maximal bounding box created using individual bounding boxes **(c)** Scaled image is fit onto page



(a) Rectangle ABCD

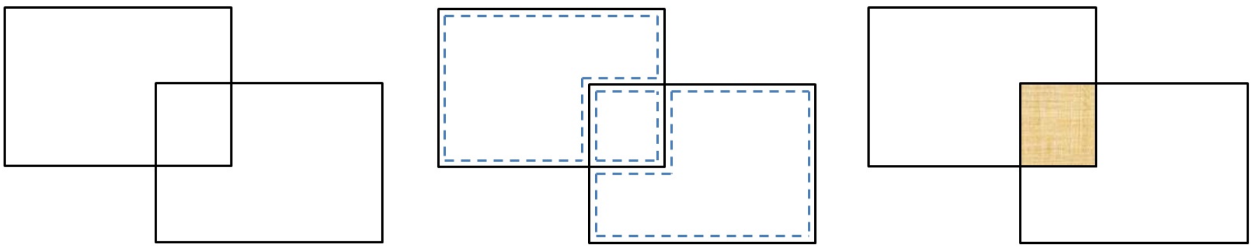
Shape Type	Attribute List
Rectangle	x=100,y=100, ...
...	...

(b) Representation in table-like data structure

Shape Type	Attribute List
Line	x1=100,x2=150,...
Line	x1=150,x2=150,...
Line	x1=150,x2=100,...
Line	x1=100,x2=100,...
...	...

(c) Decomposition

Figure 4: **Edge/Arc Decomposition** - **(a)** Shape component of type *Rectangle* corresponding to rectangle ABCD **(b)** Representation of rectangle in the table-like *Shape* data structure **(c)** Decomposition of rectangle ABCD into four line segments AB, BC, CD and DA



(a) Input image (b) Bounded areas (c) Texture changing

Figure 5: **Texture Flipping** - **(a)**Two rectangles with common region **(b)** Calculation of different bounded regions **(c)** New texture applied to particular bounded region

3.3 Chemical Equations Module

Representation of chemical equations involve a specific format. Furthermore, many compounds and reactions involve specific spatial arrangements. For example, hydrocarbons like benzene etc. and several structural re-arrangement chemical reactions like reactions of aromatic compounds. Edutactile provides for creation of tactile versions of such chemical equations. During the creation and edition many operations can be performed, promoting insertion, deletion, modification and movement of chemical symbols. Concurrently with entering chemical compounds appearing in the equations as reactants, products, precipitates and catalysts etc. - which includes selection from drop-down menus - layout and positioning is automatically handled, ensuring consistency in the diagram.

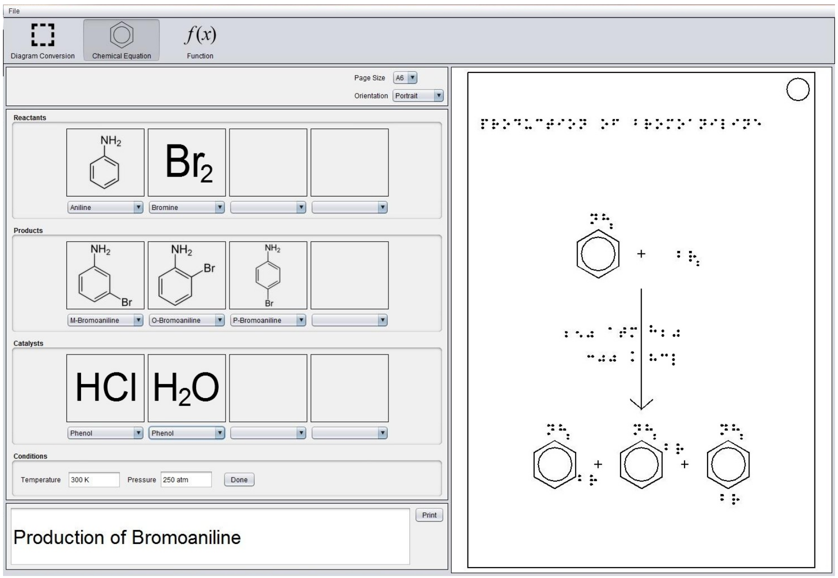


Figure 6: GUI for chemical equations module. The equation shown is the production of bromoaniline.

3.4 Mathematical Functions Module

Graphs of mathematical functions are a key diagrammatic component of imparting mathematical education. A variety of functions exist which are difficult to graph manually. Edutactile provides for interpolation based plotting of 1D mathematical functions. The software supports polynomial, logarithmic, trigonometric, exponential and statistical functions as well as any combination of them either by mathematical operators (addition, subtraction etc) or by function composition. The mathematical function plotting module takes the expression as an input that is parsed (with the help of a open source parser Math Expression String Parser[5]) and then point wise interpolated to yield the function graph. Different line types and labelings are also added. Since this module has no visual component as input, a visually challenged student may input a function string to obtain it's 2D figure.

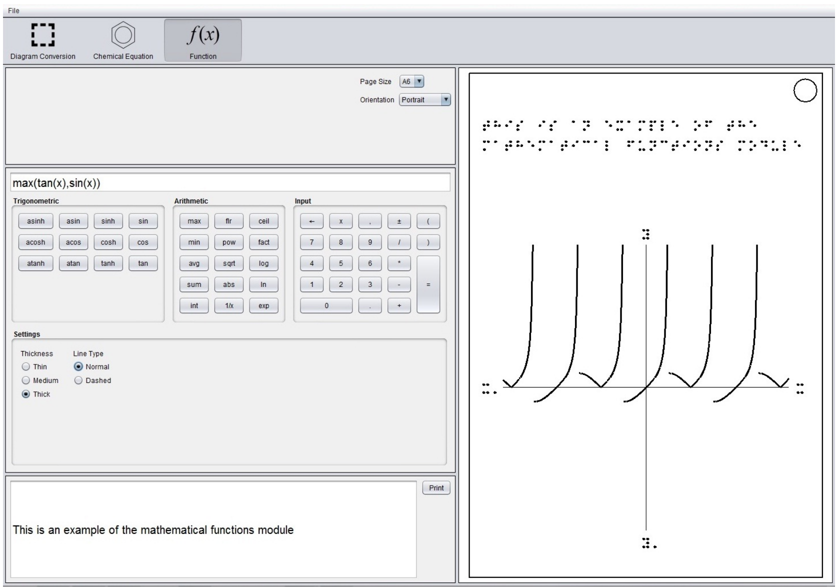
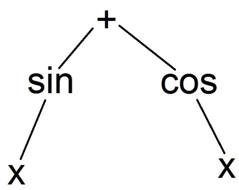


Figure 7: GUI for mathematical functions module. The function shown is the *maximum* of $sin(x)$ and $tan(x)$

[5] `http://sourceforge.net/projects/expression-tree/`

sin(x)+cos(x)

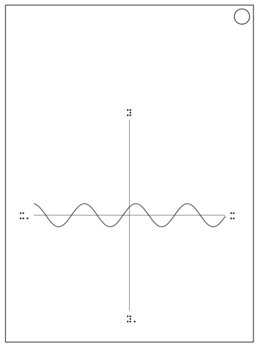
(a) Input string



(b) Expression tree

x	sin(x)+cos(x)
1	0.99984
2	0.99993
3	0.99862
…	…

(c) Function evaluation



(d) Graph plotting

Figure 8: **Plotting of mathematical functions** - **(a)** Mathematical function is input in form of a string **(b)** MESP is used to parse string and get a function **(c)** Function is applied to various points (corresponding to points on the x-axis) and the obtained set of coordinates are plotted **(d)** A curve is interpolated through the plotted points

4 Results and Evaluation

Diagrams were created using Edutactile and then produced on both braille embossers and swell paper which were then tested with high school students at the National Association for the Blind [5]. The students were able to interpret and understand the diagrams. Detailed feedback was taken from three special educators about both the software as well as the diagrams produced. The tests are summarised below.

4.1 User Evaluation on Software

The three special educators were asked to rate the software on various criteria on a 5 point Likert scale (with 1 being the lowest possible score and 5 being a perfect score). Furthermore, they also assigned scores to the perceived diagram quality and output interpretability by students. The scores are summarised below.

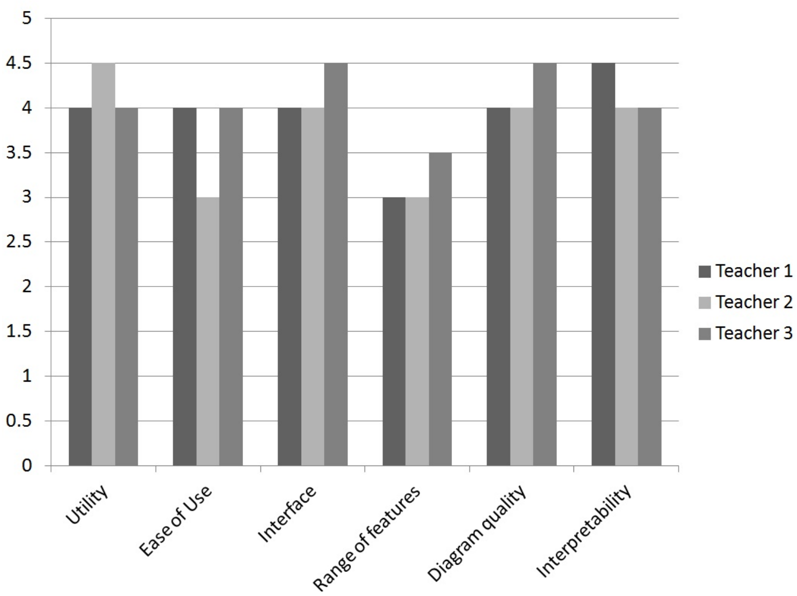
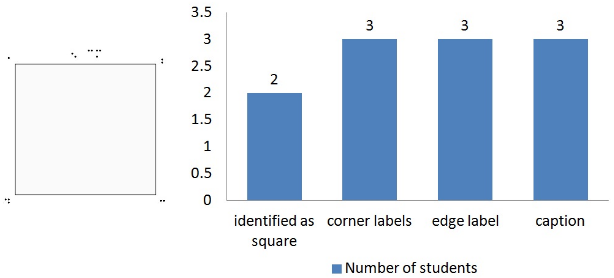


Figure 9: Ratings by special educators

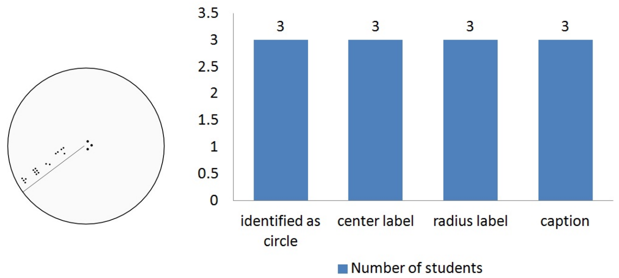
Feedback from the special educators was positive, as can be seen in the universally high ratings. They stressed on the need for such a tool, especially in the context of teaching blind children in India.

4.2 User Evaluation on Diagrams

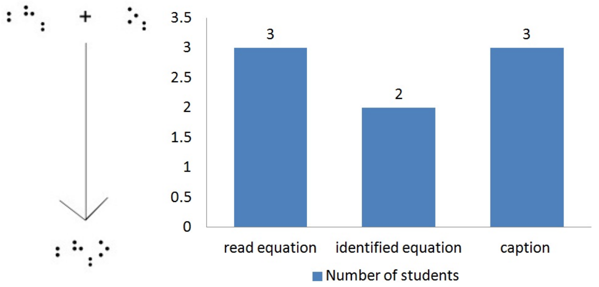
To gauge the effectiveness of the diagrams produced, a set of six diagrams was given to three students and they were asked to interpret what the diagrams meant. The results are summarised below.



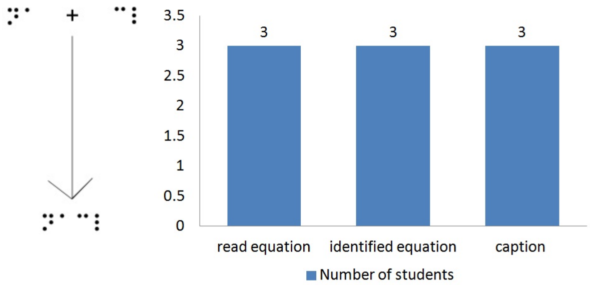
(a) Square



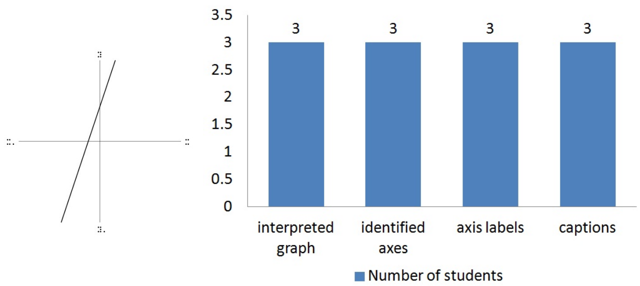
(b) Circle



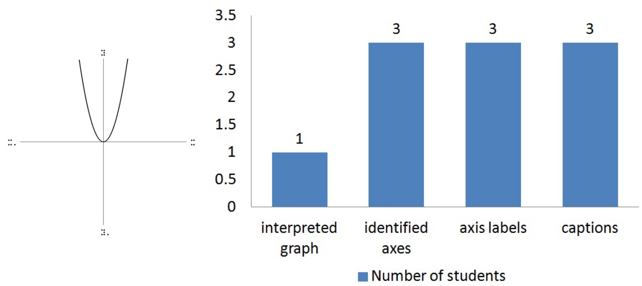
(c) Formation of water



(d) Formation of common salt



(e) Graph of a straight line



(f) Graph of $y = x^2$

Almost all elements of all the images were located, identified and interpreted by the students. In four instances a student failed to interpret a particular element.

- One student interpreted the square as a rectangle.
- One student couldn't recognize the equation of the formation of water as he didn't know the equation (although he could tell what the reactants and products were).
- Two students failed to recognize the graph of $y = x^2$ as both of them did not know the nature of the graph for that function. One interpreted it as a parabola.

It can be seen that there was a high level of understanding and apart from the first case any mistakes in interpretation were due to the lack of knowledge of the student rather than the quality of the diagram.

Figure 11: Output tactile diagrams being tested by high-school students and special educators at the National Association for the Blind, New Delhi

5 Conclusion and Future Work

In this paper, we have presented the design and development for an open source cross-platform system which amelerioates challenges faced by special educators. Hence, making it easier for special educators to focus on the quality and content of the diagrams. The system provides a low barrier to entry as it uses simple mouse actions for interaction. Feedback has been very positive from special educators and end-users during preliminary feedback. In future, we plan to improve the accessibility and diagram generation directly for end-users. Also addition of newer functionalities is planned, e.g., conversion of printed images into tactile drawings. A beta version has been released online [6] which is updated regularly. Both the source code and an executable is available.

References

[1] http://www.who.int/mediacentre/factsheets/fs282/en/l

[2] Tactile View, http://www.tactileview.com

[3] TGD-Pro, http://www.duxburysystems.com/tgd.asp?choice=pro

[4] R.E. Ladner, M.Y. Ivory, R. Rao, S. Burgstahler, D. Comden,S. Hahn, et al.: "Automating tactile graphics translation", The7th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS), Baltimore, USA, 2005

[5] National Association for the Blind, http://www.nabindia.org

[6] https://github.com/assistech-iitd/Edutactile