Atomatic

An Inclusive Chemistry Learning Aid for Visually Challenged Children

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Guide: Prof. Girish Dalvi

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Approval Sheet

The interaction design project II titled "*Atomatic* - an inclusive chemistry learning aid for visually challenged children" by Sylvan Lobo is approved in partial fulfilment of requirements for the degree of Masters of Design in Interaction Design.

Guide:

Chairman:

Internal Examiner:

External Examiner:

27 November 2014
Industrial Design Centre
IIT Bombay
Powai, Mumbai

Declaration

I hereby declare that this report has been written in my own words. I have appropriately cited and referenced the original sources of any existing ideas and work I have built upon or used to support my ideas.

I declare that I have adhered to all principles of academic honesty and integrity and have not falsified, fabricated or misrepresented data, idea, fact or source in my submission.

I understand that any violation of the above will be cause for disciplinary action by the institute and can evoke penal action from the sources which have not been properly cited or from whom proper permission has not been taken where needed.

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Date: 14 Nov 2014

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Abstract

The path to education for visually challenged is filled with many challenges. There are primarily two approaches to teach visually challenged students: special education in a blind class or school, or integrated education along with sighted students. Traditionally, blind schools have been the approach to delivering education. Currently, there is a movement towards integrated and inclusive education being considered a better approach.

Visually challenged students need to learn certain compensatory skills such as Braille, in the early stages. They also need to develop concepts through certain adaptations in curriculum, and hands-on activities and experiences. At school level, many topics are omitted because of content being highly visual in nature, especially certain topics in mathematics, science or geography. Teachers and students both face difficulties in teaching and grasping such topics.

We identified chemistry as an area of focus after discussions with professionals in education and teachers, and a survey of educational aids and facilities at Smt. Kamla Mehata Dadar School for Blind. Chemistry has a lot of visual aspects involved in teaching—e.g. shapes, colour changes in reactions, litmus papers, etc. and is also unsafe when it comes to performing experiments, due to strong acids and bases, and glass equipment. So, quite often, concepts are only taught in the classroom as a normal lecture, with little hands-on activities for the reinforcement of concepts.

Based on the studies and interaction with educators, we designed *Atomatic*—a chemistry learning aid that lets students explore and discover the concepts of the atomic model (Rutherford-Bohr model). It allows a student to construct an atom with its constituents—protons, neutrons and electrons. The device is a board with holes to put in pegs which represent the constituents. As the student tries various combinations, the board guides them through sounds and voice towards making a valid combination. When a valid stable atom is created on the board by the student, information about the atom is spoken out by the board. While the larger goal would have been to work with chemical experiments, as the students were not yet ready with basics, we decided to start at the basic point, i.e. the atom.

In designing for visually challenged, we understood that an inclusive approach would be more effective, so that blind, partially blind and sighted students can use it equally. The product provides and engaging game-like experience, and has two levels of complexity. An attempt has been made to make it low cost and scalable.

Preliminary evaluations with teachers suggest that the product would be appropriate in teaching students the concepts and would not involve many usability challenges. The product will be evaluated with visually challenged students from at Smt. Kamla Mehta Dadar School for Blind and Xavier's Resource Centre for Visually Challenged, and sighted students from Kendriya Vidyalaya at IIT Bombay. We hope that the product would prove an effecting learning aid, with minimal usability challenges.

Table of Contents

Introduction

Education for Visually Challenged

Disability in seeing[1] in very prevalent in India, with over 5 million people affected [1, 2, 3]. The prevalence in children is much lower than in adults, but considered a priority.

Being deprived of vision imposes a lot of challenges to children in being brought up in a society that is highly vision dependent and not aligned to their impairment. This deprivation can influence their personality and way of life in a big way, as they unable to interact with others and environment as their sighted peers would. They hence need to be brought up and trained appropriately so that they can interact with the world effectively.

Effective training and education is very important for one to live an independent, good quality life and be productive and contributing to the community. This is equally applicable to the disabled community, and has been recognized by the government. The Right to Education Act (2009) along with other legislations such as Persons with Disability (Equal Opportunities, Protection of Rights and Full Participation) Act (1995), and Rehabilitation Council of India Act (1992) strive to provide access to education, employment, barrier free environment, social security, rehabilitation services, etc [4]. The *Sarva Shiksha Abhiyan*

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[1] People with disability in seeing was estimated over 10 million in the Census 2001. However in the Census 2011, one-eyed persons were not treated as disabled and there was a test conducted to ascertain blurred vision. Such instructions were not provided in the Census 2001, and hence probably the reason for the lowered figure.)

(SSA) is a government programme for compulsory education for all children from 6 to 14 years as a fundamental right [12].

If one compares education needs for blind children with that of sighted, there are quite a few differences [5]. Sighted children can implicitly learn a lot through vision simply by observing and mimicking others. What may seem obvious and trivial is not so for visually impaired children. Hence special attention is required. For instance, they cannot easily pick up gestures or mannerisms, or easily be aware of the working of say transport systems such as the railway, etc., or even daily-life objects such as trees, roots, eggs, etc.

Traditionally, education for blind was through blind schools that catered to the special needs of visually impaired children. Today a lot of importance is being given to integrated education, which is a more inclusive approach where visually impaired and sighted students learn together. Integrated education is recognized as a better approach as the students are given the same opportunities and experiences as sighted students, where they can make friends and interact socially. Children are seen as children first, and then blind. Special training may be given to teachers and special assistance is provided to the students [10].

Teaching Chemistry to Visually Challenged

Chemistry is a core science and can open up careers in science and healthcare to the children. Yet, chemistry is not effectively taught to visually impaired children in school, because of the highly visual nature of chemistry, the safety challenges involved, and unavailability of accessible equipment. Certain topics are often omitted. Chemistry usually uses visuals such as shapes and diagrams to explain certain concepts. Reactions generally involve changes in appearances, colour and smell. Strong acids and bases, and glass equipment need to be handled carefully or they can be dangerous.

These challenges can be got around by designing accommodations so that the chemicals, shelves, measuring devices, equipment, and the lab itself are safe and accessible. These accommodations are not easily available and hence the difficulty of teaching chemistry.

Problem Statement

Based on my findings that chemistry and chemical experiments are not usually taught in depth at blind schools (or as much as in sighted schools), I decided to start with addressing the basic. In this project, we aimed to explain basic concepts of chemistry. We identified the following topics to explore through various design concepts to teach chemical reactions and allied concepts to visually impaired children:

- Atomic model
  (electrons, protons, neutrons, atomic number and atomic mass number)
- Ions
- Valency
- Categorization
  - Metals, non metals, noble gases
  - Oxidation, reduction
  - Reactions: combinations, decomposition, displacement
- Reactions and balancing equations

The original aim of this project was to find out which topics from the curriculum children found difficult to learn because of visual impairment; or which topics teachers found difficult to teach—and then design a teaching aid or game that the teachers and children could use.

Chemistry was chosen as the topic to explore further, based on interactions with teachers, students and observations at Smt. Kamla Mehta Dadar School for Blind (SKMDSB) and Xavier's Resource Centre for Visually Challenged (XRCVC).

We decided to use an interactive, engaging and fun technological intervention, with an inclusive approach so that it could be used equally for learning by blind, partially blind and sighted students.

"Training sharpness of hearing in a blind person has natural limitations; compensation through the mightiness of the mind (imagination, reasoning, memorization, etc.) has virtually no limits"

Lev Vygotsky

Literature on Education for Visually Challenged

Education Needs of Visually Challenged

`Enable-india.org` and `teachingvisuallyimpaired.com` discuss how a blind school generally approaches education for blind children. This has been summarized below. Usually only after these interventions, children would study further in integrated environment [7, 9].

Early intervention for compensatory skills: Before regular curriculum can be taught to visually impaired children, it is essential to develop certain compensatory skills. This is done early-on in their childhood (before six years) so that they have a good foundation. They learn to use special tools to communicate. At this stage they prepare with pre-Braille skills, where they develop their touch sensitivity. Gross motor and fine motor skills would are developed. They learn communication modes like large print, tactile symbols, adaptive equipment. In some case, they may also learn enough handwriting for a legal signature. They learn to make the best use of their abilities. For instance if a child has some residual vision, then they are taught to make the best use of the available vision rather than being solely dependent on facilities such as Braille.

Compensatory skills also include the development of concepts, spatial awareness, speaking and listening, and language development. These skills are usually taught through first-hand experiences and interaction with their environment.

The children also need to develop functional skills which would help in play, work and socialising. This includes organization skills and self-help skills.

Parental reinforcement is another aspect of importance. Parents are educated to deal with the child's development, so that a good learning environment can be created at home with exercises that will aid developing their capabilities.

General intervention (adapted curriculum): At the later stage (6-18 years), the student is supported in education by making the regular curriculum accessible through suitable adaptations, e.g. using tactile diagrams, models, and teaching aids, or sometimes even cutting out topics that are difficult to teach/learn. It is especially important to make adaptations to curricula that are visual and spatial in nature. Students require material in various alternate formats like large text, high-contrast colours, Braille, magnified, talking, etc. Certain topics (usually mathematics and science) that are challenging to the students are often omitted or taught at a later stage as compared to regular children.

The student should be able to take notes and read using Braille at a good pace.

In this stage, the children are taught to explore their surroundings and navigate effectively and safely through Orientation and Mobility exercises.

Integrated and Inclusive Education

There are various educational settings possible when it comes to providing education for blind, namely: e.g.: regular classrooms, special education classroom (along with children with other disabilities), special classroom (only blind children), special school for various disabilities, special school for blind, and home schooling [15]. The approach of special schools for blind is more common.

Academic standards in a blind school might not be on par with what is provided to regular students in regular schools and classes. A blind school amounts to a limited experience to the children, and might not prepare them sufficiently to cope up to living in a sighted world [16].

These limitations of blind schools have led to an understanding that integrated learning is a better way to provide education to visually impaired children. In an integrated learning environment, blind children attend regular schools but use alternative tools, methods, materials and adaptations. Other than the regular teachers, there are para-professionals (specially trained facilitators) available to support them with adapted material, equipment, clarification of concepts, etc.

The benefits of integrated learning are that it allows for equal opportunities, social interaction with sighted people, and more appropriate preparation for life. There are however some concerns in integrated learning too. For example, due to the presence of para-professionals other than class teachers can lead to a laid-back attitude of blind children during class (as they expect to learn the concepts later from the para-professional). One of the primary objectives of this environment is to promote independence among the students. So, it should be attempted that visually challenged children learn from the class teacher itself rather than separate para-professionals and other students. Parallel sources of learning can lead to class-within-class situations, issues in peer relationships, and redundancy of learning from the para-professional rather the class teacher.

Beyond integrated environments, the movement now is towards inclusive education, where regular education is itself designed to cater to disabilities. Special schools can lead towards exclusion. In an inclusive environment, general education is more sensitised. Firstly, with various legal acts like the Right to Education Act (2005), it is a legal expectation to provide education for disabled students. Secondly it is beneficial to regular children to for various reasons. The teacher would be inclined to communicate better, and would need to make use of 3D models and learning aids which will reinforce learning for the sighted too. Further such an environment can make regular children more empathetic and learn to respect differences.

Related Learning Theories

Montessori Education

Montessori education is an approach developed by Maria Montessori, where the child learns directly by themselves in their own way. This is a commonly used approach to teaching visually challenged children in the early stages. It can involve a mixed age classroom, where children have an uninterrupted work time of around three hours. Specialized education materials are provided to children and they learn at their own pace by interacting with the materials, environment and other children. Teachers are trained in Montessori education, and they give attention to individual children or small groups. This is like a constructivist approach, however the teacher have a larger role in guiding the child's exploration and research based on their inclination or excitement towards the subject [18].

Vygotsky on Special Education

In his work - The Fundamental Problems of Defectology (1929), Vygotsky discusses inclusion of people with differences in the larger cultural system. He calls impairments of organs as defects, and, defects are not considered as some abnormalities unless considered in a social context.

Development is a result of social learning. The disabled child is not less developed from his peers, but developed differently. The teacher has to deal with the social conflicts that arise, rather than the disability itself. Vygotsky highlights that rather than dealing with the impairment physically by providing accommodations, it would be highly beneficial to develop psychological functions namely:

- the lower (natural) function which includes perception, memory and attentions (biological); and
- the higher (cultural) function which includes abstract reasoning, logic, language, attention, planning, decisions making.

Takeaways

Blind schools and special education is making way towards integrated and inclusive education environments. Vygotsky expresses that the disability is because of the social context. It makes sense to hence design interventions that are inclusive and catering to blind, partially blind and sighted students so that they can interact and use the aid for learning equally. It would be good if the solution can also cater to other disabilities, as well as other aspects of inclusivity such as multiple language support.

The product can be a hands-on experience where both Montessori and Constructivist approaches can be used where the child can learn independently, as well as under guidance of a teacher.

We could also attempt to develop other senses of students by providing spatial, sound and tactile interaction. Development of senses and concepts is an important learning activity for visually impaired children. Aside from concepts of chemistry, the intervention could also indirectly develop secondary concepts.

Vygotsky also highlights the importance of developing psychological functions of the child, rather than simply making a device that caters to the disability. It would be ideal to also include features in the solution that develop perception, memory, attentions, language, decision making, etc.

Data Collection

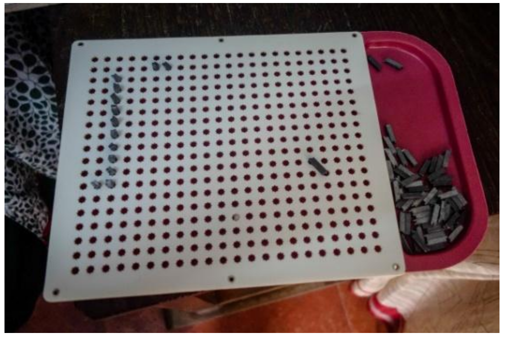
Secondary Studies

Survey of Existing Products

Existing products were evaluated for knowing the state-of-art. These included the tools used for compensatory education, education aids in math and science, and some games that have been designed for visually challenged children. The survey is exhaustive but covers a wide range. These products and their features were useful for inspiration towards the design solution.

1. Tools for Math and Science

a. Taylor frame slate

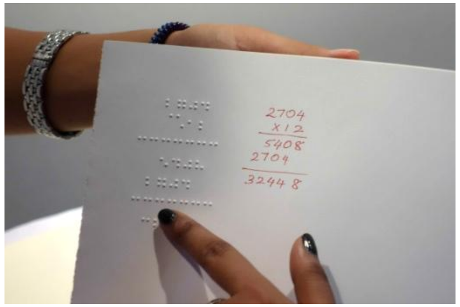


Designed in the mid 19th century, the Taylor frame is a traditional tool used for expressing mathematics figures and operations. It is a slate of holes in a grid, in which pegs are placed. The pegs have two pins on one end and a slab on the other end. By arranging the pegs, one can represent various number and operations [6].

It is widely used in schools as it is a good means to represent intermediate steps in calculations.

There are no studies present that evaluate its effectiveness and efficiency of use and methods of teaching [23]. It seems like a difficult to use tool (although it is popular).

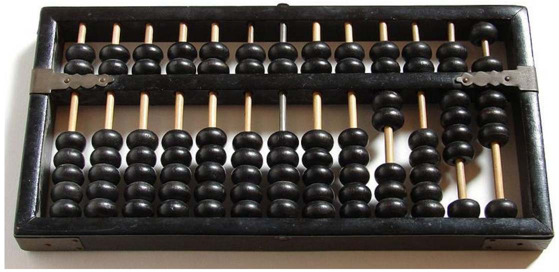
b. Nemeth code



Nemeth code [19] is a Braille based system for math and science notation. Advanced math can simply be encoded in Braille, and it is possible to use the usual Braille printers (transcribers) for printing mathematical notations. All steps in a calculation can be presented.

There is a large complex range of notations in Braille, and so a steep learning curve. It is introduced gradually to children.

c. Abacus



[Image source: Wikimedia Commons]

It is an ancient tool for counting and mathematical calculations, and is popularly used as a learning aid. It involves sliding beads on sticks in a frame. It is quick and easy to operate.

As compared to a Taylor frame, one cannot represent intermediate steps in a calculation. It is not ideal for evaluation of a student where presenting the steps of a calculation is important.

d. Talking calculator

[Image source: attainmentcompany.com]

Talking calculators are accessible calculators with large displays, and high contrast screens, with voice feedback. They are accessible and can do complex operations quickly. The synthetic speech is usually high quality and can be operated with one hand. The keys are regular, without Braille, except for a marker dot on the key 5.

It is automated, and hence may not be ideal as a learning aid where it would be preferred to do some level of mental calculations.

e. Emboss film

Emboss films can also be used with embossing pens for raised drawings. The film is a bit expensive and not easily available in Mumbai. Errors cannot be easily corrected.

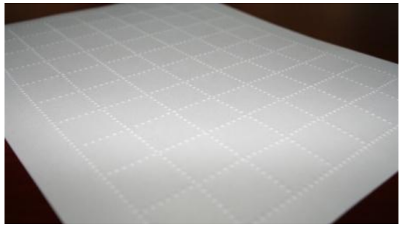
f. Rubber mat and tracing wheel

[Image source: http://shop.quilt.co.jp]

Cheaper paper films can be used for drawing with the help of a rubber mat and a tracing wheel or sharp point. The film is kept on the rubber mat and a sharp object or tracing wheel is used to scratch on the film. This leaves traceable marks on the film which blind people can feel.

Again, errors are not easily corrected.

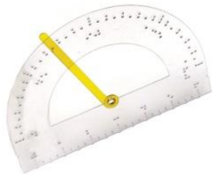
g. Embossed graph paper



[Image source: https://www.prcvi.org/]

Graph paper is made accessible with raised lines, but it is not possible to have high precision grids in a tactile way.

h. Measurement tools

[Image sources: `http://atwiki.assistivetech.net`, `http://shop.aph.org`, `http://www.rockler.com/how-to/blind-woodworking-school-brings-workshop-projects-blind-students/`, `http://cdn.lssproducts.com`]

There is a range of measuring tools available such tactile rulers, tactile protractors, click rules, and talking tape measure as shown in the pictures above.

The challenge is of accuracy and precision. It is difficult to provide precision with tactile tools as it may not be possible to separate dots/perceive them by say a millimetre. Sound based feedback such as clicks of voice can provide more accurate measurements, but such devices would tend to be more expensive.

2. Educational Aids

a. Geometry tutor

Geometry tutor is a product designed by Mr Bhausaheb Shinde of Saraswati High School, Mumbai. It is a kit of geometry tools to explain concepts of points, lines, rays, angles.

b. Geo board

[Image source: `http://www.thecraftycrow.net`]

A grid of spikes around which a rubber band (elastics) can be used to form shapes.

c. Paper folding techniques

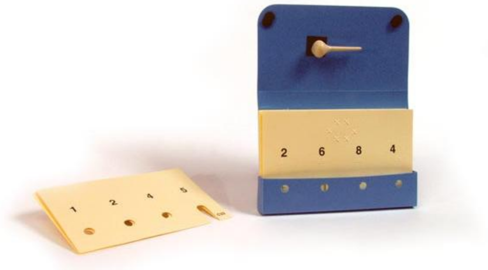
Paper folding is an effective way to explain geometrical concepts. Sundara Row's book on geometric exercises in paper folding is a good example of the possibilities with this medium. Although this book deals with sighted users, the technique is popularly used to teach concepts to visually impaired children

d. Shape sorters

[Image source: `http://store.tagtoys.com`]

There are many types of toys available that teach the concepts of shapes and constraints, and allow children to sort, count, categorize. This may include everyday items like grain, pulses, cards, household items, cloth, etc. which can be stored in various everyday containers like drawstring bags, boxes, Pringles containers, cups, ice trays, fast food containers, etc.

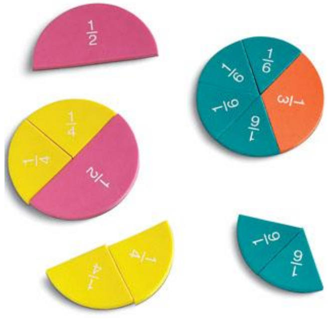
e. Quick pick flash cards



[image source: `https://shop.aph.org`]

This is an interesting mechanical solution for multiple choice questions/quizzes. This quick pick flash cards set provides cards with a question in Braille with four options as answers. There are holes corresponding to the options. A peg has to be placed in the hole of choice. If the answer is correct, the card can be removed out of the container, else it remains locked in. This is because of a slit under the correct answer which allows the card to come out of the box in spite of the peg. But in the rest of the cases, the peg remains locked in the hole.

f. Fraction boards/circles



[Image source: learningresources.co.uk]

These are common and effective tools to explain the notion of fractions.

g. Braillephun math

[Image source: http://shop.rnib.org.uk/]

This is a toy with interlocking bricks with numbers (or letters) which can be used to form sums (or words). The bricks also have large numbers and symbols printed on them along with Braille.

3. Games

a. Dots to shapes

Dots to shapes is a computer game based on 3D audio and haptic feedback. Input is provided by a tablet which has haptic feedback, and output is through a 3D audio which is like a sound screen. The game teaches points in a plane; lines—length, orientation, start and end points; and polygons and curves—to recognize relationships of length and orientations. There are three variations:

Simon: The player has to listen to a sequence of sounds (which represent tones and location through 3D audio) and then reproduce on tablet by locating the points (by matching the audio).

Points connecting: The player listens to audio cues for two points and then makes a line connecting them, or listens to a line and identifies the start and end points.

Concentrating: The player has to identify sonified pairs on lines, squares, rectangles and circles in a grid of 8 cells.

b. Math Melodies

Math Melodies is a tablet based game with audio feedback. The aim to utilise the students' free time in practising math exercises, while keeping it enjoyable. The experience is gamified by providing the reward as a complete melody. Exercises are provided in increasing difficulty. As the student completes them, parts of the melody are unlocked. In the end, the student can play the whole melody.

c. Lugram computer game

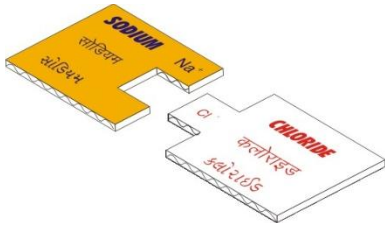
Lugram is a computer game for visually impaired for teaching geometry concepts. It uses the number pad as a 3x3 grid to compose shapes out of basic shapes—squares, rectangles and triangles. No additional tactile devices are needed. It provides puzzles through voice instructions. The main version is *Lugram Memory Game*—where the audio describes a task matrix which is a large shape composed of smaller shapes. It then provides one element at time and the player then composes the shape. There are two variations *Lugram arrow navigation* and *Lugram 3 point navigation* game. In all versions the interaction is through voice and sound feedback that helps the player navigate and make the shapes.

4. Chemistry - interactive solutions for sighted

a. PhET interactive simulations

PhET interactive simulations [14] are a series of simulations in physics, chemistry and other subjects and covers topics like building an atom, building molecules, concentration levels of acids and bases, balancing chemistry equations. They are interactive online simulation but are not accessible to blind.

b. Valency Cards



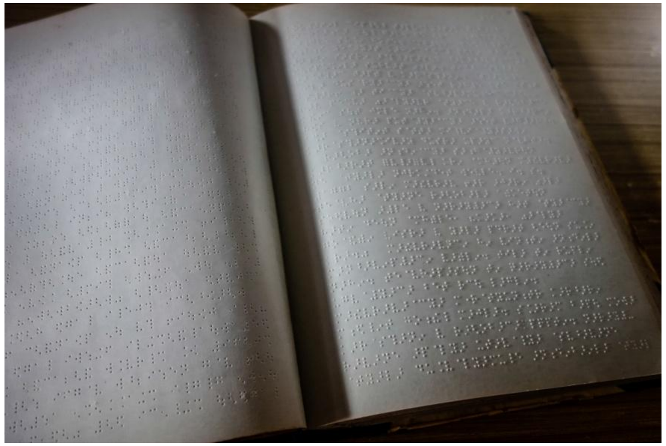
[Image source: `http://www.eklavya.org/chemval.html`]

Valency cards are jigsaw like puzzles which teach the concept of valceny of elements. The cards represent elements with positive and negative valencies and have shapes which can interlock to form valid compounds. I did not come across accessible cards.

Note: A list of detailed resources for visually impaired is listed in the appendix.

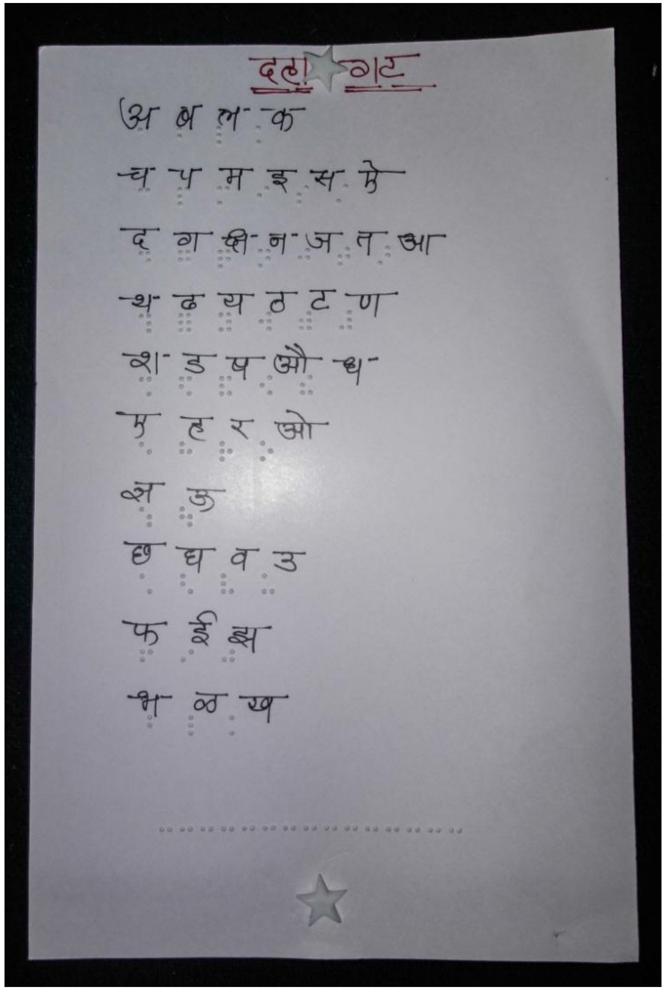
Photo Gallery

Following are some photos taken at SKMDSB of products for teaching.



1. A Braille story book at the library

2. Braille typewriter (Perkins Brailler)



3. Devanagari alphabet in Braille

4. Tactile 2D abstractions


5. Adapted chess board


6. Tactile and soud based alphabet toy


7. Phases of the moon

8. Tactile globe with Braille markings

9. Tactile globe with Braille markings

10. Tactile globe with raised latitudes and longitudes

11. An electronic model of the solar system
with voice feedback

12. Tactile map of India

13. Tactile map of India with labels

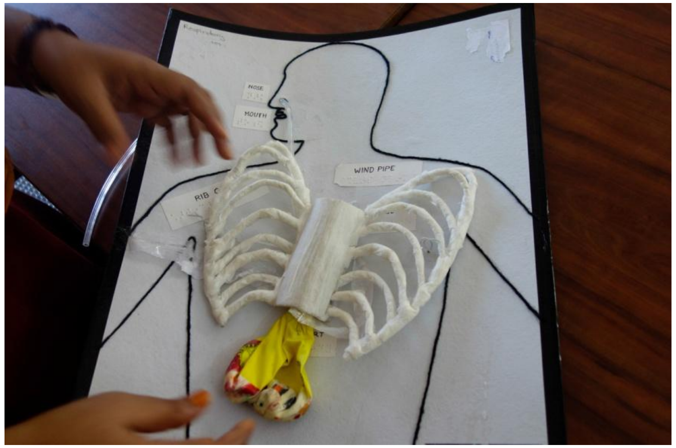
14. Taylor frame slate for mathematical expression

15. Geometry tutor

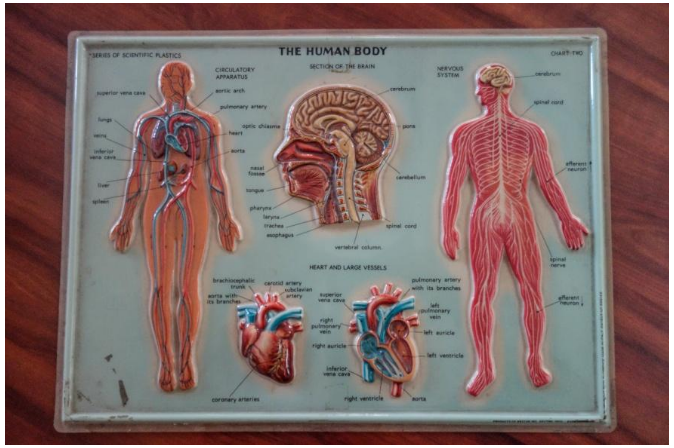
16. A play-kitchen in the pre-Braille class

18. Chemistry lab equipment

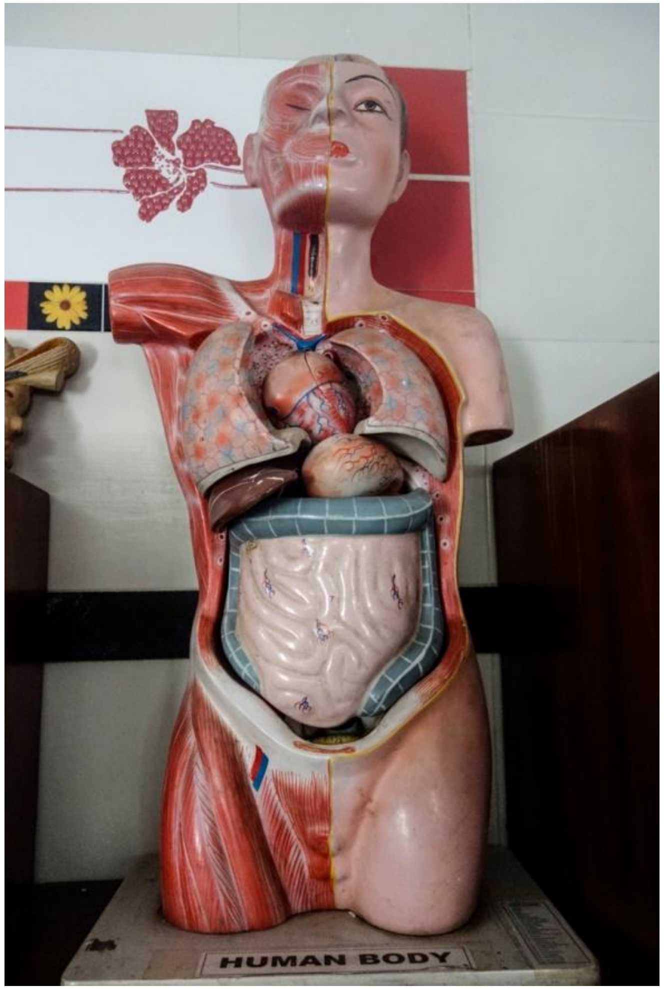
17. A real kitchen in the home science class



19. A model of the respitory system



20. Human body on an embossed sheet



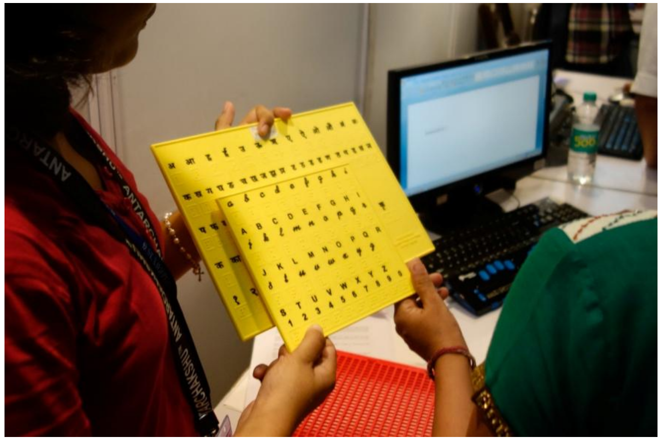
21. A model of the human body and organs

22. A human skeleton in the science lab

23. Tactile model of an animal cell

24. Tactile model of a plant cell

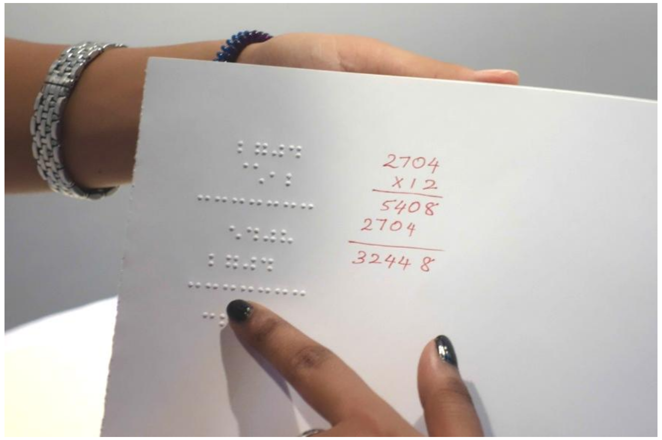
The following pictures were taken during Antarchakshu 2014, an exhibition and workshop on inclusive education for visually challenged children, conducted at XRCVC.



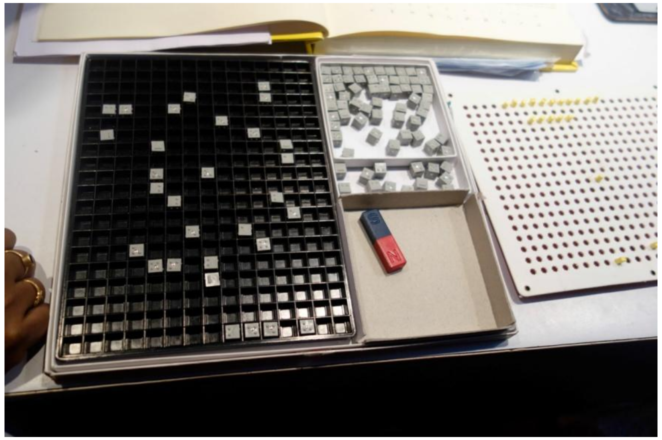
25. Charts of Braille and raised regular alphabet (English and Devanagari

26. Refreshible Braille

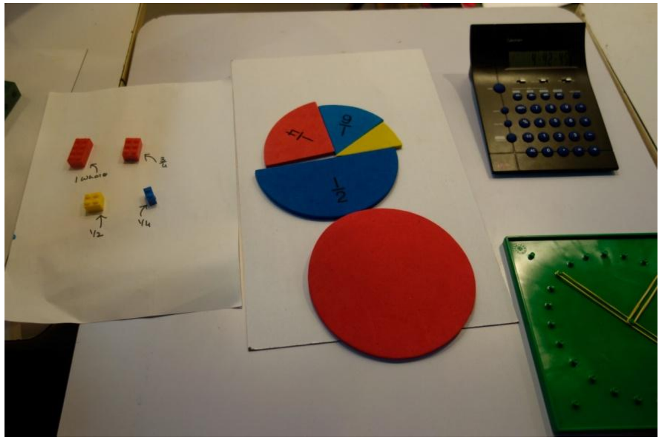
27. Devices to zoom and read printed text



28. Nemeth code



29. Cubarithm: A dice like alternative to Taylor frame

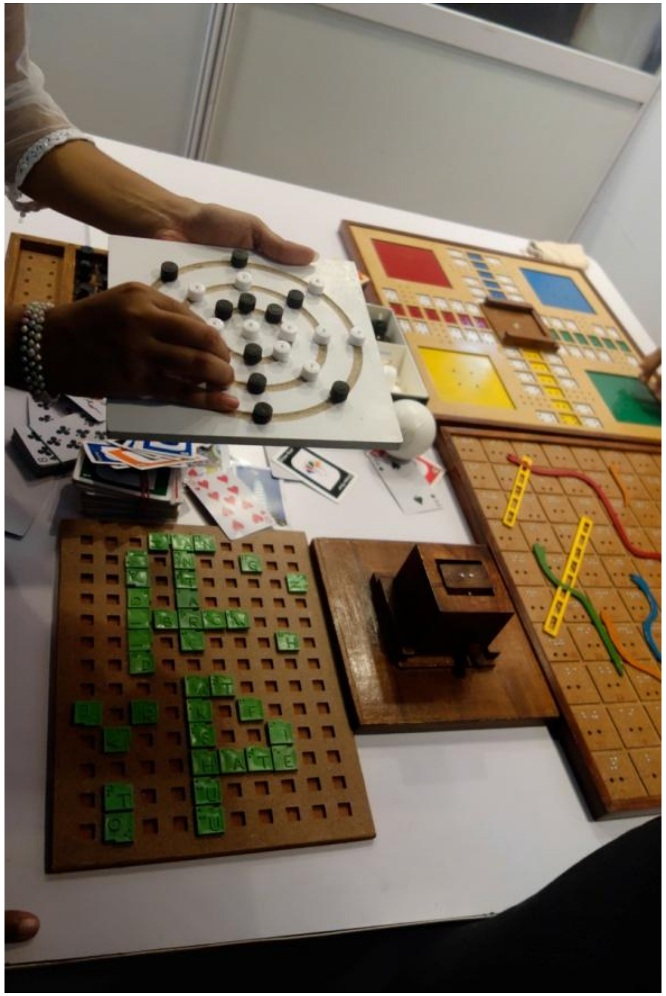


30. Aids for learning fraction

31. Abacus and aids for fractions and geometrical shapes

32. Texture books and Braille calendar

33. Velcro based tools for graphs, a grid for diagrams with thread on foram board, and raised diagrams on paper



34. Accessible games

Key Observations and Takeaways

Modern tools are not easily available or are expensive. So the schools use traditional tools, which are still effective, e.g. the Taylor frame and abacus.

Technological and electronic solutions seem to be less in use. Many solutions are simple non-technical and low cost. This could also make the products more robust.

Tactile products can have limitations of accuracy. Adding voice and sound feedback can make interactivity more effective and useful over pure tactile interfaces. 3D audio (audio which give a good sense of space/direction) can added further dimension to comprehending space. Clarity of voice based instruction is important.

Tangible products seem better suited rather than purely computer based software.

Visible text and Braille can take the same space. The text is in high contrast colours and large font for visibility by partially blind.

Primary Studies

Primary studies were conducted to uncover topics that could be addressed through a learning aid. The aim was to find out what topics teachers found difficult to teach, what students found difficult to learn, and what was omitted from regular curriculum.

Participants

Participants included six teachers from SKMDSB, two retired educational professionals and two college students

Focus of Interviews

We identified three focus areas for discussion and interaction with the participants:

1. *Utility: What is critical to students' quality of life?*
   What skills and values taught in early education are fundamental to living a fulfilled life? Which concepts (from the curriculum) do visually impaired children find difficult to grasp? Are these critical for life—future, jobs, making a living? What challenges they face in learning? What challenges do the teachers face in teaching, and in teaching which lessons?
2. *Expression*
   How do visually impaired children express themselves through art or other means? What are the challenges? What are the children's thoughts about art and craft classes? Is there anything new that can be introduced for expression (that they do not already do)? What is aesthetics without the visual sense?

3. *Technology* (new equipment and electronic)
   Is there a role that technology (electronics, computer, apps, and mobiles) can play in aiding the teaching, learning, or institution in general? What are the current technologies that students learn to use? What are the challenges?

Note: Due to challenges in accessing the blind children in the school due to circumstances, a retrospective interview was taken of two blind students at junior college level, about their education experiences at schools. Most of the findings herein are hence through interactions with the teachers and education professionals.

Interactions with participants were done as conversations, with the following details kept in mind:

With students:
Demographic details:
Name, age, class, home town, language spoken, blindness type and onset.

Education related:
Challenges faced in learning, studying, revising subjects and for examinations; The fun activities as part of mathematics, science and geography; Favourite subjects, least liked subjects, most difficult subjects.

Self-Expression related:
Favourite games, pass time; What they liked doing during arts and crafts classes; Learning music, difficulties involved; Favourite books, songs, poetry; What audio books are read.

Technology related
Devices used (computers, mobiles, apps, radio, watch); What they do with it, when they start using it, what difficulties are faced.

With teachers
Demographic details:
Name, age, (blindness category and onset); teaching experience, subjects and classes taught/

Education related:
Challenges faced in teaching particular topics; Teaching aids made and used; Evaluation and tracking of child's progress; Topics that are left out and not taught.

Self-Expression related
What is fun and enriching to the students.

Technology related
What technology is introduced to students (computers, mobiles, apps, radio, watch) and when.

Findings and Learning

The educators (retired educators, and teachers of arts/crafts, Braille, science, mathematics) reinforced that education needs to move away from blind schools to inclusive learning. A plus-curriculum is necessary where adaptations are made for visually impaired children and a focus on developing compensatory skills at an early stage, where they are taught additional tools for communication. There should also be natural teaching at home.

They highlighted the importance of teachers being well trained, motivated and resourceful. For instance, teachers should go to the extent of blindfolding themselves while preparing an activity to test it. They felt that good teachers are not easily available. Teachers are like mothers away from home to the children, as the children stay away from home in a blind school.

Hands-on approaches and Montessori aids are effective means of teaching. Sensory experiences are important to the children, and as many such experiences should be provided to the children whenever an opportunity arise, whether as part of the curriculum or not. Many concepts may be taken for granted by sighted, but should be taught to the visually challenged. For instance, it may not be evident that an omelette actually comes from an egg, and its original form may not be experienced. They felt that village children were exposed to more experiences than urban children.

Models and educational trips are an effective means to teach concepts. To be more effective, as far as possible, the real thing should be experienced rather than models. SKMDSB has for instance stuffed birds in its museum that children touch and experience. Students may need to use a lot of material for learning.

Braille is quite a versatile language and with its 63 characters it can be used for various languages including Marathi. Students find that Braille is easier than the shapes of sighted characters of Marathi. It is better to teach to read first and then write using Braille as writing with a Braille slate and stylus involves making marks in reverse.

Detailed information is and should be provided orally to the children about the activities and surrounding. For instance, they are very capable of providing detailed instructions for directions in way finding. They can form a strong mental map through sensory experiences. Diagrams and maps should be explained verbally. Orientation and mobility training is an important activity where children are taught to get around safely and effectively in their surroundings.

They may use all their senses, including taste, which may seem socially awkward to some but is fine. Some students need guidance in posture, walking, etc. so as to fit in the sighted world.

One has to keep in mind that partial blindness is more common than total blindness. Even in blind children, there may be some slight light perception. It is important to develop all capabilities that the child has. They should optimise use of available vision. If the child has some vision, help them make optimum use of it rather teaching them and making them use only Braille.

There is little difference in children born blind, and those whose onset was before 7 years. Otherwise there is quite a bit of difference, as a lot of concepts of the world are already clear to those who have lost sight at a later stage. Generally this results in differences in mannerisms.

Visually impaired persons should have an attitude of acceptance that one is visually impaired—rather than not accepting and challenging the fact. Life can be difficult for those who do not accept, e.g. they may not learn to use assistive devices, special canes, etc. and hence not experience the world effectively.

It is difficult for blind children to express themselves—for instance facial expressions, gestures, emotions, etc (as they have not learnt such activities by imitation, unlike sighted children). Theatre is one good way to develop their self expression.

Math and science are difficult and some topics are omitted. Mathematics, for instance is only taught till standard 7, and the textbook is continued till standard 10. They are encouraged to learn, but all students may not have the capability. Students that do have the capability and inclination do pursue math and science, and also go on to become professionals in these fields. E.g., there are students who have gone on to start a clinic and practice physiotherapy.

Music is not taken up by all alike. It depends on their likes. Generally students take up singing, and some students may take up keyboards (which is more common nowadays because of the range of voices), harmonium, table, violin, string instruments, etc.

Children are encouraged to play physical games and physical education is considered important. Gym, indoor games, etc. are compulsory in their time table. Some games such as carom can only be played by partially blind, but other games such as cricket can be adapted for blind.

Interactions with the students uncovered that English language tends to be a challenge to students during integrated education at college. Most school education was in local language, Marathi.

The students are motivated to do further studies, answer common entrance tests for certain positions, etc. but quite often cannot because they have not studied certain subjects and concepts. The students interviewed had difficulty in concepts of maps, angles and some concepts of math and science.

The interviewed students were more familiar and preferred abacus over other math tools and did not consider art and crafts periods as serious.

The following topics were generally found difficult to teach/learn:

- Teaching science/chemistry and performing experiments: Teachers are unsure of taking up certain topics because of difficulty in teaching and visual nature, e.g. colour changes, litmus paper, reactions, etc. which are very vision dependant. Some topics may be dropped out. A verbal lecture on the basic concepts is taken, followed by a hands-on exploration of the chemistry lab and its equipment. No experiments are conducted by the students using the chemicals and equipment.

- Learning languages can be a challenge. The language learning lab has CDs and audio books, but the teachers felt that there is scope for making learning more effective.
- Sound sensitivity development tools are lacking.
- 2D abstractions of shapes are difficult to comprehend. E.g. the common drawing for trees that sighted use is actually a poor abstraction for visually impaired children, yet they are taught such concepts.
- Due to difficulty of 2D abstractions, concepts such as maps and drawing/reading graphs are difficult.
- Geometry concepts such as angles and shapes are difficult. There are tools available for explaining geometry concepts, but there is scope for improvement.
- Taking measurements with high level of accuracy is not easy.
- Colour is only manageable by partially sighted students. Blind children also learn the notion and so that they can communicate with others about colour.

Other observations at Kamla Mehta Dadar School

The layout of the school does not seem to be specifically designed for blind. It appears that this is to prepare them to live and navigate in the regular world.

There are some specific adjustments—such as Braille labelled desks, signs and time-tables in Braille. The lunch mess tables have slots to keep glasses so as to not spill water. Students have assigned places to sit in class and mess.

Braille textbooks are large, so the books are kept in drawers in the desk in the class itself. Students have assigned study hours where they revise and do homework.

Cost of equipment and material is a concern to the teachers, and it is sought to keep interventions at low cost.

I observed a general lack of interactive and electronic models/aids. Those that existed were non-functional because of lack of battery or maintenance issues.

Photo Gallery

Celebrations during *Nag Panchami*


Pre-Braille slass


Singing in a Music class


Sorting different types of grain as a pre-Braille exercise

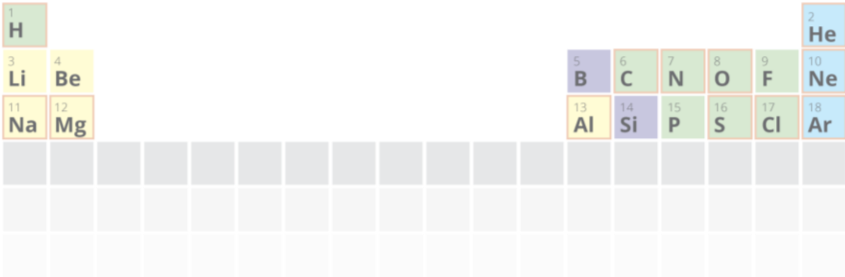

Math class activity, teacher with an assistant

Math class

Math class activity, students learning the use of letters in mathematical expressions on a taylor frame

Math class activity, students learning the use of letters in mathematical expressions on a taylor frame

Students' work displayed in the arts and crafts class



The solution was restricted to teaching concepts of elements of the first three rows of the periodic table (up to atomic number 18 – Argon)

- *Approaches*
  - First-hand experience
  - Simulated experience
    - Group/Individual activity
    - Mediated/Not mediated by teacher
    - In/out of class
    - With/without artefacts

A summary of the approaches used towards the solution concepts

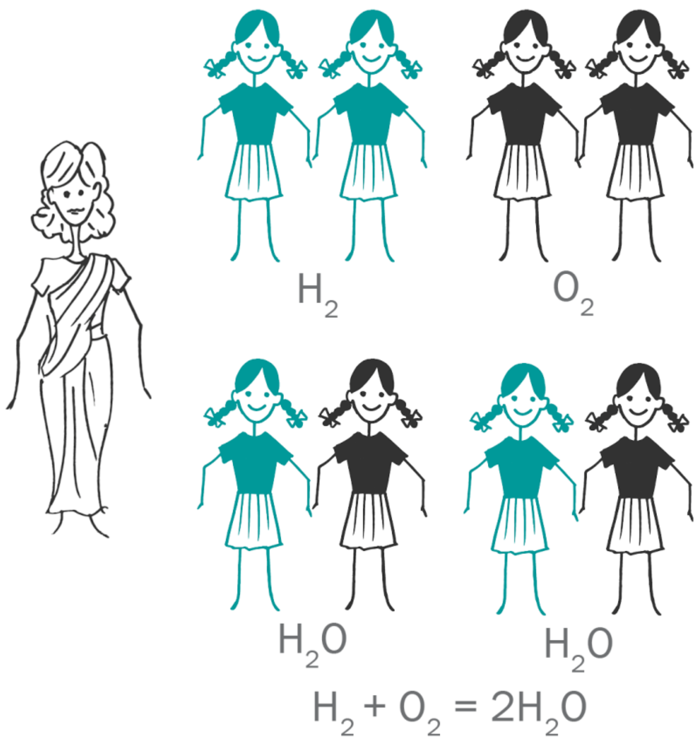
Concepts

Approaches

The student can understand chemistry concepts either through *first-hand experiences* or *simulated* ones. In a *first-hand* approach, the child can directly operate on the chemical reactions through adaption of equipment and lab environment. One approach to make experiments safe is to work on activities involving common kitchen chemicals such as lime juice, soaps, etc. Measurement of quantity, heat, colour changes, pH and transferring of liquids should be made safe by accessible equipment. This approach has been left out of scope of this project, as there are quite a few readily available products, although they are not commonly available or used in local schools.

A safer alternative to performing activities with chemicals is to *simulate* experiments through computer tools or with tangible products. The solutions could be *group activities* with the involvement of sighted, partially blind and blind children as teams, mediated by a teacher (or without), and supported by additional artefacts (or without). The solution can alternatively be an *individual activity* with a focus on self study in or outside of class. A combination of the two would also be appropriate.

We went ahead with thinking of concepts with this broad classification in mind, and considering that the activity should be game-like in its approach, but with a larger focus on the learning aspect.



Teacher guided activity, where students enact reactions by role playing

Concept 1 – Role Playing Group Games

This concept is about games in which students play the role of elements/molecules. The teacher announces tasks (such as forming a molecule or reaction). Students have to find other students who fit into the reaction/molecule, and form groups. These groups can be validated by the teacher.

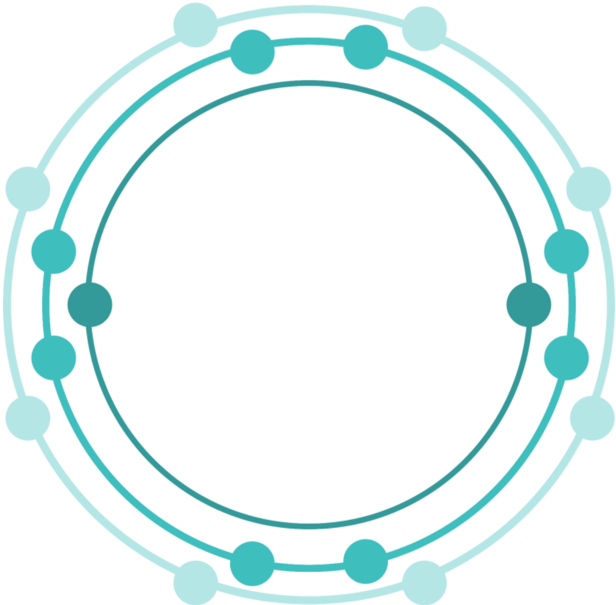
There could be versions of the game where the students may have additional artefacts to support the concept. For example, the concept of valency can be explained to negative and positive shapes that students can mix and share to form proper combinations.

Pros: This approach could be fun and engaging to play, as the class would be involved. It also does not require much in terms of artefacts and technology.

Cons: The learning element and retention of concepts could be questionable. Also, the teacher would have a load on memory to validate combinations.

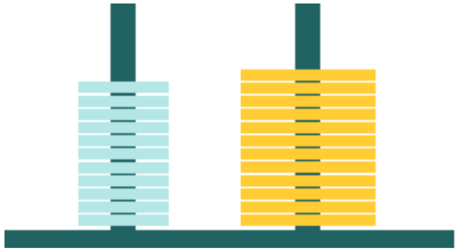
Suitable for teaching:

- Atomic model
- Ions and valency
- Chemical reactions and types
- Balancing equations

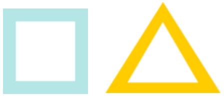


Top view of electron orbits (with switches for electrons)

Side view of electron orbits (with switches for electrons)

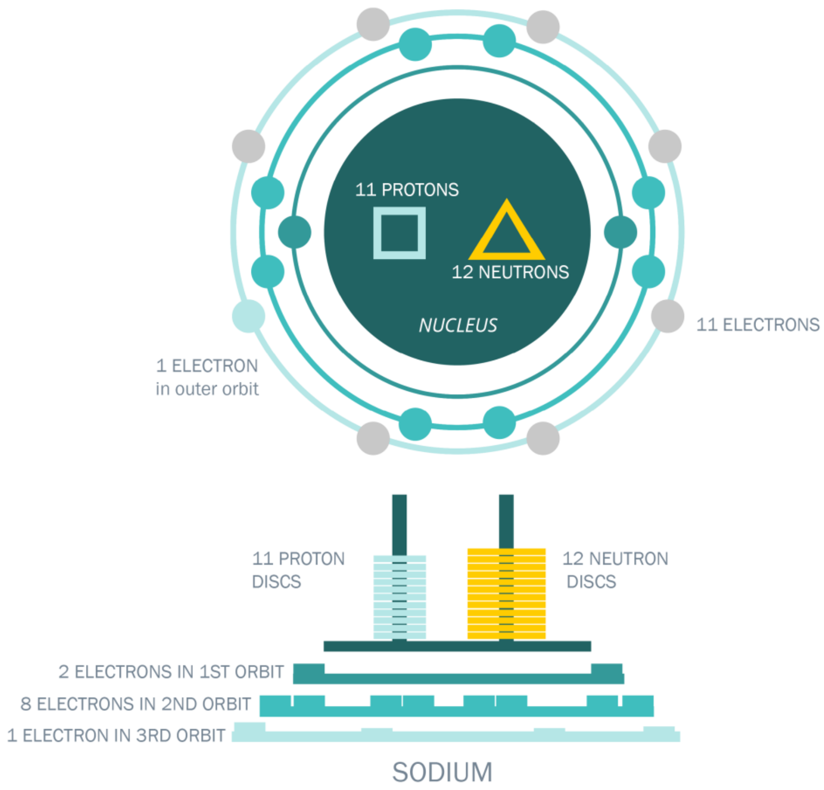


Side view of protons and neutrons stacked in the nucleus



Proton and neutron shapes

Top view of protons and neutrons stacked in the nucleus



Configuration for Sodium (Na) atom with atomic number 11, i.e. 11 electrons (2, 8, 1), 11 protons and 12 neutrons. (Grey dots indicated that the electrons are not present/switched off)

Concept 2 – Interactive Atomic Model

This concept involves an atomic model, which has a region for nucleus and orbits around it. It has building blocks: discs of two shapes for protons and neutrons, and pegs for electrons. The protons and neutrons can be piled up in two slots provided in the nucleus. The electrons can be put in holes in the orbits.

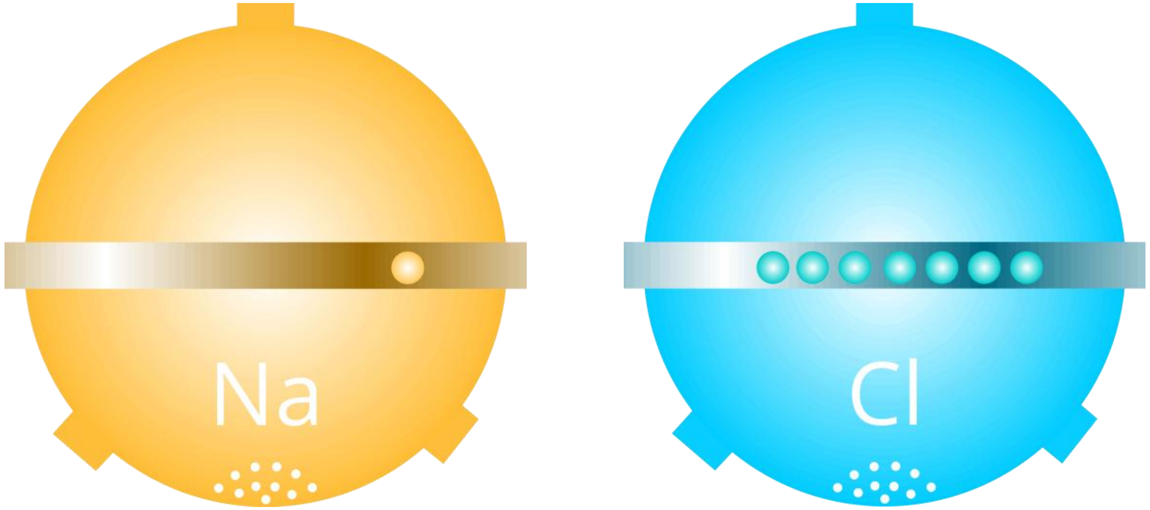
As the student puts various constituents on the model, the board provides feedback through voice. In this way, the student can explore various configurations of atoms.

Pros: Interactive and explorative.

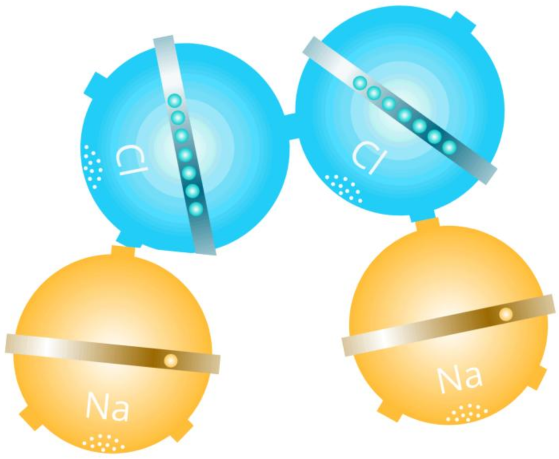
Cons: The shapes might not give a sufficiently appropriate abstraction of the atomic model. Only one or few students can interact at a time with the model. A game concept could be worked around this.

Suitable for teaching:

- Atomic number, mass, periodic tables
- Isotopes
- Stable/non stable atoms

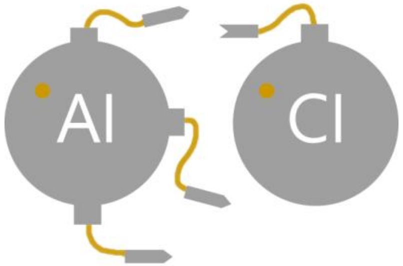


Sodium and Chlorine atoms with the valence electrons in the outer orbit. Sodium needs to get rid of one atom so that the last orbit is stable with 8 electrons (i.e. the next inner orbit). Chlorine needs to receive one electron to complete 8 electrons in its last orbit. This is an ideal pair to combine via a reaction.



$2Na + Cl_2 = 2NaCl$

Na exists in nature as a monoatomic molecule, but Clorine exists as a diatomic molecule (because of the nature of covalent bond to achieve stability). So, two Na atoms are needed to react, break the covalent bond, and form NaCl (common salt). This approach can be used to teach balancing equations.



An alternative form for the same concept, where the negative valency atoms have female connectors, and positive valency atoms have male connectors

Concept 3 – Atom orb (Chemistry Ball)

This concept involves interactive ball units that represent an element (balls can be distinguished by Braille markers that name the element). The student can interact with the ball in multiple ways. The ball poses tasks to the student, which requires them to find other elements to react or combine with. The balls can be attached to other balls depending on their valency (propensity to give or take electrons). The balls can then provide feedback and information about the atoms and molecules formed.

The following interactions are possible:

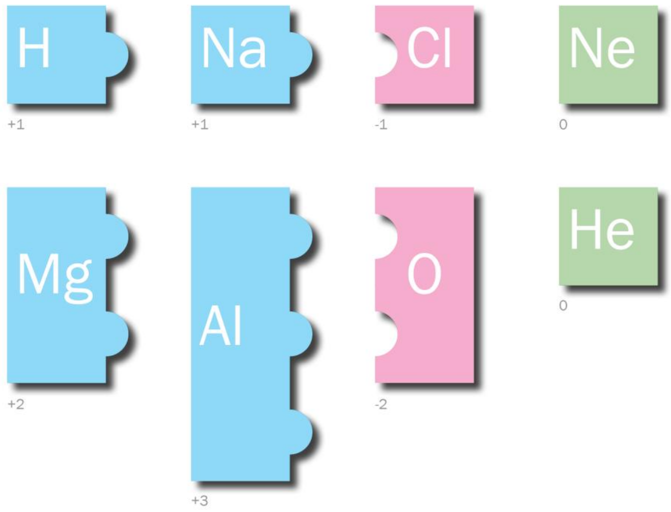
- Shake – to get information about the element,
- Squeeze – the ball speaks out a task to perform (e.g.: given the atomic number and mass number, input the number of neutrons; Form a compound with another element, Form a covalent bond with another atom).
- Tap – provide input (number of taps equals number of neutrons, as per above task)
- Buzzes, tones and voice – for feedback and information.

Pros: Might be interactive and fun

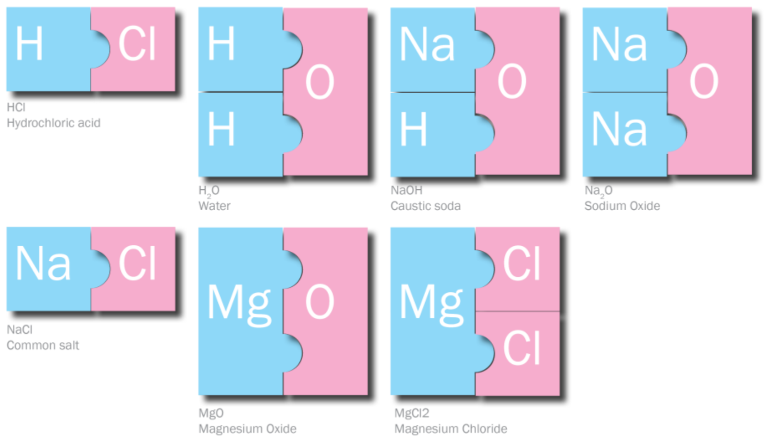
Cons: Would involve a lot of sensors and accurate implementation.

Suitable for teaching

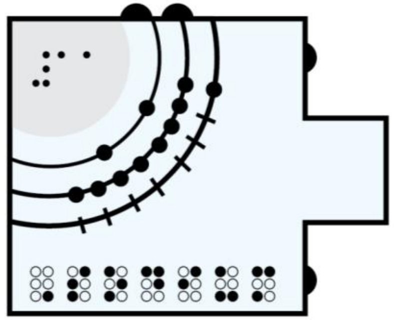
- Atom (mass, number, electrons, protons, neutrons, isotopes)
- Stable/non stable atoms
- Reactions



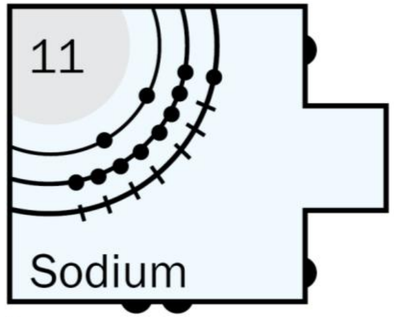
Jigsaw like representation for positive and negative valencies



Some of the possible combinations

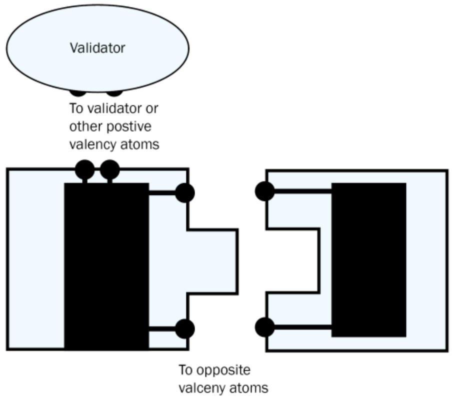


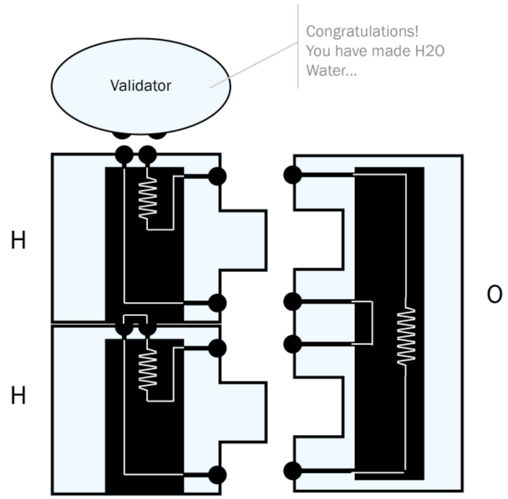
Front



Reverse

Accessible form of the cards, with electronic connection points to complete circuits which will speak out details of the compound formed by combining atoms





Internal circuits to detect valid combination by connecting to a Validator with a processor and speech output capability

Concept 4 – Chemistry Cards/Blocks

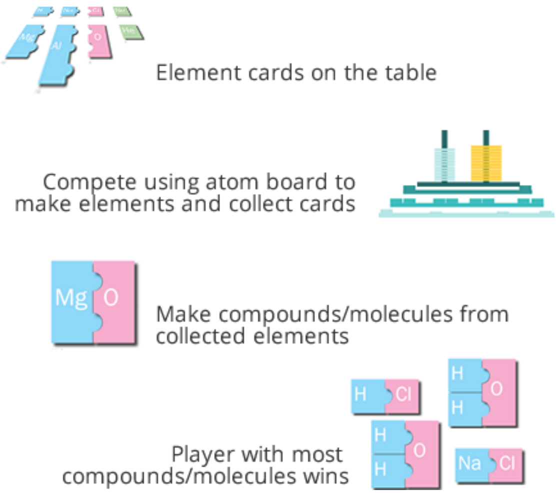
This is similar to concept 3, however a different form has been explored. The disadvantage of too many sensors has been removed. This concept uses a jigsaw like approach where elements with positive valency are blocks/cards with protrusions. E.g. if an element has valency of +2, then it will have 2 protrusions. Elements with negative valency have cavities in which the positive valency elements can be fitted. If different valencies are available, there would be different types of blocks. In this way, elements can be combined to form valid compounds. The blocks can be identified by their size and markings on the surface which informs about the atomic number, name, etc. Each block has partial circuits embedded within, and when a valid combination is achieved the circuit is completed. The combination can be plugged in to an external validator with a processor, which provides more information.

Pros: The student will be able to discover various possible compounds by trying different attachment. It is like a simulation of reactions.

Cons: Many such jigsaw approaches exist, and this (the form) may not provide a clear mental model of the element itself, because of the shape.

Suitable for teaching

- Reactions
- Compounds
- Valency



Concept 5 – Game Ideas

The concepts 2 and 4 (the atomic model and cards) can be combined and used as part of a game. This would be useful as reinforced learning, once the student is a bit proficient in the concepts of atoms.

The basic concept is as follows:

- There are some elements (cards) on the table.
- Each player has to compete to collect as many elements.
- They collect by forming new molecules with them, i.e. the player can pick from the table by using their cards to combine and form a valid combination.
- The player ending with most cards wins.

There are various configurations possible:

- Each player has an atom model board (concept 2)
    - Players first build an atom with the board,
    - Use this atom to pick cards from the table.
- Only one board for all players
    - Each player gets a turn to form an atom,
    - Use this atom to pick cards from the table.
- No board, only cards/blocks are available
    - Each player has cards to begin with.
    - Players react with other's cards to capture elements.
- No cards, only board
    - Players challenge each other to form stable atoms

Evaluation of Concepts

The concepts were discussed with the science teacher at SKMDSB. The ideas are discussed in increasing order of acceptance.

Concept 3 would involve a too many items and may get chaotic in finding the right ones. Integrating sensors could be difficult to manage.

Concept 1 is very simple, but would be a load on the teacher to manage. The learning and retention of concepts may not be sufficient. I felt that I should explore a technological solution rather a very low cost approach, although this approach could have been effective through an appropriate game.

Concept 4 would be easier for students as compared to concept 3 (which is similar, but differs in form—concept 3 being closer to the atomic model). We felt that using large blocks would not be very effective, but if they were like small cards, it could work better. Such valency based jigsaw cards however exist in the market. I felt that adding accessibility for visually challenged may not be sufficient to the scope of the project. The concept explores adding electronics to speak out various combinations, which would be a useful extension to the concept, but validating the combinations would involve a large amount of circuitry and also make the cards larger leading to block-like structures, which may not be very usable.

Also, the concepts of valency are not taught to the students. Sufficient knowledge of the atom would be required before using concepts 3 and 4. They could be good ways to learn reactions

Concept 4 seemed ideal to explore further as the final concept as it covered one of the fundamental topics before advancing to other topics in chemistry, i.e. the atomic model and its constituents. We felt that the shapes of the components and the structure would not be a very appropriate abstraction of the atomic model, so in the final concept, alternatives were explored. This could work with interactivity for students one at a time more appropriately, and could also work out as a group activity.

(Concept 5 is a combination of the concepts 2 and 4, and can be explored further after these concepts are evaluated).

Hence we explored concept 2 and modified some of the aspects which is discussed in the next section.

Final Concept

Atomatic—Interactive Atom Builder

Concept: The atomatic board has a nucleus region and orbits. These regions consist of holes in which pegs can be inserted. The pegs represent protons, neutrons and electrons. The correct pegs need to be put in the appropriate holes. I.e. Protons and neutrons can be put in the nucleus, and the electrons in orbits around the nucleus.

As the student inserts pegs, the board responds by hums, sounds and voice. The board guides the student in building a valid atom by means of voice and tones.

A valid stable atom needs an equal number of protons and electrons, so that the charge is balanced, and the right number of neutrons. Variations from this could either result in unstable ions or isotopes, or an unnatural atomic configuration.

As the student explores the board gives cues whether the student is close to making a stable atom, if there are unbalanced electrons and protons, and whether the number of neutrons need to decrease or increase. In case the student seems lost, the board might speak out suggestions. The board provides voice and sound feedback and suggestions based on different situations, thus teaching various concepts of the atom and elements.

As soon as the student configures the atom correctly, the board speaks cheers the student and speaks out details about the atom.

The information itself is spoken out in first-person voice of the atom, where each atom is given a character based on its properties. Information about the element is delivered through a rhyme or song. By keeping the information in an interesting format, we expect the student to be motivated to explore and find other elements and over time learn about them, and easily memorize properties.

The teacher can also intervene and provide challenges and hints to the students at various points.

In this way, the student can explore various combinations of atoms, and learn about atomic configurations, orbits and constituents, and properties of various atoms. The teacher can, in this way, provide a fun and engaging learning experience.

Alternate mode of operation: In the above mode, the assumption was that the student knows only basic information about atom i.e. that its constituents - electrons, protons and neutrons. Student may not know what combinations make which elements.

However, if the student is proficient enough, the board can run in a challenge board, where it is essentially silent and does not give cues while constructing. Only upon pressing a validate button, would the student provide the status and clues.

In both cases, prior training of the basic concepts of the atom would be useful, probably as a lecture by the teacher.

Learning Goals

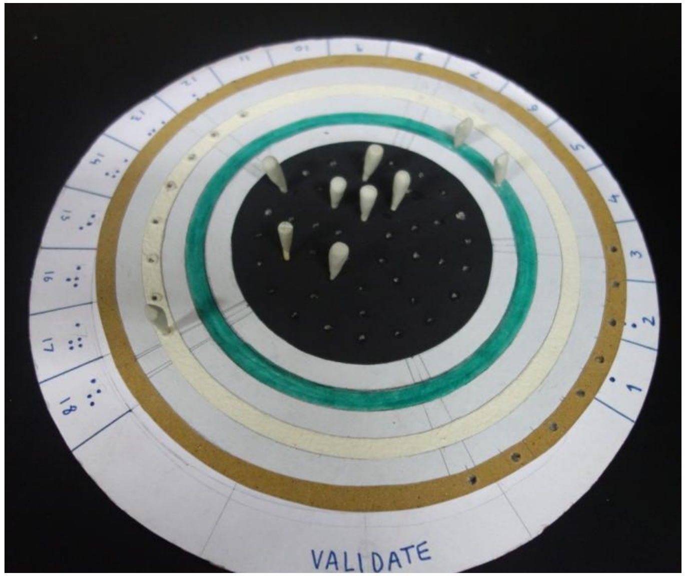
The student should be able to explain the concept of atomic model with nucleus and orbits of electrons. The student should be able to state constituents of an atom—protons, neutrons and electrons.

The student should describe what makes the atomic configuration stable.

Given an atomic mass number, the student should be able to calculate the number of neutrons and protons in the nucleus.

The student should be able to recall over time, the atomic number of an atom, and some information about the atom—e.g. where is the atom found in nature and its properties.

Initial Prototype



I created a prototype of cardboard and Thermocol to demonstrate the concept, and simulated the adding/removing of pegs to the board with the responses separately in Processing. A black circle with chart paper for texture represented the nucleus on the board. Textures from smooth to rough represented the orbits (inner to outer)—smooth transparency for orbit 1, rougher watercolour paper for orbit 2, and very rough sandpaper for orbit 3. 40 holes were scattered in the nucleus to permit 18 protons and 22 neutrons. The holes for electrons in the orbits were kept clubbed together so that they can be easily found and counted. Pegs were made of craft m-seal and match sticks. The pegs (as on figure on pg 52) were shaped as smooth top for neutron, flat top for protons, and as an edge for electrons (the idea was to provide the concept of negative, positive and neutral charge).

Evaluation of Prototype

I discussed the prototype with a resource educator, teacher, a design student with experience in design for blind, and 5 visually challenged (3 blind, 2 partially blind) college students. In general, the students would be able to identify the holes, the nucleus and orbits. Sound (pitch and notes) based approaches to counting or judging the number of protons and electrons (which is more) seems feasible and can be explored.

The visually challenged students were able to grasp the concept of atom but were a little reluctant as they had not studied about it earlier, and it was slightly challenging to explain it effectively

The key challenges that can be re-thought are presented below:

Minimise mental model mismatch with the abstraction (abstraction of the atomic model should be as close to the reality as per the theory): The orbits were represented with thick textured lines. In reality, an electron simply orbits the nucleus. The representation in the model is an abstraction based on visual abstraction. An attempt can be made to bring the abstraction as close to the accepted notion. Similarly, the nucleus is just a collection of the protons and neutrons in the central region, and the black chart is simply a means to identify the region. This should be made as clear as possible to the students through the design of the board. Also rather than clubbing electrons together to make it easier to count, the electrons could be spaced apart as per the usual model. The visually challenged children should be able to find the holes.

High-contrast colours: The prototype very little high contras colours (black, white and green). The colours could be used more effectively. Preferred colour schemes are black and white (or yellow), yellow and blue and red and green.

Very rough textures can be harmful to the sensitivity of fingers: Sandpaper is a bad choice as it is very rough and can harm the sensitivity of finger tips. Textures should be in subtler shades.

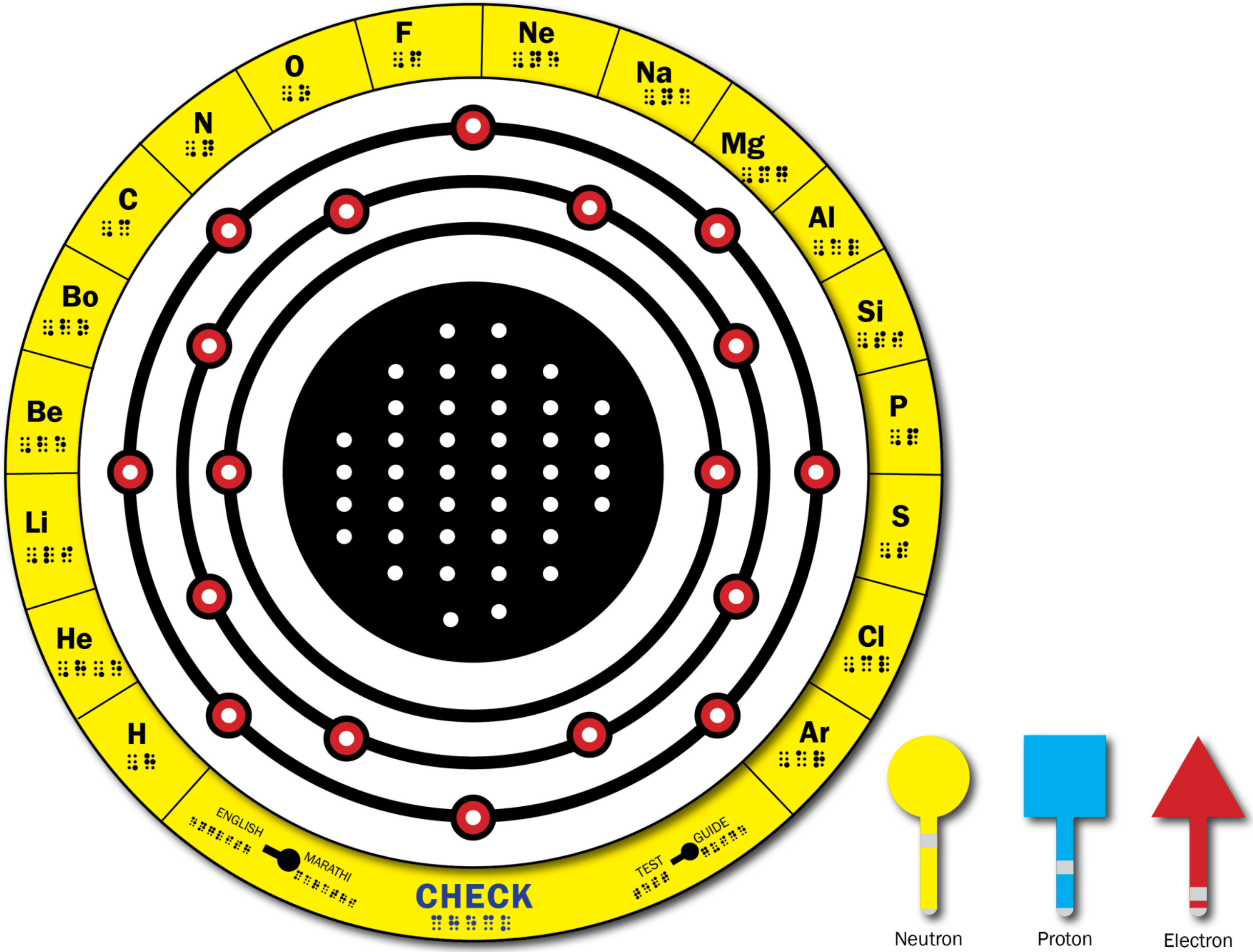
Grooves or textures for orbits: both options would be fine. Grooves could help find the holes by sliding the pegs along the grooves. Textures would require the use of fingers.

Need for initial training on the concepts of atoms: Many students of higher classes do not have sufficient knowledge of atoms and chemistry as they have not been taught the topics. Hence to understand the concept, would require sufficient initial training probably through known analogies.

Identifying the pegs easily: The pegs can be more distinguishable. In the prototype three shapes are quite similar. The blind students could identify them correctly, but the partially blind student had difficulty as he depended on sight and all three pegs looked similar at a glance. Hence colour and texture would help.

All student may not know the visual representation of positive and negative (+ and -) but as long as they are told which shape represents which constituent, they would be able to use the pegs correctly. The shapes can be arbitrary.

The reference list of elements: surrounding the board could highlight the element name rather than the atomic number. Also Braille can be laid over the visible text (by use of Braille stickers and polymer deposits) and the visible text should be in high-contrast and large font size of around 20 points. Audio labels could also be explored, but are expensive.



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Product Details

Form: The board is circular as shown in the figure across with a diameter of 13 inches. Electronics are embedded under the board, with speakers at the side. The board surface is of acrylic with paper textures for the orbits.

Textures: the nucleus has a smooth texture of acrylic sheet. The orbits have textures of increasing roughness from inner to outer orbit, so that they can be easily distinguished as first second and third.

Text: Surrounding the board is a reference sheet of elements arranged by their atomic numbers. The text is in large text and Braille. (Transparent Braille text will be overlaid on the visible text if possible via polymer deposit printing.)

Colours: High contrast colours black on white background are used for the board, and yellow, blue and red for the pegs.

Sound and voice feedback: Audio feedback is provided as tone, buzzes and voice messages.

Errors are indicated by a buzz followed by a voice message which directs corrective action.

When the student places a pin in the board (or removes one), the state of the board is indicated by three notes played quickly and successively. Protons, electrons and neutrons are represented by three musical instrument voices. If all notes played are the same note, it implies that there are equal number of protons, neutrons and electrons. An uneven set of notes imply in imbalance. A combination of higher note and lower note implies that the quantity of one constituent is higher than the other by the tonal difference.

A low pitch instrument like bass guitar or double bass (instrument 1) represent protons, and a high pitch instrument like a harp or piano (instrument 2) represent electrons. A third contrasting instrument (instrument 3) represents neutrons. Notes are played successively on placing or removing pins. If there are equal number of protons, electrons and neutrons, then all tones are of the same note, e.g. a C played by instrument 1, 2 and 3. If there are more protons than electrons the notes are different. The proton instrument will play a higher note, and the electron will play a lower note. The difference in notes will represent the difference in number. Assume one electron/proton is represented by the note C. If there are 5 protons and 2 electrons then, the notes played will be G and D of two different instruments. Similarly different notes will be played if there are more electrons than protons. The third note will represent the number of neutrons.

When a correct configuration is reached, the board will beep and speak out a voice message with information about the element.

Each element is provided a humanized character based on its properties and speaks in first-person voice. Helium in this case is a noble gas, and hence would have a proud voice and language of nobility such as a prince. Following is a sample script:

"Good day, I am Helium! My chemical symbol is H. I have 2 protons, 2 electrons and 2 neutrons. I am a gas without colour and you cannot smell me. You can find me in large amounts in the sun. My name itself comes from the Greek word for sun Helios. I am so light that you can fill me up in balloons and I will make the balloons float in the air, because I am lighter than air. I am also used in rockets as fuel. My electron orbit is full with two electrons, and so I do not react or mingle with other elements. I do not need their electrons."

Analogies and details of atoms have been referred from `chem4kids.com` [13].

The board also speaks and suggests action if the student seems lost, has waited too long, or is very far away from making a valid element.

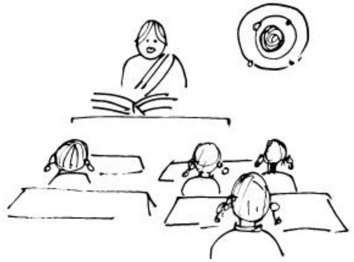
When the board is switched on, a short voice message explains the concept of an atom. On placing the first pin, a voice message explains the rules.

Learning: Mistakes are encouraged on part of the students. Any peg (electron, neutron or proton) can be placed anywhere in the board, but the board will then respond appropriately with feedback. In this way, the student will learn the number of electrons in each orbit, the order in which the orbits are filled, and the location of constituents in the atom.

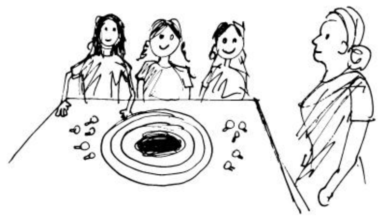
Atomic number (protons, electrons, neutrons)	Key characteristics
Hydrogen (1, 1, 0)	Most abundant gas, Combustible, lightest element
Helium (2, 2, 2)	Noble, present in sun, balloons
Lithium (3, 3, 4)	Used in batteries
Beryllium (4, 4, 5)	Rare, poisonous, found in gems
Boron (5, 5, 6)	Low abundance, found in ceramics and detergents
Carbon (6, 6, 6)	Basis of life, almost everywhere
Nitrogen (7, 7, 7)	80% of atmosphere, liquid nitrogen is very cold
Oxygen (8, 8, 8)	Breathe to survive, part of water and ozone
Flourine (9, 9, 10)	Poisonous, keeps teeth white
Neon (10, 10, 10)	Noble, glows, TV, lasers,
Sodium (11, 11, 12)	Salt
...	

A list of atoms and their properties (also see appendix)

Working (ecosystem)



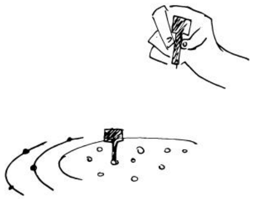
The teacher takes a lecture from the chemistry text book on the basics of atoms. The concept of atom and its constituents are introduced



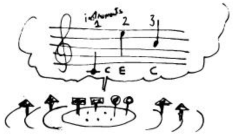
Later, as an activity, the teacher introduces the atomic model. The students first touch the textures to learn the structure—the nucleus and the orbits. They also feel the holes which represent the locations for protons, neutrons and electrons.

The product should work appropriately whether where a single student operates or a group operates it.

The product is switched on by a toggle at the side. It beeps and a voice introduces the concept of atom.



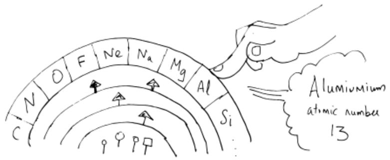
A student can interrupt the voice, by placing the first peg in the board. This results in explaining the rules of operation. The student then explores possibilities by placing pegs at random (if the student is novice, or deliberately if they know the configuration of an element).



As the student places pegs on the board, the audio tones provide a sense of the balance in the number of protons, electrons and neutrons.

If the student seems to be struggling or is nearly making a valid atom, the board speaks out clues. The student can also press the ‘check’ button for clues at any point in time.

In the alternative mode, the teacher can test the students by turning the guiding sounds off. The student is given a target atom and has to form the atom. The combination can be validated by pressing the ‘check’ button. In this way, games could also be constructed as suggested in concept 5 of the previous chapter.



There is also an interactive ring around the board, which is like a reference sheet about each atom in the periodic table (up to atomic number 18). The student can get basic details about the atom by pressing the atom name. This reference board can be attached and detached from the model board.

Implementation Details

The circuit is implemented via an Arduino Uno board. Each hole is connected to a series of analogue multiplexers. The multiplexers provide the state of the hole to the processor. The pegs have rings which can complete one of three possible options in the circuit—to represent protons, neutrons and electrons. Upon identifying a change in state of the board, the processor takes actions (play a voice clip, sound tones, etc).

Evaluation

Evaluation Plan

The following factors will be assessed with blind, partially blind and sighted students:

- Usability of form factor and interactivity
- Effectiveness of learning
- Game design parameters: fun and engagement, repeat play…
- Effectiveness of using as a teaching tool

The following methods would be used

1. Expert evaluation from the teachers
2. User evaluation by students

The student evaluation would follow the protocol below:

- Informed consent
- Pre-test questionnaire on the existing knowledge of atoms and elements.
    - Evaluate based on some questions about simple atoms, number, concept of atomic number, mass number, protons, neutrons, electrons, properties, where you find the atom.
- Brief initial training
- Allow the students to explore in two modes: single person and as a group

    - Observe and video record/photograph the interaction of the students and analyse for game design parameters
- Post test of similar questions to the pre-test
- Collect feedback from students and teachers.

Evaluation Outcomes

Observations during game play

- Students enjoyed the poetry and the error sounds.
- They could easily identify the pins. Blind students used their fingers to identify shapes, partially blind depended on their of their partial vision to identify colour and shape.
- They followed grooves with fingers rather than using the pin to follow the grooves.
- If an atomic number was known (eg. C - Carbon) by the student, they would put all the protons first, followed by electrons and neutrons. In this case the board currently informs the students that that there are too many protons on the board, and they should try putting in more electrons. But the student is aware, hence such cases need to be designed for further.
- The tonal differences which represented the state of the board (number of protons, electrons, neutrons) were not easy to identify, and alternative mechanism is required or better sounds).

Feedback after game play (both from students and teachers)

- The students were able to retain some amount of information about the atomic model and properties of elements from the nursery rhyme (and were able to recite the rhyme).
- The textures were too subtle, but distinguishable and did not really aid in distinguishing the orbits, but the spacing helped.
- Inconsistent spacing of orbits helped in identifying the orbit number better than the texture (we can possible save on the cost of texture by using this approach).
- Voice clarity was appreciated.
- It would help to have a voice snippet to explain the board initially.
- Pins can be of shapes identifying positive (+), negative (-) and neutral charge, instead of only the geometric shapes. The pins can also have markings along the sides. E.g textures on side of pin and dots on top.
- A three dimensional model can be explored to provide a better mental model of the atom.
- Blue colour orbits might be easier to distinguish. A Blue and Orange scheme of high contrast may work better than Black and White. Adding white borders to the holes will help find the holes easily.
- The game can have multiple levels—for beginners and advanced. Different tone of language can be used for advanced students (the current tone is for younger children)

Future work

After working on evaluating the effectiveness of this approach, the model can be improved further to add more aspects of learning. One needs to understand the various strategies that a user may use to construct an atom and provide bits of learning at various stages. More advanced concepts of isotopes and valencies can be integrated. Support can be provided for more elements (greater than atomic number 18). The board can be developed in multiple languages, and for a beginner and advanced level of users. Alternative forms can be explored (e.g.three dimensional) to provide a better mental model about atoms.

Conclusion

Atomatic is a product aimed at introducing the fundamental atomic structure to students as a stepping stone towards study of chemistry. The initial concept has received positive response from the teachers and students, the only concern being that students felt reluctant as the atom is a concept they have not learned and are not comfortable about. The idea is to break this discomfort and provide an enjoyable experience to learn the concepts.

The project was a source of learning to me in the context of the challenges and factors involved in designing for visually challenged, while keeping the solution also inclusive of sighted. It was a great experience interacting with the community and learning about their challenges and their attitudes. It was also an insight into the challenges and working of the special education community.

The project also helped me experience designing not-digital and tangible interactive products which required me to work in the wood and plastic studios and learn to use appropriate tools and materials. The project also provided me some learning in electronic circuits, and prototyping with Arduino and Processing. I explored the option of using audio and voice as interface, with humanized characters to the elements.

I hope that the product evaluations would be successful in teaching students about the atom in an enjoyable and uncover the necessary refinements for the design. It was observed that math and science education is lacking for the visually challenged community simply because of the belief that it is not possible for them to learn. However with good design, the students could be taught complex visual concepts. I hope that the product can be a step towards this and encourage more students to participate in science learning.

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23. Teaching Mathematics to visually impaired children in low income settings: a review of the literature. Stacy Rowe

Appendix

Text books referred

1. General Science—Standard 8 Maharashtra Board
    a. Atomic structure; Chemical reactions and their types; Metals and non-metals; Carbon and Carbon compounds.

2. General Science—Standard 7 Maharashtra Board - Ch. 17. Acids, bases and salts.

Resources for visually challenged

- http://www.fredshead.info/2009_05_01_archive.html
- http://www.teachingvisuallyimpaired.com
- http://www.tsbvi.edu/national-agenda/1831-preparing-tactile-adaptations-for-math-and-science-iowa-state-university-video

Elements

Number	Name	Short	Protons	Electrons	Neutrons	Mass Number	Type
1	Hydrogen	H	1	1	0	1	Non metal
2	Helium	He	2	2	2	4	Noble gas
3	Lithium	Li	3	3	4	7	Metal
4	Beryllium	Be	4	4	5	9	Metal
5	Boron	Bo	5	5	6	11	Metalloid
6	Carbon	C	6	6	6	12	Non metal
7	Nitrogen	N	7	7	7	14	Non metal
8	Oxygen	O	8	8	8	16	Non metal
9	Fluorine	F	9	9	10	19	Non metal
10	Neon	Ne	10	10	10	20	Noble gas
11	Sodium	Na	11	11	12	23	Metal
12	Magnesium	Mg	12	12	12	24	Metal
13	Aluminium	Al	13	13	14	27	Metal
14	Silicon	Si	14	14	14	28	Metalloid
15	Phosphorus	P	15	15	16	31	Non metal
16	Sulphur	S	16	16	16	32	Non metal
17	Chlorine	Cl	17	17	18	35	Non metal
18	Argon	Ar	18	18	22	40	Noble gas