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Sensory Substitution, Key to Inclusive Learning

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Contents

Abstract

Visually impaired students, in primary education, encounter unique challenges while learning creative skills, exploring artistic expression and developing problem-solving skills, because so much instructional content is delivered visually. Sensory substitution—an approach that replaces visual information with feedback from other intact senses like touch, sound, taste or smell—provides an opportunity to address those challenges.

Through the use of sensory substitution, this thesis proposes concrete ways to capitalize on the enhanced abilities of visually impaired primary school students. The research outcome of this thesis is a system of templates that puts these enhanced abilities to work for visually impaired students, to support them while they learn creative skills and practice problem-solving in a classroom setting. Each template contains a lesson that can be learned by using the process of paper quilling. The templates work equally well for sighted and visually impaired students, since all will be able to understand the lesson by using the sense of touch, as they learn by making.

Introduction

Mariam is a student at Al Noor Institute for the Visually Disabled in Doha, Qatar. She loves to paint; however, her eyesight had been depreciating slowly for the past few years. Mariam painted landscapes and flowers using bright colors. Laila, her art teacher at the institute, displayed her work all over the building. In 2019, Mariam lost sight in her left eye and had a range of 2 centimeters of sight in her right eye, but that did not stop her from exploring and expressing her creativity. She used to position her canvas within her range of sight, so she could see and paint. Mariam has since lost her sight entirely, but she continues to paint using muscle memory and Sensory Substitution techniques.

Sensory Substitution (SS) is a principle of learning used at Al Noor Institute. This approach to learning relies on replacing visual information—needed to conduct a particular task—with information perceived by using an intact sense.

Through this technique, visually impaired students find ways to participate in similar activities as sighted people, by using other senses: touch, sound or smell.

I went to the institute to talk to the students, to understand how they manage in a school environment that teaches them how to use tools made for sighted students. I focused on Al Noor Institute's art and craft lessons. I was surprised and intrigued to find a school for visually impaired students teaching visual modes of making (Fig.1). The idea that a school for visually impaired students has a department dedicated to arts and crafts—including visual modes of making—surprised me. I was curious to understand how the students use creative tools and how they express their creativity.

Figure 1 - Examples of artwork displayed in Al Noor

The Arts and Crafts Department within Al Noor Institute teaches various methods of making, including laser cutting and mold making, as well as crafts processes like pottery, painting, collage, crochet and latch hook embroidery (Fig. 2). For this department to successfully teach students these processes, the teachers have developed a set of classroom strategies. The first step includes training and recognition. When introducing a project with a new mode of making, the teachers arrange all required tools on the table in front of each student. The teachers then spend time describing, in detail, what each student has in front of them, and defining the main objective of the project. This helps the student to create a mental picture of what is expected, and how to master the process.

The Physiotherapy Department is involved at this initial stage of learning as well. Improved dexterity is one of the most important benefits of teaching arts and crafts to visually impaired students

Figure 2 -Examples of crafts results displayed at Al Noor

Training is a vital principle used in Sensory Substitution (SS). The art teacher and the physiotherapist, together, spend about ten minutes with each student at the start of a project, in order to introduce new tools. They hold both the student's hand and tool, guiding the hand while performing the action multiple times, training the student to use the tool. During this time, students develop a certain level of comfort, learning to do a particular task with an appropriate tool. In addition to teaching students to use art tools, they also use techniques of Sensory Substitution (SS) to help students understand and utilize tools they will find useful in their daily lives, like screwdrivers (Fig. 3). For visually impaired students, for instance, scented markers allow each marker's color to be identified by smell.

Throughout this study, I examined how these tools can be manipulated or 'hacked' to aid visually impaired students. The focus of this research examines the ways in which visually impaired students can capitalize on their sensory capabilities and strengths to facilitate a creative process within a pedagogical environment; to generate alternative forms of creative practice driven by their abilities, to eliminate the disadvantages otherwise posed by their disabilities. To do this, I utilized the concept of Sensory Substitution (SS). This concept has specific principles that are a requirement when designing a successful Sensory Substitution Device (SD), which allows use by the visually impaired without much assistance or extra effort. The strategy considers the natural, enhanced abilities of the visually impaired, so that any device that utilizes Sensory Substitution (SS) is intuitive and user-friendly.

Figure 3 – A student training to use a screwdriver at Al Noor

Literature Review

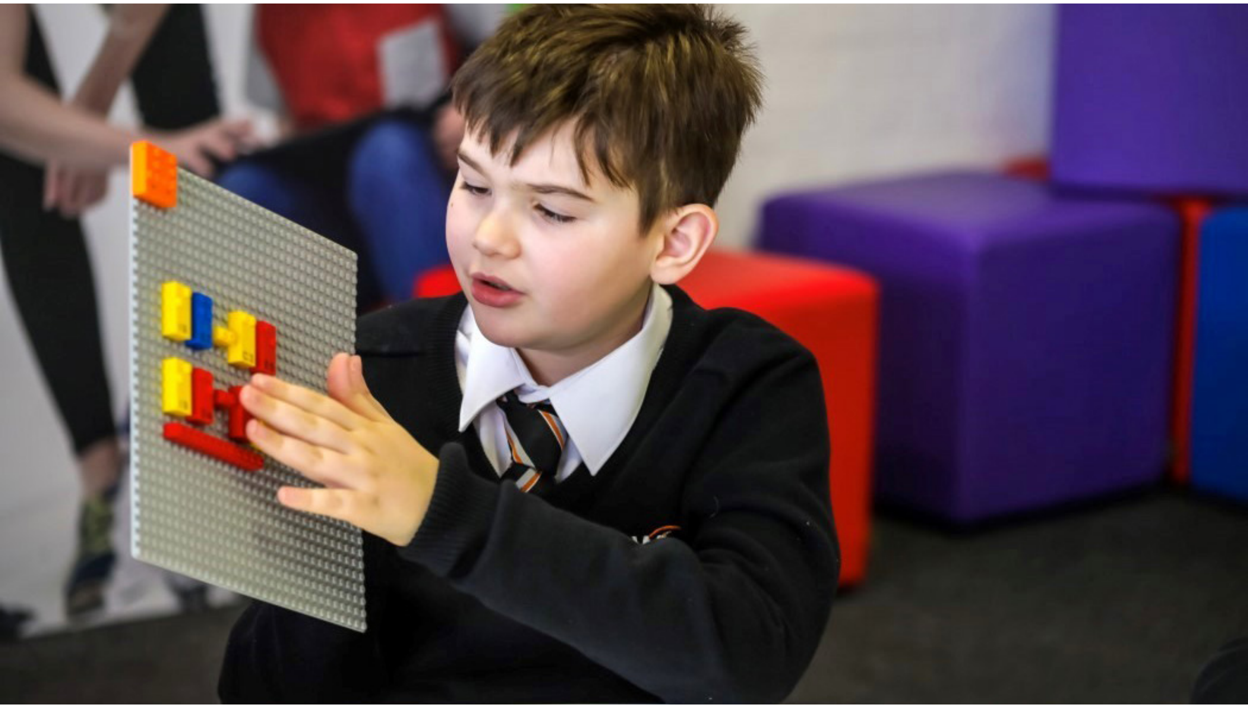

Figure 5 – Students using LEGO Braille Bricks

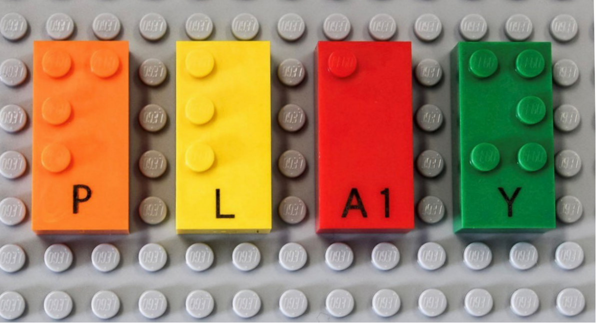

Figure 4 – LEGO Braille Bricks

Visual impairments occur along a scale, from diminished vision to total blindness, and they manifest in many ways, such as accidents and birth defects. Professionals, therefore, need to be able to identify these disorders accurately, in order to effectively assist affected individuals. General educational services should not only consider clinical assessment of the visual disability, but also the strengths and abilities of the children with visual impairments.[1] It is a widely accepted fact that we experience the world through the whole body at once, and sensations are not merely a biological process, they are also a social process.[2] In the field of Education, it is generally understood that visually impaired learners present a distinct set of pedagogical challenges in terms of sensory inclusion. These challenges include the need for a unique range of strategies relating to instruction, organization, management and environmental factors. These arise when there are situations that include the exchange of information, the learning of various processes, and safety in the educational environment.[3] LEGO blocks are a widely used method of play and exploration for students to build structures and understand concepts. LEGO blocks have the ability to form complex structures, teaching children the basics of construction, symmetry, form, pattern and color. The raised bumps that form the top surface of each standard LEGO brick, with slight modification, have been adapted to facilitate teaching the braille language. LEGO Braille Bricks allow children to learn braille, form words and build sentences (fig. 4). Children use their sense of touch, running their fingers across the specially bumped blocks, and also using their fingers to read the printed text below each set of bumps.[4] These braille blocks help children understand and learn language skills, such as English, enabling them to live in a more inclusive world while also promoting brain development and independence (fig. 5).

1 Johnson-Jones, "Educating Students with Visual Impairments in the General Education Setting."

2 Norwich and Lewis, "How Specialized Is Teaching Children with Disabilities and Difficulties?"

3 Morris, "Making Sense of Education."

4 Skybrud.dk, "Lego-Braille-Bricks."

Art education is a powerful tool for developing children's social skills, making them more aware of cultural and social contexts.[5] Both learning and teaching benefit from engaging the entire range of senses. The addition of art in any child's education provides them with intuitive, emotional and divergent thinking abilities. The arts enrich primary education by giving students awareness and knowledge of the world.[6]

Unfortunately, in pedagogical practices, there is a tendency to privilege the visual. This is evident in the use of visual aids such as presentations, infographics, printed material and diagrams. Due to this prioritization of visual modes of learning, the benefits of other sensory modes such as auditory, olfactory, tactile or kinesthetic can be overlooked. This oversight negatively impacts visually impaired learners.[7]

5 Nicholas Addison editor and Lesley Burgess editor, Learning to Teach Art and Design in the Secondary School.

6 Land, "Visual Arts and Students with Visual Impairments."

7 Morris, "Making Sense of Education."

Education for the visually impaired has sought new ways to provide access to visual information. Class participation, for visually impaired students, is impacted by practical realities, such as the increase in time required to read braille.[8] The use of magnifiers and assistive technology can be very helpful; however, the time it takes to understand these tools and use them effectively often results in the student losing valuable instructional time. Effective teachers of students with visual impairments are able to use strategies that support the multi-sensory capabilities in the classroom environment, in order to meet students' needs.[9]

Sensory Substitution (SS) is a development in the field of design for the visually impaired. It involves methods and strategies to compensate for the loss of sensory function by providing the missing information through intact senses. The brain responds to sensory stimulation and is able to interpolate information from intact

8 Carson Y. Nolan and Cleves J. Kederis, Perceptual Factors in Braille Word Recognition.

9 Norwich and Lewis, "How Specialized Is Teaching Children with Disabilities and Difficulties?"

senses compensating for disabled or damaged senses. For example, the visually impaired often use a white cane to translate information about the surrounding environment into haptic and proprioceptive feedback, just as braille is used to translate verbal information through haptic simulation.[10]

Figure 6 – Visually disabled person pouring water

In order to design a functional SSD there is a range of significant information that needs to be considered. The first and most important consideration is sensory overload. Information conveyed through SSDs must align with the capabilities of the human nervous system, in order to be useful. Designers need to determine what information is critical and what aspects of the SSD's task are functionally the most important.

10 Kristjánsson et al., "Designing Sensory-Substitution Devices."

Ordinarily, when filling a cup with hot or cold liquid, a visually impaired person places a finger at the rim, to know when the cup is full. This can result in injury and is unsanitary (fig. 6).[11] An alternative to this is a water level. An electronic water level is clipped to the rim of a mug, and as the water reaches the brim, it will either vibrate or beep. However, visually impaired people prefer using their fingers as this eliminates both the additional step of attaching the device to the rim and beeping sounds that could alarm them. The visually impaired would receive feedback from the heat of the cup, while pouring, as well as the beep or vibration together creating sensory overload.

The Buoy Cup, designed by Jongil Kim, is an SSD using floatation to address this problem.[12] A buoy is connected to a pivot on the cup's the handle. As the liquid rises, the outward edge of the buoy tilts downward, tapping the user's hand, alerting her that the cup is full (fig.7).[13] The cup effectively translates visual information into tactile feedback without causing sensory overload.

Figure 7 – The Buoy Cup

The second consideration in the design of an SSD for the visually impaired is the determination of how to effectively convey information through the haptic and auditory sensory systems. Other design considerations include ease of use, comfort and mobility.[14] Something as simple as color coordinating a set of clothes can be difficult for a person

11 "It's All About the Ring | Yanko Design."

12 "Buoy."

13 "Buoy Cup."

14 Kristjánsson et al., "Designing Sensory-Substitution Devices."

who is visually impaired. Bright-F, a prototype by designer Lifeng Yu, seeks to improve the lives of people with color blindness. The device detects the brightness, saturation, and hue of color of clothing. A visually impaired person can then sort through garments and organize them by color for future convenience. The device scans clothing and communicates the color audibly, with a spoken identification.[15 16]

Bright-F looks like a flashlight, with an LED in the front end (Fig. 8). The device's light source displays the color of the clothes in its truest form, i.e. under white light. With the press of a button, it identifies the color. The "learning button," when pressed, states the color aloud. There is also an adjustable knob for volume control. Battery life can be monitored via an embossed indicator (fig.9). Bright-F provides all of the information needed to make a choice of clothing through auditory and tactile stimuli. Reliant on sensory substitution, the device is user-friendly and does not cause sensory overload.

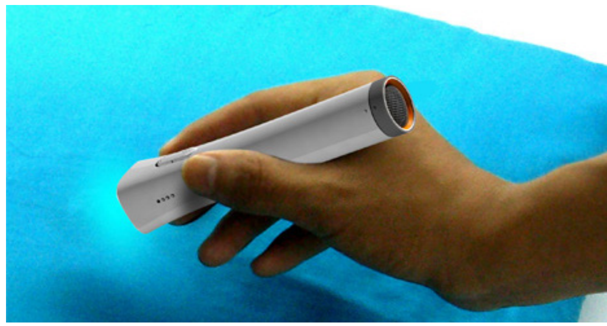

Figure 8 – Bright-F

Figure 9 – Battery life and indicators

15 "See Color With Sound | Yanko Design."

16 "Bright-F Clothes Scanner Lets The Blind Hear Colors."

Substantial research has been conducted in order to understand the potential of sensory substitution. However, technology has yet to be able to accurately portray non-impaired senses of touch, smell, or taste. SSD's aim to ensure the recognition of objects or the completion of a task through an alternate sensory mode. Therefore, additional skills need to be learned through the intact, non-impaired senses for recognition.[17] Yanko Design redesigned the game of chess to enable the visually impaired to play. The project, Play Chess with Your Eyes Closed, extends the strategic game of chess to users with visual impairments. Although standard chess pieces have unique shapes which can be recognized by touch, the game requires strategic planning, based on knowing the location of other pieces on the board. Without increased ability for object recognition chess can be a very difficult game for a visually impaired person to understand (Fig. 10).[18]

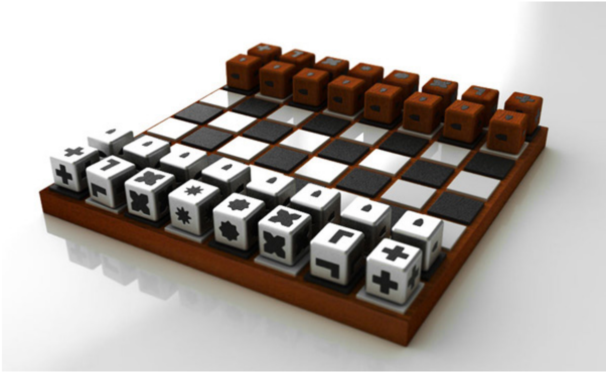

Figure 10 – Yanko Design – Play Chess with Your Eyes Closed

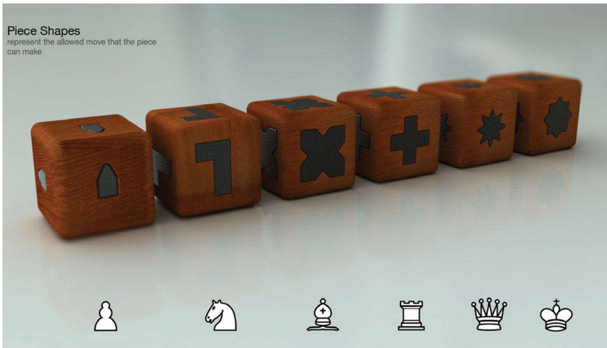

Figure 11 – Chess Cubes

17 Deroy and Auvray, "Reading the World through the Skin and Ears."

18 "Play Chess With Your Eyes Closed | Yanko Design."

Yanko Design embedded textured rubber symbols into each of their cube-shaped chess pieces to indicate the chess piece type—king, queen, rook, pawn, bishop, knight. (Fig. 11) The pieces are all the same height, allowing visually impaired players to run their hands over the board, in order to feel where all of the pieces are located, without knocking any pieces over. Textured magnets hold the pieces in place. On the game board, white tiles are equipped with weaker magnets than black tiles, helping visually impaired players navigate the board by feel, placing game pieces correctly in response to tactile feedback (Fig. 12).White game pieces are made of steel, black pieces are made of wood, making them instantly distinguishable by temperature, weight and texture (Fig. 13). The game still works for sighted players, but due to the game's tactile design, it also addresses the needs of visually impaired players, making it inclusive and universal.[19]

Figure 12 – Demonstration of magnetic intensity

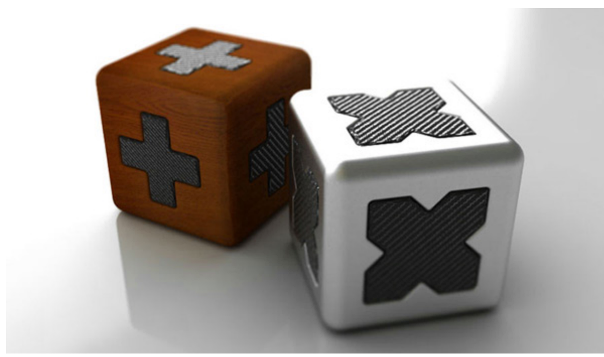
Figure 13 – Wood and Steel Pieces

19 "Chess Set - Duncan McKean."

Conceptual Framework

SENSORY SUBSTITUTION

According to Kristjánsson (et al) in their article 'Designing sensory-substitution devices: Principles, pitfalls and potential,' the main principles required for a successful SSD include:

- Assessment of the spatiotemporal continuity for the different senses.

The design of SSD's requires an assessment of the nature of spatiotemporal continuity for the different senses. Perception is a continuous process and does not involve understanding snapshots of the environment or objects. For example, when a cookie-cutter was pushed onto participants' palms but remained otherwise stationary, identification rates of its pattern were just under 50% percent, while if the cutter was pushed around in the observers' palm, recognition became about 95% correct.[20]

- Convey the most important piece of information.

There is a limit on the amount information humans can perceive at a given time due to selective attention. This results in information going unnoticed. There is a risk that providing too much information will cause sensory overload. Therefore, SSD's must only convey vital information.

- Psychological comfort

The visually impaired are accustomed to a procedural, step-by-step way of completing tasks. This procedural training with alternate senses begins in primary education.

- SSD's must not interfere with other perceptual functions or other modes of sensory feedback.

The environment in which the SSD is being used must be carefully considered. The way visually impaired people perceive their

20 Kristjánsson et al., "Designing Sensory-Substitution Devices."

environment is crucial, because individuals need to work in an environment comfortably. If the SSD interrupts with distracting non-visual stimuli, it might cause sensory overload.[21]

- SSD's should be task focused

Being task-focused and goal-oriented is crucial. SSD's must help the visually impaired reach goals, without interruption, because visually impaired students work through tasks or activities in procedural steps.[22]

- Training requirements.

Active training of the use of any SSD is necessary to achieve maximum efficiency of a device or tool. As previously mentioned, training alternate senses begins in the early stages of life. Typically, this done by specialized schools with the assistance of teachers and physiotherapists. The training is important for forming muscle memory and dexterity.[23]

21 Ibid.

22 Kristjánsson et al., "Designing Sensory-Substitution Devices."

23 Ibid.

PEDAGOGY

The teachers at Al Noor Institute for the Visually Impaired follow a system of strategies when teaching their respective classes. The system allows students to become accustomed to step-by-step processes in learning. The system also accommodates certain SS principles, which make learning and using tools more comfortable and effective for the visually impaired students.

The step-by-step teaching strategy is as follows:

- Introduce new projects to the class by describing the objects they are about to use, as well their colors.
- Clearly state the objective of the projects so that the student is able to create a mental image of the object and tools, as well as the anticipated end result.
- Use the physiotherapy department when introducing new tools, to help with fine motor skills and muscle formation.
- Spend 10 minutes or more (based on students' abilities) to further describe the project, one-on-one.
- Hold students' hands while they use new tools, to correct and assist them, the first few times.

Two additional strategies used by Al Noor are the color comparisons between objects or concepts with which the student is familiar (e.g.: Blue as the sky, Red as blood, Yellow as a lemon) and labeling all tools and books the students will use with braille. The label will include the student's name, as well as the name of the object.

Investigations

UNIVERSAL PAINTING KIT

I conducted numerous observations and interviews at Al Noor and gathered significant information about the range of lessons being taught in the Arts and Crafts department. I learned that painting is a core activity being taught Al Noor and began to analyze the types of tools used in specific lessons.

I analyzed the set of tools needed to complete a full painting using acrylic paints in order to identify opportunities for additional sensory modes of feedback. This was done by following the same step-by-step process the students follow in their lesson.

Tool	Physical Attributes	Method of Use
Paint Brush	Straight tapering handle with bristles on one end	Fingers wrap around the wooden handle
Palette	Flat surface with dividers	Paint is placed on the surface; dividers are used to separate paint colors
Paint Tubes	Sealed tubes with color indicators	Use the top of the lid to break the seal and squeeze paint onto the palette
Canvas Board	Flat cotton surface with wood frame	Paint is applied, with a brush

Tool: Paint Tube

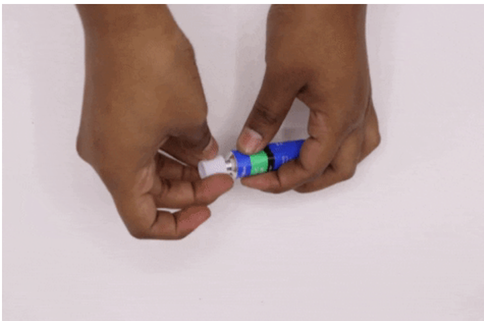

Figure 14 – Opening a tube of paint

Information required to use tool effectively	Sensory feedback	Possible modes of SS
• How to open tube • How to open seal • Paint Type • Paint Color	• Ridges on lid • Tapered point inside the lid	• Tactile or olfactory representation of color and type of paint, instructions or alternate method to break seal

Tool: Paint Brush

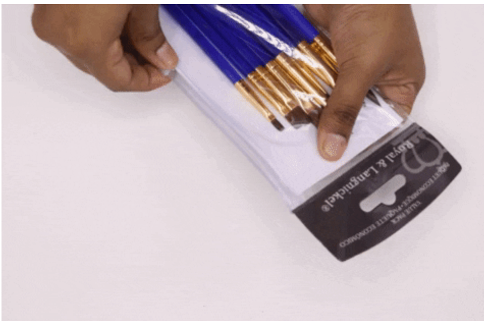

Figure 15 – Opening pack of brushes

Information required to use tool effectively	Sensory feedback	Possible modes of SS
• Opening the packet • Choosingabrushsize and shape	• Bristles can be felt, use of spatiotemporal feedback with training can allow for recognition of shape and size	• Instant recognition of the tactile representation of size and shape • Simpler and easily recognizable packaging, that uses technology that does not require training

Tool: Paint Tube, Palette and Paint Brush

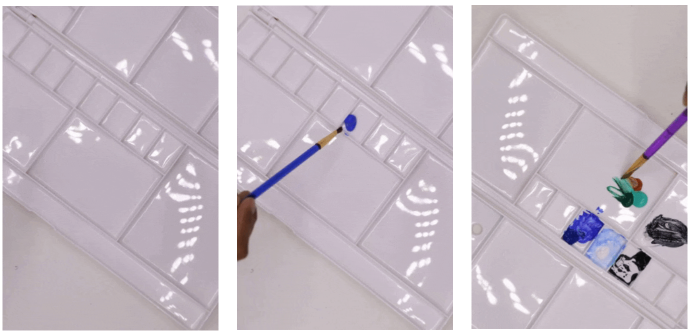

Figure 16 – Dipping the brush in the palette

Information required to use tool effectively	Sensory feedback	Possible modes of SS
• Placement of paint • Ability to pick up paint with a brush	• Ridges on the palette represent tactile feedback	• Apart from the available tactile simulation, olfactory feedback from paints can aid in the process of picking up paint

Tool: Paint Brush, Canvas

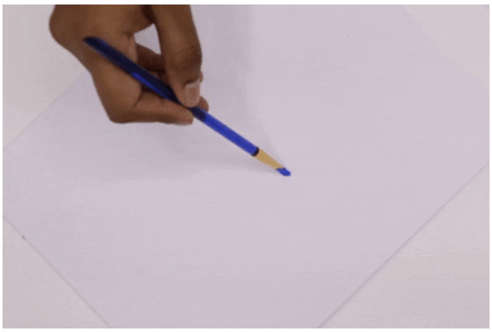

Figure 17 – Painting

Information required to use tool effectively	Sensory feedback	Possible modes of SS
• Applying paint in the right area of the canvas	• Interaction between the brush and canvas texture	• Tactile representation of areas to place paint

Tool: Paint Brush

Figure 18 – Cleaning the brush

Information required to use tool effectively	Sensory feedback	Possible modes of SS
• Ability to recognize the water container • Knowing when the brush is clean	• None	• Olfactoryfeedbackto determine whether the brush is clean • Tactilerepresentation of the container

Having analyzed how each of these tools works, I began to experiment with the main principles of sensory substitution.

Tool: Paint Tubes

To focus on and convey the most important piece of information, in the case of the paint tubes, the color and the placement of the tip were used to open the seal of the paint tube. This tip is usually placed on the inside of the lid of each paint tube. To access it, one must open the lid and flip the lip and push the lid and the tube together. I experimented with how the tip could become easily accessible to the visually impaired student. The process of opening the seal and placing the paint on the palette was an opportunity to combine the tasks. This would make the process more streamlined, eliminating the need for the student to feel for the tip each time a tube is opened.

The combination of these features allows for easy access to the tip, which is needed to break the seal of the paint tubes. Placing it on a level surface allows the student to feel it and use it efficiently. The placement of this feature conveys the most important piece of information. To provide ease-of-use and reinforce the role of the palette in the process of painting, a tip is placed next to each palette section. Students can now easily pierce the seal, and then immediately place the paint in the palette, minimizing mess and using the palette's inherent structure to organize the paints.

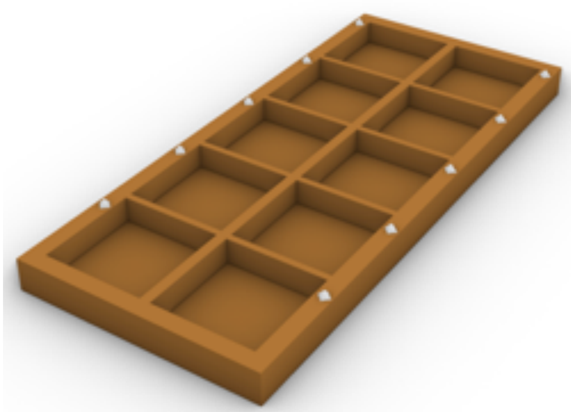

Figure 19 – Model of Palette with tips

Tool: Palette

As I worked on this palette, I looked for more opportunities to streamline the task of completing a painting. Making the products task-focused but not overwhelming the user with too much information is vital to this process. Therefore, I approached the painting process as a whole, and then sought opportunities to make the tools of painting more intuitive and accessible.

The palette extension includes the space needed to clean paintbrushes in a container of water and space to wipe off excess water or paint from the brush. The need for functional space arises from the concept of perceptual function. When visually impaired students work, they arrange their tools around them in a systematic manner. Students develop awareness for the location of everything in their surroundings. To access tools, they extend their arms and build a mental image of what is in front of them. Doing this multiple times (training), allows them to become comfortable with their surroundings. This is usually practiced by using of a disposable cup and a rag cloth. The potential for creating a mess, while training, is immense. Integrating the tools into a cohesive system, with each element on the same level surface, students are able to train and locate all the tools more efficiently.

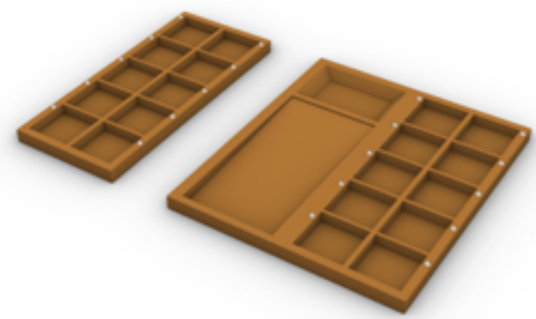

Figure 20 – Model of palette with cleaning extension

Tool: Paintbrushes

Paintbrushes vary greatly in bristle materials, size and shape. The visually impaired at Al Noor usually like to use large brushes or their fingers to create a painting. The students are more likely to see and appreciate what they are painting if the paint strokes are bolder. Therefore, the brushes gave me a unique opportunity to experiment with the notion of spatiotemporal continuity of the senses. As previously mentioned, the concept of spatiotemporal continuity of the senses states that perception of an object is aided by continually handling an object rather than touching it for a short period of time.

Choosing a particular brush can become a chaotic process when using multiple brushes at the same time. To address this, I incorporated brush holders directly into the palette.

The addition of brush holders helps students locate brushes with ease, as they paint. However, the holders had not yet addressed another problem, which is that students need to be able to recognize the brush size and type without confusion. Visually impaired students are able to recognize their brushes by touching the bristles and training through spatiotemporal continuity of their haptic senses. However, once a brush is used, it is impractical to touch the paint-covered bristles.

The same way the bristles can be recognized through training, in this system, the students learn to recognize the brush holders. Each brush size, bristle material and shape is represented, using lines and dots on the holders. Students using the kit could either associate the brushes with the representations on the holders or train their haptics to recognize where each brush is housed on the holder, so that they would not have to feel the bristles once they have been used.

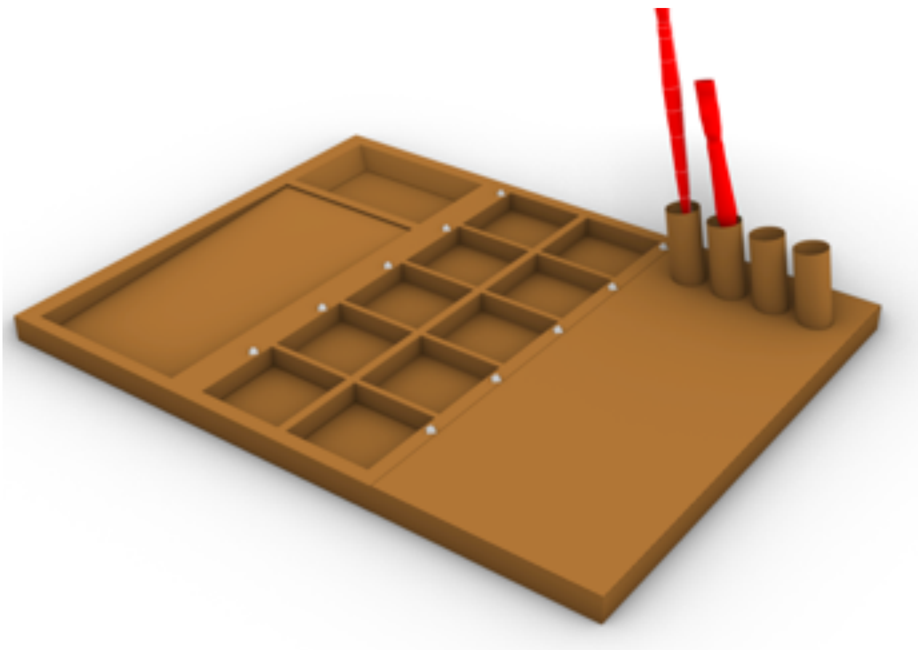

Figure 21 – Model of palette with cleaning extension and built-in brush holders

Tool: Easel

One of the main concerns described by the school's physiotherapist was that students who need to get as close as possible to the board, in order to put it within their range of sight—which can be as little as 2cm—often develop problems with posture when they paint. Students often stand hunched over the table, or hold their canvas boards pressed up close to their faces.

As a remedy, I incorporated an adjustable bracket, to prop and hold the canvas board. The angle can be adjusted, using a ladder hinge, to accommodate the needs of individual students.

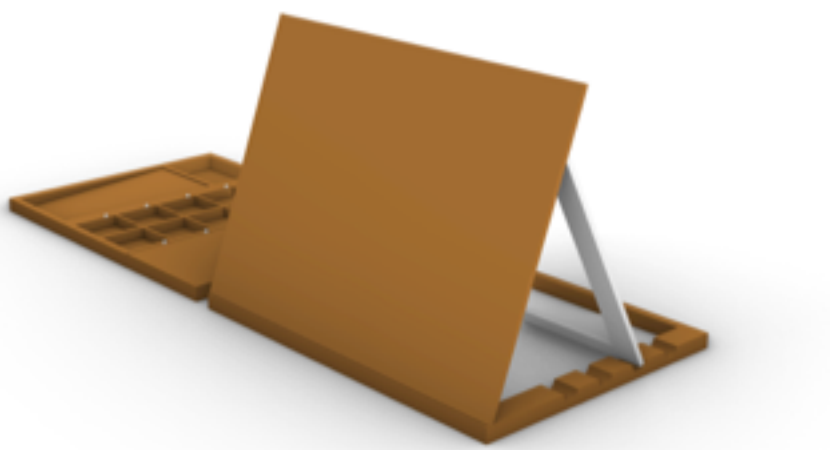

Figure 23 – Model, showing board propped on adjustable easel

The initial system included the majority of the tools required to create a painting. Taking into consideration the context in which this would be used, a school for the visually impaired, there needed to be a few more developments in the kit of tools. For instance, for students to use the kits, they need their brushes and paint tubes arranged for them. The art teacher at Al Noor arranges all of the necessary tools. However, in order to facilitate independent use, the brushes and paint tubes needed to be incorporated directly into the kit.

The final model housed the paintbrush holders and the paintbrushes, and it took the students' fine motor skills, dexterity and ability to grip the paintbrushes into consideration. Visually impaired students are able to instinctively pick up objects and hold them, due to years of training. The removable easel serves a dual function as a lid for the kit, so that, when slid over the palette, it becomes a portable, all-inclusive painting kit (Fig. 26). The model pictured below (Fig. 28) was produced using the CNC router in MDF. This material choice allowed the prototype to serve as a mold for use with the thermoforming machine.

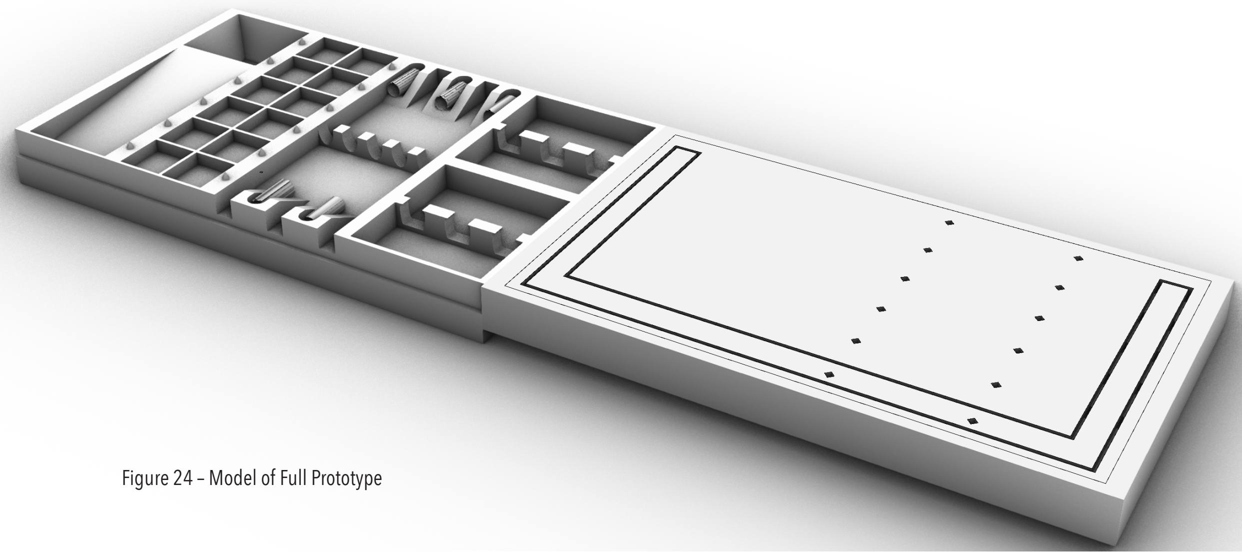

Figure 24 – Model of Full Prototype

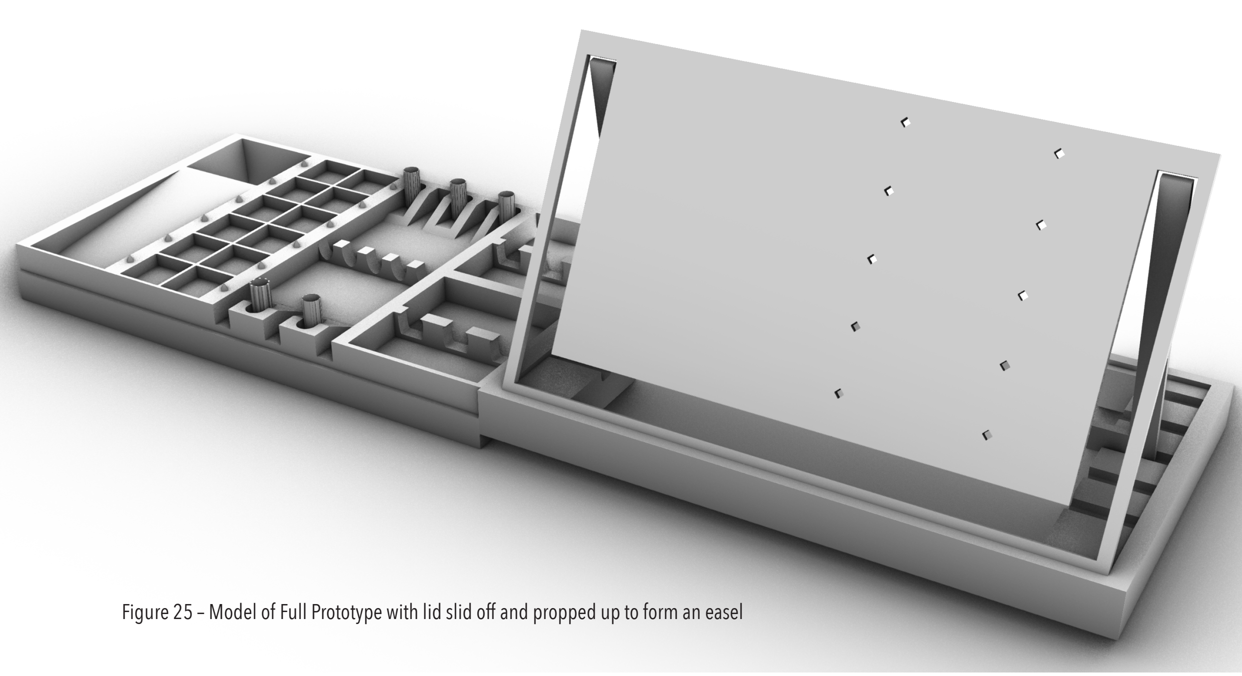

Figure 25 – Model of Full Prototype with lid slid off and propped up to form an easel

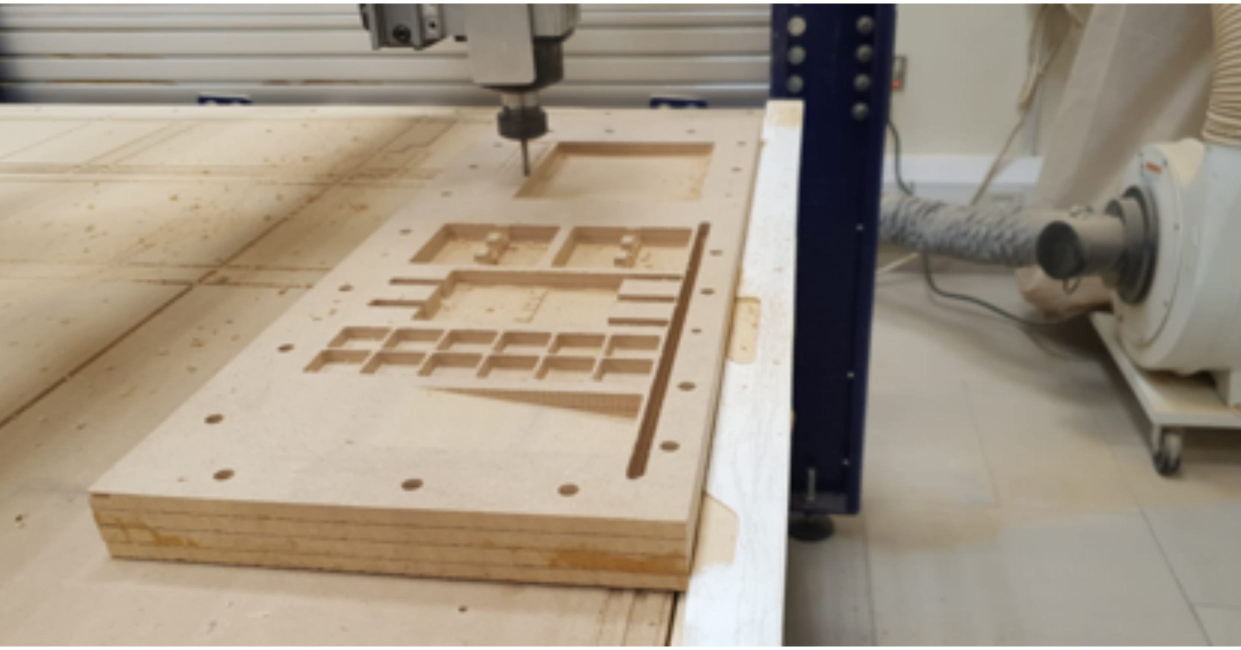

Figure 26 – CNC production of prototype

Kit serves as an easel, to support the painting

Adjustable easel brackets offer a variety of angled positions

Figure 27 – Full Prototype details

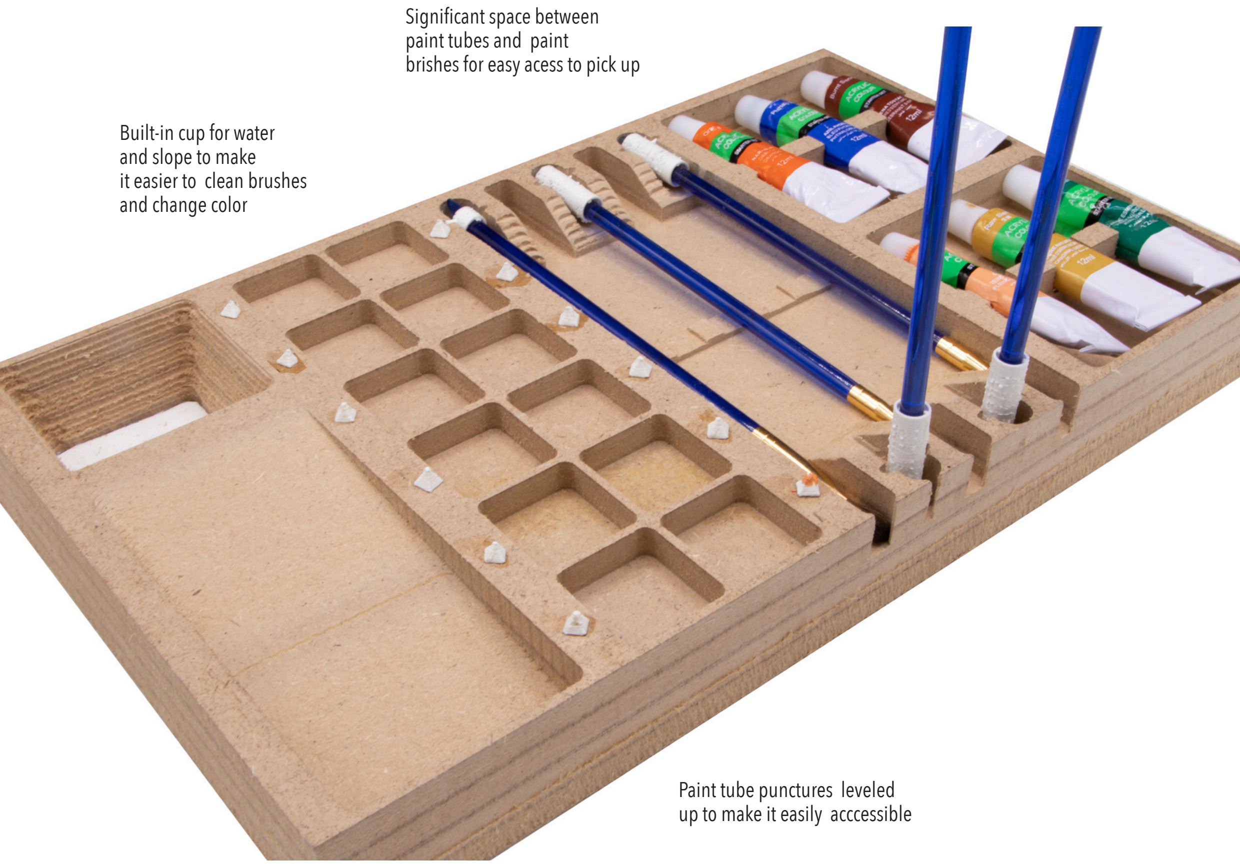

Figure 28 – Full Prototype being used

Al Noor provided useful feedback about the project's form, material, and color. They recommended using acrylic, which is lightweight, portable and provides multiple color options. The color yellow was suggested, due to the high-contrast background it creates for the dark tools, an advantage for the visually impaired. One teacher suggested using the canvas frame as a lid, opening horizontally rather than vertically so that the space between the student and the canvas increases. This would help the students sit up straight and control their posture. Another teacher suggested a reduction of the number of brushes and an increase in the variety of colors. They felt that the built-in space for washing brushes eliminated the need for so many different brushes.

Figure 29 – Model revised in response to feedback from Al Noor

PAPER QUILLING

Paper quilling is an established craft activity that uses a pen-like tool to roll strips of paper into coils, which can then be molded into different shapes. By repeating the process, sets of cell-like coils can be assembled using white glue to form objects, shapes and characters. The repetition inherent to the process, combined with its heavy reliance on haptics, makes it well-suited to the needs of visually impaired learners.

Using spatiotemporal continuity of the haptic sense, visually impaired students are able to create a mental image of each cell. Once trained to use the tools they can learn to mold each shape, produce multiple copies, and assemble the parts.

Figure 30 – Tools used for paper quilling

Figure 31 – Examples of paper quilling outcomes

Based on this process I developed a test case—a template that could be used to create a flower sitting in a flowerpot. The entire project—the flowerpot, flower, leaves and stem—could be made using the haptic sense exclusively. From a sheet of acrylic, using the laser cutter, I cut the shapes of each different coil. For this project the shapes are the tight coil for the center of the flower (yellow), the loose coils for the container (blue), the tear drop shape for the leaves (green) and the almond shape for the petals of the flower (pink) (Fig. 32).

A first row of holes in the template is designed to hold pre-made coils—molded in advanced and housed in these holes to provide an example of each type of properly made coils for students to compare with their own attempts as they train. A second row of cuts guide students as they make each type of shape needed to complete the project. A third row provides a guide for assembling individual coils into project components—individual pink petal coils form the flower, individual blue coils become rings, and groups of rings stack to form the pot.

The 3mm thickness of the acrylic sheet allows students to trace along the cut shape with their fingers, creating a mental image of each shape. These features, combined with the pre-made shapes, allow students to perceive and recreate each type of coil required for the project. The acrylic sheet is adhered to a sheet of cork. Cork provides a flexible work surface, where the paper can be molded and shaped to the correct size. Quilling paper, complete with perforated lines, is included in the template.

Figure 32 – Flower pot made from quilled paper

First row: Holes designed to hold pre-made example coils

Second row: Holes designed to guide students as they make each type of coil needed for the projects

Third row: Holes designed for assembling individual coils into project components.

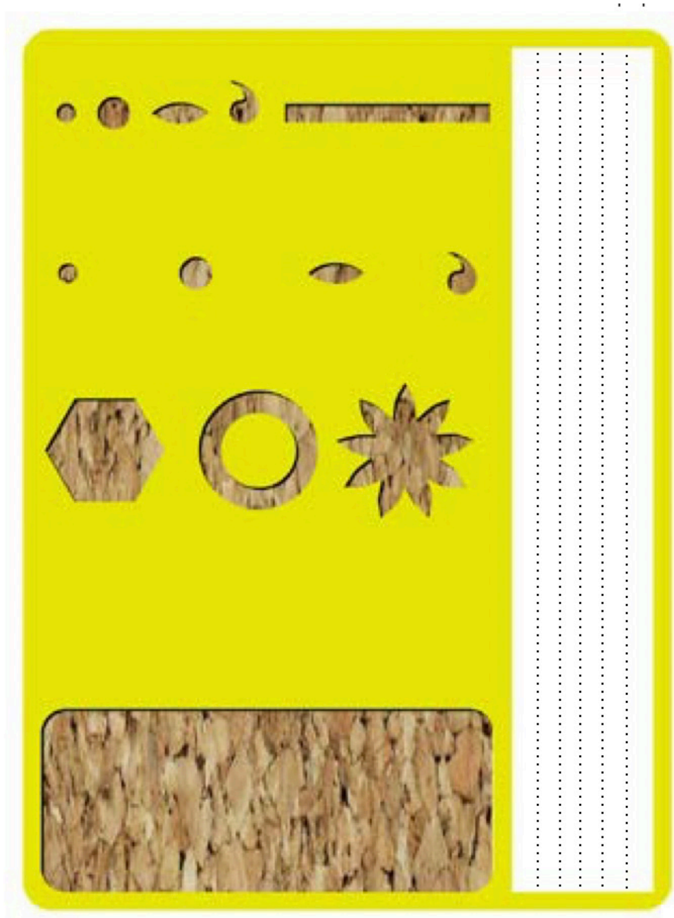

Figure 33 – Template for container, flower, leaves, stem

Outcomes

PAPER QUILLING TEMPLATES

The process of paper quilling provides students with a method to learn lessons through a creative mode of making. It allows students to physically feel shapes and understand their lessons in a new way. This process emphasizes the act of learning through the enhanced haptic abilities of the visually impaired rather than teaching a creative process for the visually able.

I worked with the teachers at Al Noor and teachers at non-specialized schools, to understand the types of lessons that could be taught using this system. I analyzed how creativity is expressed and implemented in the core elements of the templates. Therefore, I created a framework to define creativity with the aim of learning in the classroom context. Creativity in this context can be divided into three main definitions; understanding concepts, solving problems, and generating new ideas.

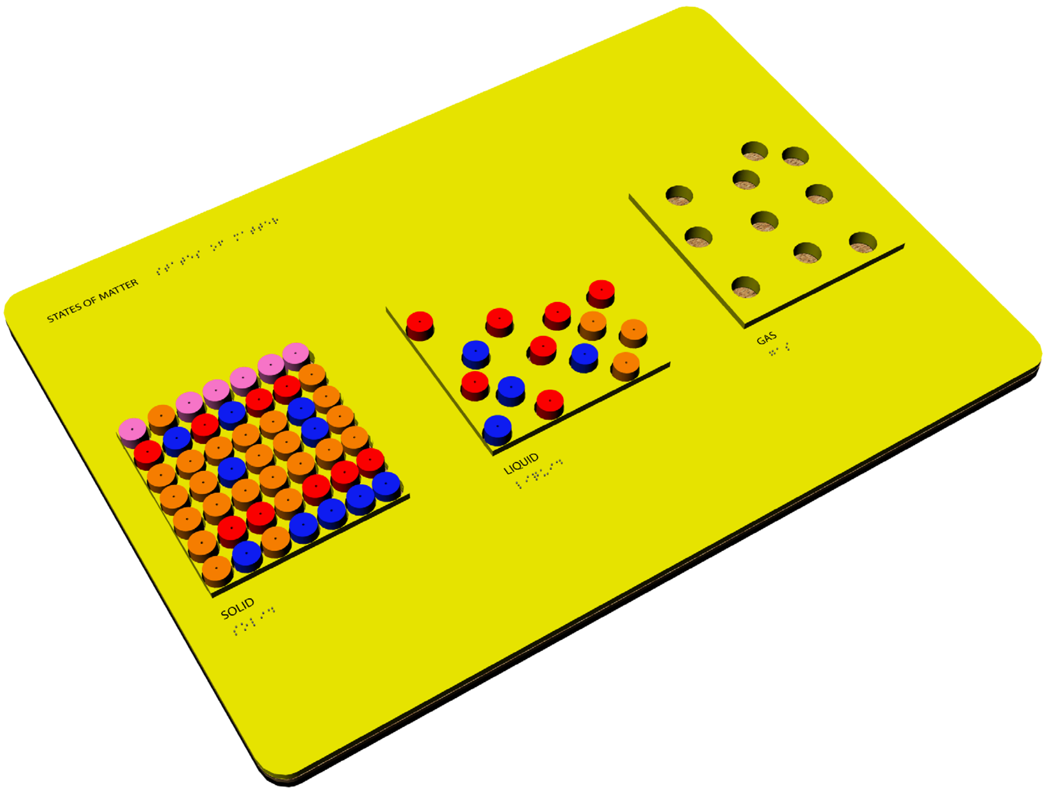

Figure 34 – Rendering of States of Matter template

UNDERSTANDING CONCEPTS

Science teachers at Al Noor use foam spheres to teach students the shapes, sizes and positions of planets and moons in a solar system lesson. Like sighted students, visually impaired students will be able to understand the universe and the relative size and positions of planets in space through this haptic mode of teaching. However, most concepts are taught using visual cues, presenting a distinct challenge for teachers of visually impaired students.

The process of paper quilling can be plugged into a lesson, to translate an abstract concept into something more tangible and hands-on. Imagine, for example, teaching the states of matter. Using coils of quilled paper, students are able to feel the tightly packed arrangement of molecules in the solid state, feel the mid-range density of molecules in a liquid state, and feel the space surrounding each individual molecule in the gaseous state. (fig 34) Similarly, concepts such as the lifecycle of a butterfly or states of matter can be taught through this creative haptic learning method.

The ability for cells to be molded plays a vital role. The fact that these cells are made out of strips of paper allows for a certain level of flexibility. This can become an interesting part of the system of templates and cells, when it comes to learning more in detail. Within the example of learning about the lifecycle of a flowering plant, shapes for the petals and leaves as well as water droplets can become "special characters," (fig 35) which make the haptic learning process more entertaining and challenging.

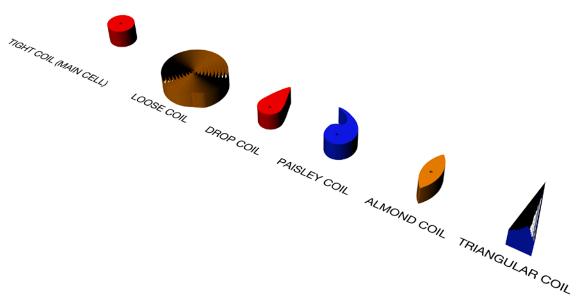

Figure 35 – Examples of special characters

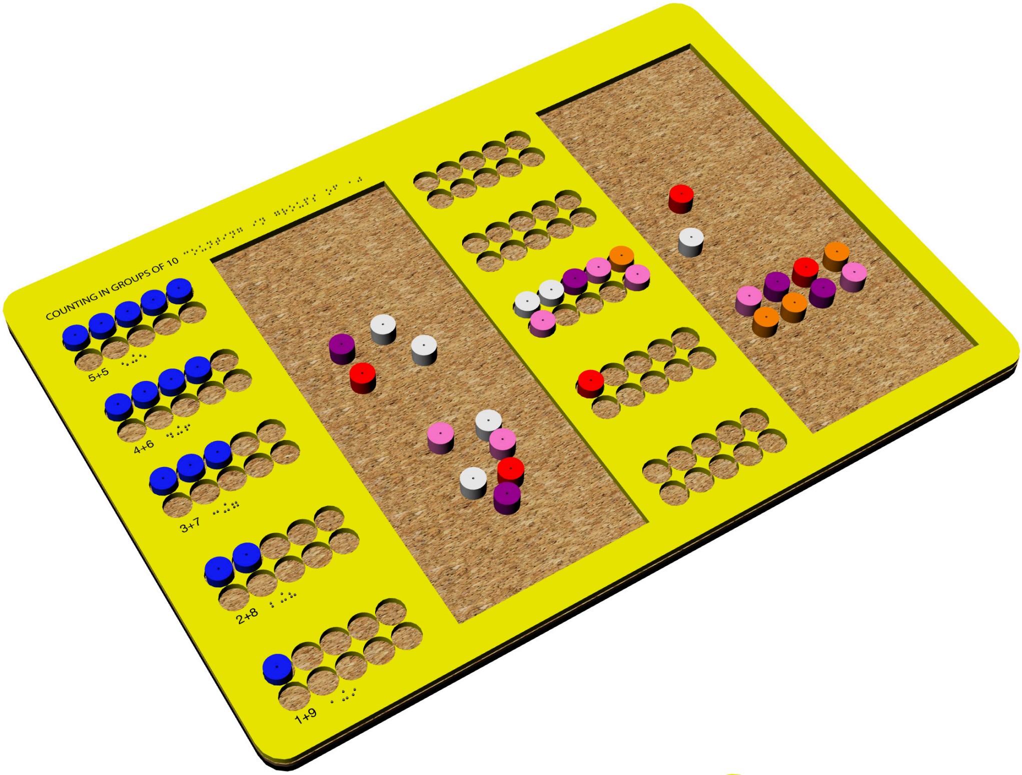

Figure 36 – Template of Counting from 1 to 10

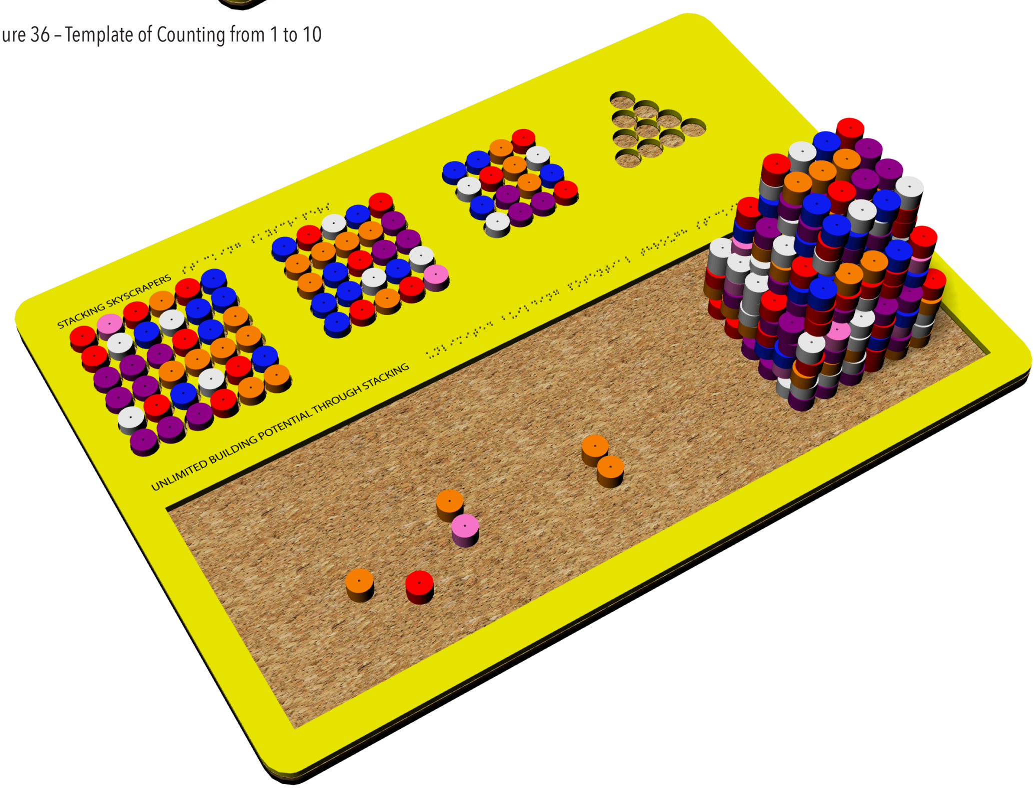

Figure 37 – Stacking skyscrapers template

SOLVING PROBLEMS

To solve mathematic problems, most of us were taught to add, subtract, multiply and divide using visual cues—pictures or objects that increased as we added, or decreased as we subtracted. We were taught about symmetry using drawn shapes and visible mirror lines. To teach the visually impaired to solve mathematic problems, without the benefit of visual cues, paper quilling provides a haptic alternative to the images and drawings found in traditional math textbooks.

Starting with basic counting, students can touch and count coils by feel. By placing individual coils in the template, an organized system guides the lesson. The template below (Fig. 36), guides incremental counting, and also has an open space for students to solve assigned problems, by combining coils.

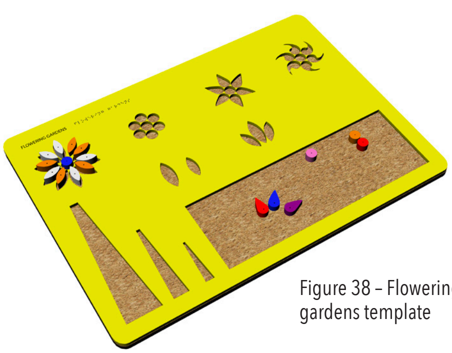

Figure 38 – Flowering gardens template

GENERATING NEW IDEAS

During my observations and interviews at Al Noor, both teachers and students stressed student appreciation of structure within lessons. Students are taught to create mental images to guide their work. This process allows them to identify a goal to work toward. Each student I interviewed had different interests and life goals. Some wanted to return to Al Noor as teachers, while others wanted to become engineers.

These templates can help students creatively express their own personality and interests. Some templates focus on the process of making rather than the final outcome. For example, the template for building skyscrapers allows the student to build unlimited sets of coils and stack them as high as they want (fig 37). The template for making different types of flowers and leaves can be used to create a single flower or a full garden (fig 38).

Conclusion

The primary aim of this thesis is to design a system for visually impaired students, to allow them to engage in a creative process, by using their enhanced haptic abilities. Principles of sensory substitution were incorporated in the design of templates, to capitalize on students' non-visual senses, to facilitate learning and creativity in a classroom context. The templates extend the haptic qualities of the craft of paper quilling in order to reinforce primary school lessons and develop problem-solving skills.

My initial interviews and observations at the Al Noor School for the Visually Impaired and explorations in material and form led to my understanding of the importance of the haptic sense in the expression of creativity for the visually impaired. The sensory substitution principle of spatiotemporal continuity and the haptic ability to recognize shapes and sizes through time and training were primary factors in developing the system of paper quilling templates as building blocks to learn and explore creativity.

FUTURE DIRECTIONS

To further develop this research, I would like to continue working at the Al Noor School for the Visually Impaired. Receiving additional feedback from students, faculty and staff would be crucial in considering further modifications and opportunities for expanding the templates into other classroom environments.

Additionally, I would like to explore ways in which spatiotemporal continuity is utilized by visually impaired adults and seek opportunities to develop templates to aid in additional environments.

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LIST OF FIGURES