Research on Creation of Barrier Free Digital Textbooks Based on Kano Model for Children with Visual Impairments

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Abstract. This article suggests using hearing and touch to make up for eyesight in product design. To reduce the cognitive load and operational difficulties faced by children with impaired vision. Selection of design elements using the Kano model algorithm. Software programming and Arduino enable product-computer-user interaction. Providing direction for future barrier-free product design and giving vision-impaired children rich psychological experiences and emotional fulfilment.

Keywords: Kano model · Barrier-free digital textbook · Educational Materials Design

1 Introduction

Nowadays, between 93 million and 150 million children under the age of 18 are disabled. Access to high-quality education is still one of the biggest problems for children with disabilities. Among these, utilizing Barrier-free digital textbooks is one of the crucial strategies to address the absence of learning materials' free from barriers (Aguti et al., 2019) [1]. According to the research, except that external factors such as national policy and economy lead to the failure of Barrier-free digital textbook (BDT) promotion. Technology is still lacking in the BDT and instructional materials' design. The current BDT do not adequately highlight the additional sensory benefits of visually impaired children beyond their flaws. This paper aims to explore the concept of sensory compensation to guide the design of BDT for VIC. Using strategies for cognitive compensation that are visual, auditory, tactile, olfactory. To Create genuinely accessible digital textbooks for those who are blind or visually handicapped. And talk about how to adapt BDT to VIC's cognitive preferences.

As a design strategy for the sensory handicapped, sensory compensation (Wang et al., 2022) [2] can successfully assist children with disabilities in perceiving external information via other senses (Xu and Zhao, 2018) [3]. And to form their own perception of things, thereby improving the ability to use products and making their lives more convenient.

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The Kano model is utilized to examine consumer requirements and satisfaction. The non-linear relationship between product functions and user satisfaction is reflected. Classify different factor characteristics using standardized research findings to increase user satisfaction (Jin et al., 2021) [4]. A well-developed theory, the Kano model is frequently employed in assessing the significance of product design. For instance, automakers want to make modest adjustments to the performance of their goods, but the entire process takes a lot of time and resources. Next, the influencing elements are categorised using the Kano model, and the impact magnitude is prioritised to make an appropriate resource allocation (Ilbahar and Cebi, 2017) [5].

2 Relevant Theoretical Foundations

Scholars Tom Ye and Wei C (Wei and Ma, 2020) [6] suggested that because young children have such a great reliance on visuals. Children who are blind or visually challenged may learn more from images created by 3D printing technology. In addition, researchers Tetsuya Watanabe and Hirotsugu Kaga (Watanabe and Kaga, 2017) [7] discovered that Braille at the size of 16 to 19 o'clock is the easiest for visually impaired children to read. Children who are blind or visually handicapped may read more quickly, more accurately, and with fewer mistakes provided the Braille is the right size. In 2022, Orly Lahav and Jihad Kittany argued that appropriate loudness, a minimal amount of noise, uncomplicated settings, familiar rhythm, type, and pronunciation can enhance the listening accuracy of audiobooks for children who are blind or visually handicapped (Lahav et al., 2022) [8]. Simona Manescu and colleagues discovered in the field of smell in 2020 that blind persons can use scent to decode spatial information from chemical stimuli (Manescu et al., 2021) [9]. When odor and textbook images are linked, the accompanying odor can increase the olfactory sensitivity of children with disabilities and aid children who are blind in understanding material more thoroughly through odor discrimination and odor recognition. Wanni Xu, a visual researcher, proposed in 2022 that children prefer the ratio of visuals to text in textbooks (Xu et al., 2022) [10].

Children can better understand the content of books if there is a good balance between the text and the graphics. Additionally, the researcher Jiang Y, Wu M (Jiang et al., 2022) [11] suggested that wearing contact lenses and undergoing color light stimulation therapy are two effective strategies to treat color vision abnormalities and improve vision. The two approaches have little impact and are expensive. SO, study show for those with visual impairments can be improved by using BDT with yellow and blue filters.

3 Research Model and Design Process

The following are the design steps in accordance with the Kano model design method (Fig. 1):

Step 1: Summarizing pertinent five sense analysis, perception compensation, and graphic design theory for visually impaired people from research and literature. Next, ascertaining and evaluating the user population's wants. Then searching for relevant case analysis and selecting design elements with high correlation between sensory cognition theme and book education purpose.

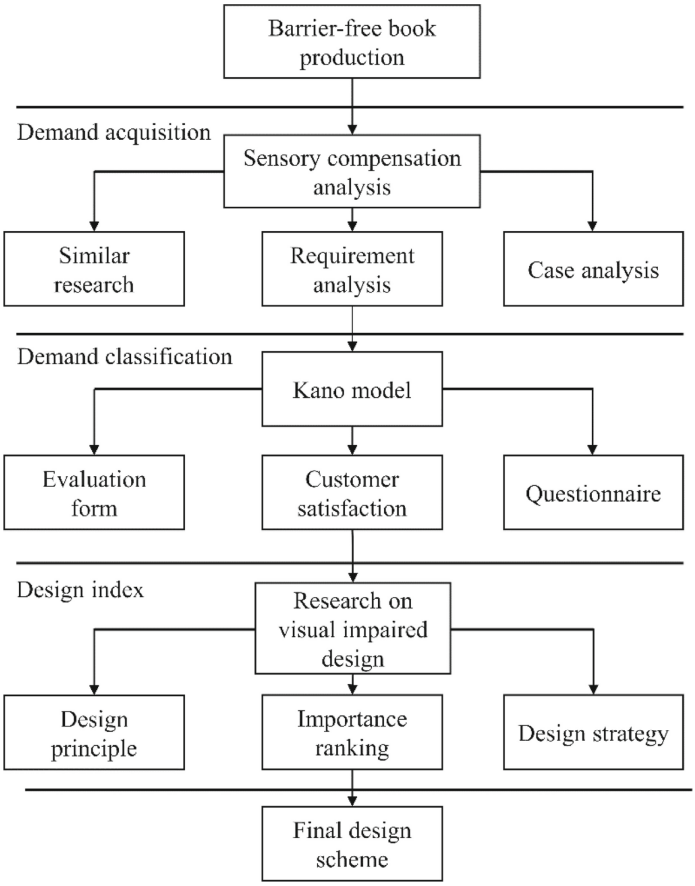


Fig. 1. Design Steps (author's own illustration)

Step 2: Computing the satisfaction coefficient to examine and assessing the design indicators after gathering actual user feedback via the Kano model's questionnaire.
Step 3: Finally, presenting a particular ADT design plan. And putting forth design guidelines, design tactics, and design features to direct the application of the design scheme.

3.1 User Group Characteristics

Total blindness and severe amblyopia are the two categories into which blind children can be loosely separated. Designing goods for people with visual impairments requires taking the user's uniqueness into consideration. The loss of some senses increases the sensitivity of others. About hearing, visually impaired people outperform peers with normal vision in terms of sound perception (Huang and Liu, 2017) [12], detail capture, and auditory recall. In touching, children who are blind or visually challenged have their own perception model. Getting a sense of an object's shape, size, texture, and hardness

by touching it, and then develop a comprehensive understanding of it. Children who are visually impaired suffer from a complete or partial loss of their visual cognitive abilities. Children who are visually impaired have a lower quality of product experience because they find BDT use to be cumbersome.

4 Case Study Analysis for Design

Because BDT mostly assists children with vision impairments. Additionally, since various VIC have varying degrees of sensory impairment. The design of BDT will compensate for children's sensory damage from the perspectives of vision, hearing, touch and smell. To improve the ability of VIC to perceive the outside world (Sun and Dong, 2021) [13]. Ensuring that children with vision impairments can study and participate in the curriculum. Due to the great limitations of the compensatory way of taste in the teaching process, the feasibility of applying it to BDT is low, resulting in less relevant product design. As a result, there are basically four categories of sensory compensation design: tactile compensation, auditory compensation, visual compensation, and olfactory compensation. Here are some examples of cases that fall into several types of sensory compensation.

4.1 Design Case

First, take tactile compensation products as an example. Investing in a unique watch for the blind on the online trading platform. The watch has a magnetic steel ball design. Even if visually impaired persons move the steel ball carelessly, magnetic adsorption causes it to automatically return to its original place (Table 1). By touching the steel ball, visually challenged individuals can determine the current time. The blind watch users are not only visually impaired people but also people with normal vision. The device has a half-hour learning curve, and the appropriate user should be at least 12 years old and have completed junior high school. The product's low cost of performance is a drawback, and the price is too high when compared to other watches on the market. 2. Oren Geva created a haptic for the blind in 2018. Many 3D pixels make up the 3D screen of the blind camera. To create 3D visuals on the screen surface, these 3D pixels adjust to different shots obtained by the blind camera. The 3D imaging technology of the iPhone X's original deep camera system and that employed by the blind camera are both identical technologies. 3D image camera is made up of a distance sensor, dot matrix projector, floodlight sensor, infrared camera, and ambient light sensor. For those who are visually handicapped, the use technique is to point at the object, press the shooting button, and the dot matrix image of the object will display on the screen. The blind camera is suitable for blind people's primary object shape recognition. The learning time is 20 min. 3D image camera is appropriate for users under the age of six. The product costs 500 dollars, and its cost performance is not excellent. 3. Blind reader purchased in Kurzweil Educational system. With the help of the National Blind Association of the United States, the inventor Ray created a tool that allows blind persons to read any text. A camera and a small computer with special image recognition software. The readers are placed on the menu while those with vision impairments are in the eating area. And they will

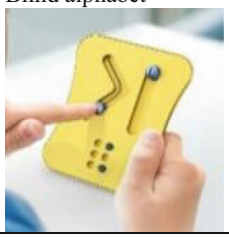
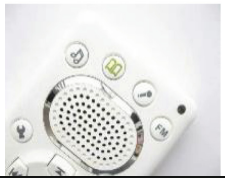
produce Braille data using the internal column array. A soft and elastic display panel on the protruding column creates a touching Braille pattern. Suitable for people with visual impairments of all ages and educational levels. The reader's drawback is that it costs $3000, which is too much for most blind individuals. 4. Braille alphabet constructed of sturdy cardboard with smooth, round plastic buttons inserted into the writing paths of the letters. By pressing and dragging the stroke order button with their fingers, visually challenged children can learn the letter writing order. Below the letter route, there is Braille that corresponds to the letters. The higher case cards are formed into squares, while the lower-case cards are made into circles, in order to distinguish between upper- and lower-case letters. All people who are blind or visually handicapped can use the blind alphabet. People who are visually impaired can fill out personal information on government websites. The product costs $20 and requires one hour of learning time. The blind alphabet's drawback is that it is only appropriate for first-year students and cannot be used to practice writing long or short phrases.

Second, take auditory compensation products (Table 2) as an example. 1. The blind kettle purchased on the online trading platform adopts the circle as the basic element. The handle is where the lid opening button is located, making it simple for persons who are blind to feel. In addition, the buttons use a metal electroplating process, which makes them feel different from plastic and lowers the temperature, making them easier

Table 1. Design Case (1)

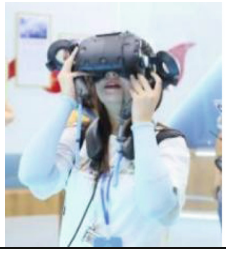
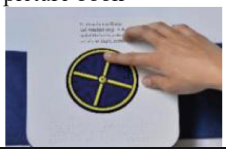
Sensory compensation type	The content of the product	detailed analysis
Tactile compensation type	Specially designed watch for the blind 	Time can be recognized by touching
	Blind-friendly camera 	The stereo form detects the shape of an object.
	Blind reader 	able to recognize, analyses, and translate into Braille words and sentences

Table 2. Design Case (2)

	Blind alphabet 	learn how to write letters and the order of the alphabet by touching
Auditory compensation types	Special water cup for the blind 	Understanding the water level by sound
	Blind navigation glasses 	Identify and remind the name, location and distance of road obstacles
	Blind listener 	Transform text symbols into speech symbols
Visual compensation type	Amblyopia treatment glasses 	Through different module combinations, visual zoom and color discrimination

(*continued*)

Table 2. (*continued*)

Olfactory sensory compensation	Odor Reminder 	Inhale the surrounding air to judge the type of objects
Multi-sensory fusion type	Aromatherapy player 	Fragrance matches the mood of music
	Voice tactile stove 	a voice prompt button that is large, simple to rotate, and easy to grip.
	Visually impaired picture book 	Use dark blue and yellow to create a strong visual contrast.

for those with visual impairments to perceive. The kettle has a water level monitoring device close to the handle that, once the water level is reached, will sound an alarm. This blind water cup is applicable to all ages. The learning time is half an hour, and the price is $20. However, most of the capabilities of the blind person's water bottle are already included in the family water bottle, so additional purchases are not necessary. 2. The tower camera provides images to the blind navigation glasses that may be acquired through Envision's official website. The visual information is extracted from the images of people, objects, public transportation. Through AI algorithm, and then the surrounding environment is described through earphone audio. The most accurate optical character recognition (OCR) software, which can read more than 60 different types of characters, is found in the blind navigation glasses. All ages and educational levels of people who are blind can use it. However, the price listed on the official website is roughly $1800, which is out of reach for most blind individuals. 3. The online listener Obook-85E who

is blind has downloaded a lot of compiled news, digital books, internet radio, FM radio, and other media. Adopting the ergonomic approach, 8G and 16G of built-in storage. The full keyboard Braille input is used in the input, which is convenient for visually impaired people to input their ideas at any time.

As visual compensation and multisensory compensation are not widely used in the design of visually impaired people, there are few cases in this regard. In terms of visual compensation: 1. The best time to treat amblyopia is before the age of eight because the condition is brought on by the brain's visual area's poor growth. AR transparent film on both sides of amblyopia treatment glasses, when the eyes switch between near and far objects, the lens and ciliary body in the eyes receive exercise. Amblyopia treatment glasses apply to vulnerable children under the age of eight who attend primary school and undergo at-home amblyopia treatment. However, the number of AR transparencies is small, which is not suitable for long-term treatment. Furthermore, for multisensory compensation, 1. People's good feelings and associated memories are recalled through aromatherapy, which enhances focus and productivity. Designer Kim Minsu designed this intelligent device. The device is suitable for visually impaired people and non-visually impaired people of all ages and all educational background. 1. Online purchases of VaqsoVR odor supplemental items are connected to other VR head displays using micro-USB or Bluetooth. The device is surrounded on the user's face in a semicircular manner, including five replaceable ink cartridges. Each ink cartridge contains 15 different commercial essential oil varieties that are acceptable for persons of all ages and levels of vision impairment as well as for people who are not visually impaired. The cost of selectively releasing the associated odor when the code is activated is roughly $2500.

5 Model and Data

In 1984, Professor Noriaki Kano put forth the Kano Model concept. The primary purpose of the Kano model is to illustrate the linear link between user satisfaction and product design components. The user's demand index is the design demand element of the product. The design demand is effectively classified to expect the function improvement of user satisfaction and help guide the innovative design of BDT. Kano model classifies five different aspects of product quality. Basic design prerequisites (M). It alludes to the characteristics and functions that the design of the book must have. Lack of them will have a significant impact on user happiness and educational goals. 2. Ideal design specifications (O) (Fig. 2). Additionally known as willing demand. When this desire is satisfied, consumer satisfaction will significantly increase. 3. Stimulating demand for design (A). It refers to the specifications that won't be overstated by readers and that will be reached to the greatest extent feasible without impairing the fundamental features and capabilities of accessible books. 4. Disparate design specifications (I). It means that whether it is offered or not, it will not affect how the user interacts with the system. 5. Requirements for reverse design (R). The traits and functions that should be avoided during the design process are referred to as reverse design. Statistics for the classification were obtained using the Kano survey result form, Kano questionnaire, and Kano assessment form.

The conventional Kano model is an effective method for categorizing and ranking user demands. When presented with a hazy problem of design elements, the user's

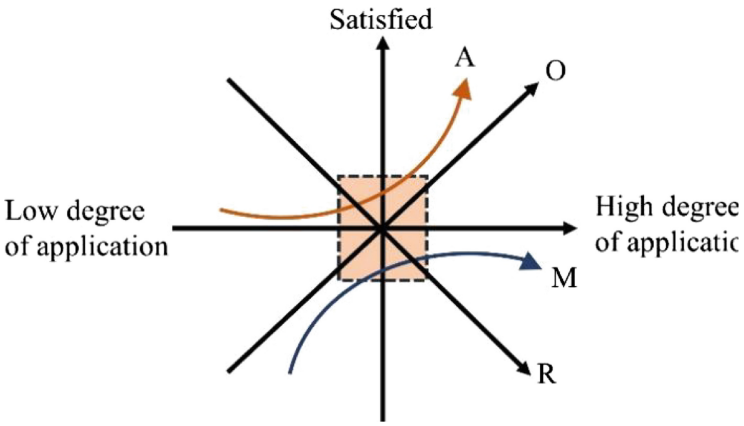


Fig. 2. Kano model (author's own illustration)

attitude is typically ambiguous. As a result, the Kano model questionnaire can more accurately reflect how actual people think when confronted with design features. A questionnaire survey was conducted with 100 visually impaired people (including groups of the totally blind, semi-blind, and amblyopic individuals), designers, and researchers. According to the results of the questionnaire (Table 1), calculate the user satisfaction when BDT has a certain function or attribute as CS_i, and the dissatisfaction is DS_i (Table 3).

CS_i and DS_i are respectively:

$$CS_i = \frac{f_A + f_O}{f_A + f_O + f_M + f_I} \tag{1}$$

$$DS_i = \frac{f_O + f_M}{f_A + f_O + f_M + f_I} \tag{2}$$

The Figure (Fig. 3) demonstrates that the voice content, Braille size, plane/three-dimensional, graphic/text proportion, and Braille/text ratio of BDT are crucial design aspects with high user demands importance. As a result, it will be listed in the final

Table 3. BDT Demand Classification Evaluation

user demand	Does not have an element				
Having certain elements	satisfy	should be	neutral	Acceptable	dissatisfaction
	Q	A	A	A	O
	R	I	I	I	M
	R	I	I	I	M
	R	I	I	I	M
	R	R	R	R	Q

Number	Design elements	M	O	A	I	R	Q	classification
A1	voice volume	19	13	51	15	0	2	A
A2	Sound rhythm	16	24	48	11	0	1	A
A3	Sound familiarity	11	58	20	10	0	1	O
A4	Sound noise	12	25	51	10	0	2	A
A5	Sound content	12	27	51	7	0	3	A
A6	Braille Size	18	61	17	3	0	1	O
A7	Braille type	18	22	40	19	0	1	A
A8	Plane/solid	70	14	5	9	0	2	M
A9	Round and smooth	20	50	14	13	0	3	O
A10	Braille spacing	2	28	50	18	0	2	A
A11	Shape texture	44	22	23	9	0	2	M
A12	Olfactory sensitivity	5	2	14	77	0	2	I
A13	Odor difference	24	21	22	30	0	2	I
A14	Color matching	11	12	20	56	0	1	I
A15	Proportion of pictures and texts	54	21	14	8	0	3	M (Traditional/ Present)
A16	Color preference	19	10	30	40	0	1	I
A17	Color stimulus	10	42	21	25	0	2	O

Fig. 3. Statistical Table of BDT Classification Results of Design Elements (author's own illustration)

design scheme as a fundamental design component. In order to determine the design time, the key indicators are chosen as the recommended design elements after extracting the projected demand and the excited demand from the table for further study.

In the calculation of this paper (Table 4), the satisfaction effect brought by the indicators is emphatically considered. Therefore, when sorting indicators, comprehensive screening is carried out according to the size of CS_i. The highest importance should be given to designing M as an essential indicator. As a result, additional screening for O (expectation indication) and A (excitement indicator) is necessary. The screening results offer thorough instructions for design practice. To lessen the impact of mistakes on the choice of design elements, indicators I and R should be suitably abandoned.

The ranking of the BDT requirements in addition to the essential design components (Table 5): $A_5 > A_{10} > A_3 > A_6 > A_4 > A_2 > A_9 > A_1 > A_{17} > A_7$. A_5, A_{10}, and A_3

Table 4. Positive and negative satisfaction of design elements

Number	Design elements	CS_i	DS_i
A_1	voice volume	0.653	0.327
A_2	Sound rhythm	0.727	0.404
A_3	Sound familiarity	0.788	0.697
A_4	Sound noise	0.776	0.378
A_5	Sound content	0.804	0.402
A_6	Braille Size	0.787	0.797
A_7	Braille type	0.626	0.404
A_9	Round and smooth	0.660	0.722
A_{10}	Braille spacing	0.796	0.510
A_{17}	Color stimulus	0.643	0.530

Table 5. Importance ranking of design elements

Number	Design elements	CS_i	sort
A_1	voice volume	0.653	8
A_2	Sound rhythm	0.727	6
A_3	Sound familiarity	0.788	3
A_4	Sound noise	0.776	5
A_5	Sound content	0.804	1
A_6	Braille Size	0.787	4
A_7	Braille type	0.626	10
A_9	Round and smooth	0.660	7
A_{10}	Braille spacing	0.796	2
A_{17}	Color stimulus	0.643	9

are the three of the highest importance. Therefore, "sound content," "Braille spacing," and "sound familiarity" all be included in BDT design criteria. Even if the absence of A_6, A_4, A_2, and A9 will not negatively impact the user's reading experience, the design should attempt to address these requirements. Due to the low importance of A_1, A_{17}, and A_7, effective trade-offs can be made without compromising the functionality of the BDT design. Therefore, it is determined that when designing BDTs, the necessary design criteria A_8, A_9, and A_{15} should be considered first, followed by design components A_5, A_{10}, and A_3, and then A_6, A_4, A_2, and A_9.

6 Design Practice

1. The well-known fairy tale The Daughter of the Sea serves as the overarching source of inspiration for BDT. The item satisfies the requirements of those who use it, conforms to kid-friendly standards, and satisfies their higher aesthetic requirements. The DBT can be folded to make moving and positioning VIC easier. The BDT in three dimensions can be spread out and positioned. The product's stability is improved by the thicker cover, which also gives VIC a psychological sense of security when using it.

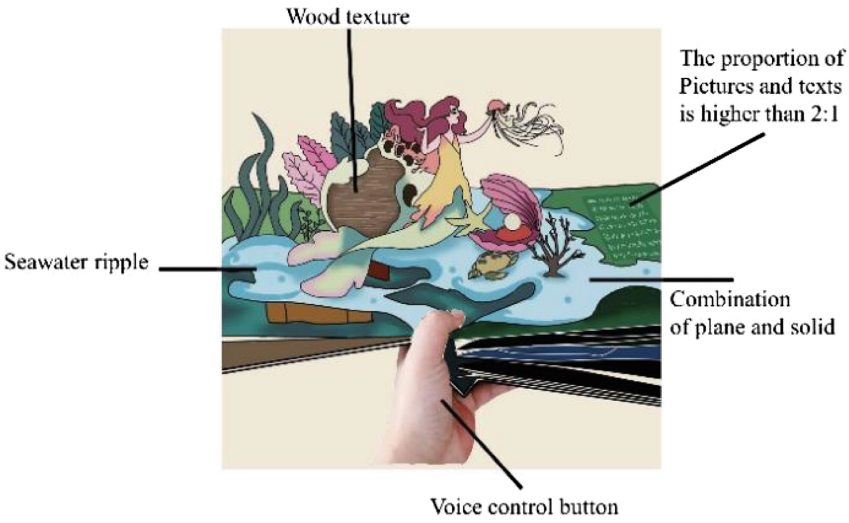


Fig. 4. Product Design Description (author's own illustration

```
import bluetooth._bluetooth as bluez
dev_id = 0
sock = bluez. hci_open_dev(dev_id)
blescan. hci_le_set_scan_parameters(sock)
Blescan.hci_enable_le_scan(sock)
measured_anterior = 0

try:
   while True:
      returnedList = blescan.parse_events(sock, 1)
      if len(returnedList) > 0;
         (mac, wid, major, minor, txpower, rssi) = returnedList[0] . split(
               ' , ' , 6)
         # CABIAR LA DIRECCION MAC
      if mac == '88: 0f: 10 :XX: XX:XX' and wid[0:
                                          22] == '01880f1096ab190d161d18' ;
```

Fig. 5. Bluetooth connectivity (author's own illustration)

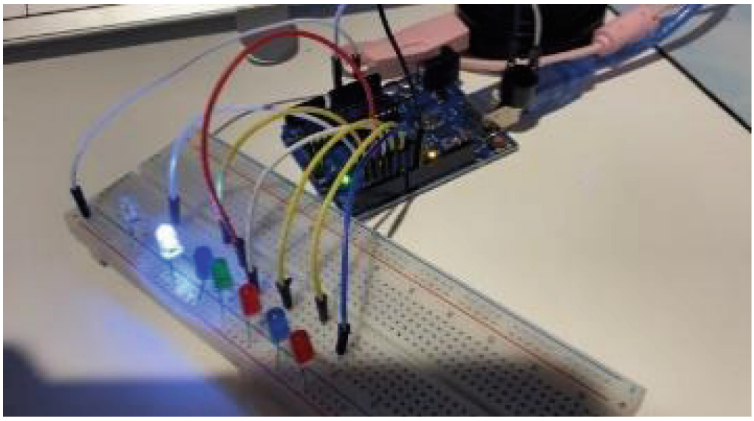


Fig. 6. Arduino voice playback (author's own illustration)

2. BDT comes in a variety of shapes and textures that correspond to the many elemental components. to assist those who are blind in feeling different components in books. VIC can recognize various materials of elements by feeling and comprehending various characteristics of elements by using water ripple and wooden concave and convex texture (Fig. 4).

3. The folding three-dimensional plane at the bottom of BDT transforms the plane narrative into a three-dimensional one. Because they lack visual experience, those who are congenitally blind find it challenging to visualize tangible patterns solely through text description. Therefore, to aid visually challenged readers in understanding the content of books, the combination of flat Braille interpretation and three-dimensional visuals is used. The item has a voice interaction system built in so that visually impaired persons can use voice commands to activate BDT and input commands to assist them in connecting to Bluetooth (Fig. 5). The BDT can be configured to transmit information over voice waves. Due to their requirements for auditory familiarity, some visually impaired people can also choose the voice users need. Different music sound effects are played through the buzzer on an Arduino to provide users with various BDT cues and feedback (Fig. 6). Additionally, various BDT text contents correspond to various vocal styles, enabling groups of people who are blind to "visualize" books.

4. Unlike other devices made to make it easier for those with vision impairment to read books, BDT does more than just convert text into Braille. Because the user group is positioned as VIC, picture books must have a minimum of a 1:1 ratio of text to pictures, and BDT must have a minimum of a 2:1 ratio of visuals to text. The readability and readability of BDT and the engagement of VIC in books can be substantially improved by the simple Braille characters and short sentence patterns.

7 Conclusion

Even with advances in science and technology and social civilization, there is still considerable discrimination towards individuals who are visually impaired, particularly VIC. There are still various problems in the existing market for VIC products. The use of the

idea of sensory compensation in the design and development of products for individuals with visual impairments is a field that merits in-depth study. The designer should next apply the other four sensory compensation techniques in addition to visual compensation, starting with the demands of the VIC. Determining the weight of the demand information for BDT for children who are visually impaired using the Kano algorithm, identifying the crucial stages of the BDT design process, and effectively encouraging the development of BDT. Due to limited resources or technology, BDT cannot simultaneously serve all its consumers' needs. The Kano algorithm offers a benchmark for the trade-off between BDT design elements and prioritizes the quality attributes with the biggest effects on user happiness. Connecting BDT with the computer through Bluetooth using programming language and controlling Arduino to use the hearing sense advantages of visually impaired children to voice describe the BDT that is difficult to understand by touch. The use of multisensory interaction mechanisms in the education of VIC can enhance the usability of BDT, providing VIC with a comfortable and enjoyable reading. Experience. Therefore, while designing products for persons with VIC, it's important to consider their hidden resources within their sensory compensation mechanism in addition to meeting their basic demands. For accessible products to properly demonstrate care and respect for blind people through design, consider the sense of hearing, touch, and other senses of individuals who are VIC.

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