Designing A Portable Electricity-free Water Volume Detector For Visually Impaired Users

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ABSTRACT
The activity of filling liquid into a bottle or container is an activity commonly carried out by persons. Without vision, visually impaired (VI) persons, particularly who are blind will rely on sound or echo feedback that is produced when the water flowing into the drinking container creates a noise. Due to its close-shaped and small opening, people with visual impairments prefer drinking bottles as a drinking container. In most situations, blind people also use glasses and mugs. This research aims to identify and overcome the problems faced by blind users in filling a glass with drinking water, with a focus on developing tools from wood waste. This study involved blind students at a special school in Yogyakarta Special Region, Indonesia, as research subjects. The research methodology followed the Double Diamond Design Thinking stages: Discover, Define, Develop and Deliver. In the Discover stage, observations and interviews were carried out to understand the challenges faced by blind users in doing task. The Define stage identified the main problem in determining the water level which often caused spills. The Develop stage involved a brainstorming and prototyping process to create suitable product. The Deliver stage tested the effectiveness of these tools through direct trials in the field. The research results showed that the use of this tool significantly increased the accuracy, safety and independence of blind users in filling a glass. It is hoped that this research can contribute to the development of more effective assistive technology and improve the quality of life for the blind in Indonesia.

Keywords: Blind users, Double Diamond Design Thinking, Waste, Accuracy

INTRODUCTION
Obstacles in Doing Everyday Tasks for Visually Impaired (VI) Users
From early of age 12, Visually Impaired (VI) students are required to do everyday

tasks independently. Since humans rely on visual imagery (i.e. approximately 80% of brain activation), blind persons would have a different brain adaptation in processing audio and touch to identify any object immediately. This method of adaptation is called cross-brain plasticity (Cattaneo & Vecchi, 2011).

Despite visual activity, blind persons' visual cortex would be activated by the brain activation on somatosensory cortex of audio and touch stimulus (Ortiz-Terán et al., 2016). The main problem is the integration of stimulus input on the visual cortex allows sighted persons to analyse the particular condition accurately and to quickly act as a response, but blind persons need time and proper feedback to do the analysis and immediate action. This problem occurs in so many tasks including simple everyday tasks, such as filling water into a glass or mug (Prasetyo, 2021).

Inappropriate Assistive Product Leads to Discomfort

According to the researchers' preliminary study at one of the special school's in Yogyakarta Special Region, Visually Impaired (VI) students, particularly who were blind faced significant challenges in daily activities, including measuring the volume of drinking water in a mug or glass. Pouring water, a routine task, were done using their sense of hearing (listening to the sound). They also dip their index fingers to touch the water.

This practice of dipping fingers into the water is unhygienic and considered an unsafe method which was also recorded by Prasetyo (2021). Moreover, it was found that blind students often felt embarrassed to fill water in public due to difficulties in gauging the water level, leading to spillage. This could lead to potential hazards. Blind students chose to use water bottles and rely on sound echoes produced when the water flowing into the drinking container as the water level indicator due to its close-shaped and small opening.

The background of this research focuses on the high cost of assistive devices for measuring water volume, making them inaccessible to many blind users in Indonesia (Image 1). These devices, typically made with advanced technology to give audio-vibration feedback and high-quality materials, are expensive to produce. As blind students' response in the preliminary study to the existing audible water-level detectors, the tools made them uncomfortable due to the potential unwanted attention towards them in public. Additionally, they also are expensive and need batteries.

The lack of effective, affordable tools for accurate water filling exacerbates this issue, impacting their confidence and leading them to avoid such tasks in public. Hence, a product design should meet users' needs and preferences (Pullin, 2009). An assistive device could become the identity of disabled users so their thought should be expressed in the product.

Image 1 An Electric Water-Level Detector (Source: RNIB, 2024)

On the other hand, wooden waste could be found easily in Indonesia, particularly in the Special Region of Yogyakarta so it has potential as the primary material for making a more affordable water volume detector. This approach not only reduces production costs but also benefits the environment by utilizing waste. The design project aims to design and innovate a portable, electricity-free water volume detection tool using wood waste. This tool will help blind users fill water comfortably, safely, and hygienically, preventing spills and bacterial contamination from finger dipping.

LITERATURE REVIEW

Cross-modal Plasticity and Multimodal Strategies in Blind Persons

Visual deprivation, the absence or severe limitation of visual input, can be caused by various factors, including genetic conditions, injury or diseases such as retinopathy of prematurity of glaucoma (Cascella et al., 2015). The onset of blindness could occur at birth (congenital) or later in life (acquired). It plays a crucial role in how the brain adapts to the loss of vision. Blindness leads to significant neural reorganisation as known as cross-modal plasticity (Cattaneo & Vecchi, 2011; Collignon et al., 2020). As the brain's plasticity is greatest during early childhood, the timing of blindness onset becomes critical. It allows for more extensive neural reorganisation when blindness occurs at this early stage (Kupers & Ptito, 2014).

Cross-modal plasticity is a central mechanism in the adaptation of the brain to blindness (King, 2015). Advance neuroimaging techniques have shown that the occipital cortex, traditionally responsible for visual processing, becomes involved in processing auditory and tactile information (somatosensory) in blind persons (Ortiz-Terán et al., 2016). Moreover, blind persons also increasingly rely on multimodal strategies to navigate and interpret their movement (Cattaneo & Vecchi, 2011). Blind persons often integrate auditory and tactile cues to improve their spatial awareness, object recognition and proprioceptive. This adaptive phenomenon is namely multimodal strategies in blind persons.

Fine Motor in the Blind

Fine motor skill, particularly those involving the fingers, are essential for performing more intricate tasks, including recognising objects for blind persons. It leads to compensatory enhancements in tactile, haptic sensitivity, and dexterity (Bauer et al., 2015). Studies have shown that blind persons can discern fine details of objects' texture and shape, more accurately that their sighted peers (Cattaneo & Vecchi, 2011; Ortiz-Terán et al., 2016). It is attributed to both neural plasticity and increased reliance on haptic feedback which allows for more precise manipulation and exploration of objects. For instance, in a certain writing task, holding a pen and making precise movements facilitates actions for everyone. Writing is a complex action that involves the integration of the hands, arms, fingers, and eyes (Abdurrahman, 2012, p. 178).

Archimedes' Law

When an object is partially or fully submerged in a liquid (either liquid or gas), the liquid exerts an upward force on the object equal to the weight of the displaced liquid. This upward force is called buoyant force. The magnitude of the buoyant force depends on the volume of the object submerged and the density of the liquid. The greater the density of the liquid, the greater the buoyant force, and vice versa. Therefore, the weight of an object submerged in a liquid is always less than its actual weight due to the upward buoyant force (Fai, 2022). An object floats in a liquid when a part of it is above the surface of the liquid and another part is submerged (Image 2).

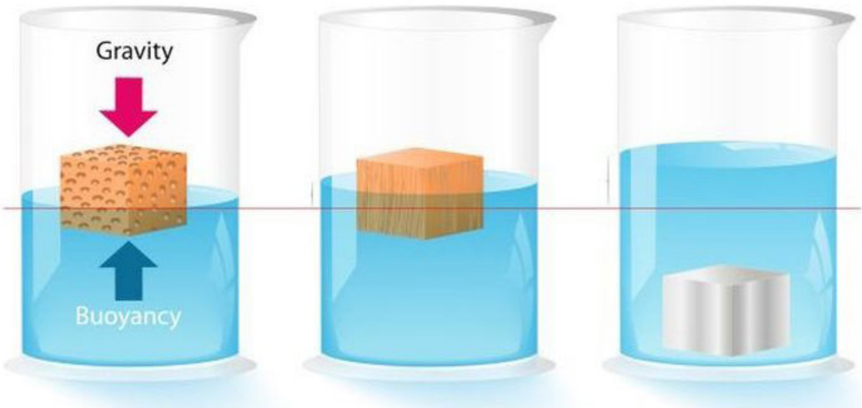

Image 2 Archimedes Law. (Source: Fai, 2022)

Mahogany Wood as Kitchen Utensils

Wood materials have been used as simple and effective tools for indicating water stream and water levels in various settings. The concept relies on the buoyancy of the wood, which floats on the surface of the water so it provides a visual indicator of the water's height (Dobriyal et al., 2017).

It is influenced by the density, shape and specific type of wood used. The use of wooden floaters is advantageous due to their simplicity, low cost and durability. Wood provides a unique natural aesthetic and is commonly used in cooking utensils. Currently, wood is also used for decorative tableware. Mahogany, known for its dense and smooth grain, is a popular choice for tableware due to its strength and durability. (Suryokusumo, S, & R, 2012). Although not as dense as steel or concrete, wood is very strong and hard. It is easier to process with less energy and is elastic and tough enough to withstand loads perpendicular to its grain.

METHODOLOGY

The research methodology followed the Double Diamond Design Thinking stages: Discover, Define, Develop and Deliver (UK Design Council, 2015). In the Discover stage, regular observations and interviews to teachers and students were carried out to understand the challenges faced by blind users in doing tasks (Image 3). It involved a special school in Special Region of Yogyakarta, Indonesia. The participants' inclusion was the totally blind or very severe Visually Impaired (VI) students. The Define stage identified the main problem in determining the water level which often caused spills.

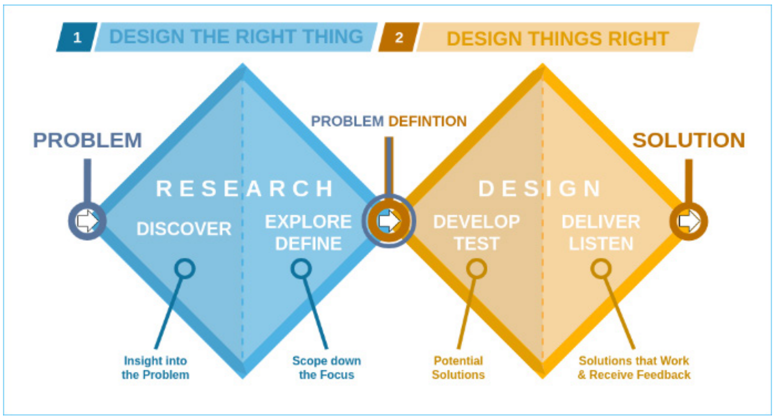

Image 3 Double Diamond Design Thinking, Illustrated by Kaishin Chu. (Source: UK Design Council, 2015)

The results of qualitative observations will be a comparison factor in making the final product. The factor that will be measured in this research is how easy it is for users to recognize and use the product. The nature of this research itself is objective and for the analysis to produce data for maximum comparison of results. The Develop stage involved a brainstorming and prototyping process to create a suitable product. The Deliver stage tested the effectiveness of these tools through direct trials in the field.

RESULT & DISCUSSION

Observation and Interview

The field study carried out had the aim of directly observing the activities of special school students while studying and doing activities in the dormitory ((n=3, age 18 ± 2,08 yr) both blind (n=1) and severe Visually Impaired (n=2). Data from observations and interviews were then analysed again together with previously obtained literature. The following data in Table 1 shows the results of interviews with blind students.

Table 1 Interview Result. (Source: Personal Documentation, 2022)

No	Question	Answer
1	What type of visual impairment are you?	• Severe VI (n=2) • Totally blind (n=1)
2	What daily activities do you do where you currently live?	• Washing clothes, drying clothes, doing chores, washing dishes, cooking rice, making drinks. • Study, listen to music.
3	What are the errors or disruptions in activities?	• When making hot tea, your fingers often get burnt when you insert your index finger. • Spill water when filling water into a mug
4	How do you deal with these distractions?	• Inserting thumb into the water • Using a drinking bottle and listening to the echo "*I prefer to drink water using a drinking bottle. The way to do this is by listening to the echo of the filling water. Sometimes if you don't focus, it overflows and spills on the floor.*" (P1)

Image 4 shows how blind participants use the dipping finger as a common way to detect the water level inside a mug. They used index or middle finger for the cold water and the thumb for the hot water.

Image 4 Existing Technique of Dipping Finger.
(Source: Source: Personal Documentation, 2022)

Archimedes' Experiment

Three wooden cylinders were created and different numbers of holes were drilled into them. (16, 20, 24 holes consecutively). Each wooden floater was weighted. This activity was carried out to incorporate Archimedes' law, by weighing the weight of the wood used as an indicator with holes and calculating the Archimedes' force (FA) using Archimedes' law formula.

W = Fa
Pb. Vb. g = pZC. V2. g
Pb. Vb = pZC. V2
Since Vb > V2, it follows that Pb < pZC.

Each floater was calculated for the density and weight of fluid object, buoyancy (Table 2) under the floating conditions: If the ρ object's < ρ liquid's, then the object will float.

Table 2 Archimedes Experiment. (Source: Personal Documentation, 2022)

Object ID	Height (cm)	Radius (cm)	Number of holes	Weight (g)	Volume (cm3) (π.r².t)	Density of an object (ρb) (g/cm3)	Weight of fluid object (N)(w_{bf}= ρb.g.V)	Buoyancy (N) (FA = ρf.g.V)
1	5	1	16	9	15.7	0.573	89.961	157
2	5	1	20	8	15.7	0.509	79.913	157
3	5	1	24	7	15.7	0.445	69.865	157

Based on the experimental data above, Object 1, 2, and 3 show that the value of Fa > W: Object 1: 157 > 89,961; Object 2: 157 > 79.9135 and Object 3: 157 > 69,865. This is in accordance with Achimedes' theory that the smaller the weight of a fluid object (W) compared to the upward force (Fa), the more the object will float. In addition, ρ object < ρ liquid shown in Object 1, 2, and 3 shows < 1 (0.573, 0.509, 0.445 consecutively).

In conclusion, the experiment was in line with Archimedes' theory which states that smaller ρ of an object compared to ρ of a liquid, the more the object will float. The upward force in this experiment is influenced by the number of holes in the mahogany. The wooden floater with more holes >24 could be used in the design.

Direction of Design Recommendations (Define)

A tool for people with visual impairments in filling water into glasses or mugs that prioritizes user comfort and safety based on tactile cues when carrying out drinking activities. The drinking aid was chosen because participants had experienced injuries when making a hot drink by inserting his finger into the glass to detect the volume of water. This tool also functions to prevent overflowing water from spilling onto the floor which could cause the resource person to have an accident.

The tools designed will be made using solid wood because wood is easy to shape, natural and environmentally friendly.

Ideation and Prototyping (Develop)

An assistive product design was made using mahogany as a basic material with a bird's tail connection technique with the aim of making it stronger. The following are criteria accommodating the blind users' needs (Table 3).

Table 3 Product Criteria. (Source: Personal Documentation, 2023)

Aspect	Details
Function	1. As a tool to help the blind to fill drinking water so it doesn't spill, which can be used by inserting the product into a glass or mug with a float as a tactile indicator so that the user stops filling water from a water source. 2. Design to prevent drink spills. 3. Opening and closing mechanism that can be operated easily.
Shape	The design of this tool is in the form of a tube with a clamp that functions as a holder for the product in the glass, and a tube-shaped float that functions as a touch indicator.
Aesthetic	Natural wood colour on the product to add a simple and natural impression.
Ergonomics and Safety	There are no sharp corners or parts that could harm the user. This tool considers materials for finishing so that the product is durable and food grade. It should only involve a simple and direct sub-activity

Some sketches were generated iteratively according the design brief and criteria (Image 5). In the process, some inputs were gathered from the teacher as a VI expert and production staff to ensure the feasibility of the design.

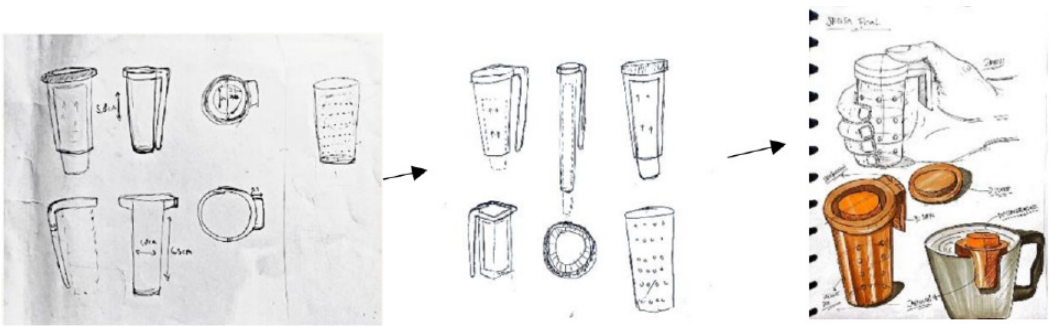

Image 5 Sketch Progress. (Source: Personal Documentation, 2023)

Prototype

Prototyping was carried out iteratively to get the best design by conducting modelling studies. The following prototypes has been created (Image 6) to fit the user's ergonomics, production procedure and durability. The wooden floater would be floating up against thumb to give the tactile cue to user as the water-level has reached its safe limit.

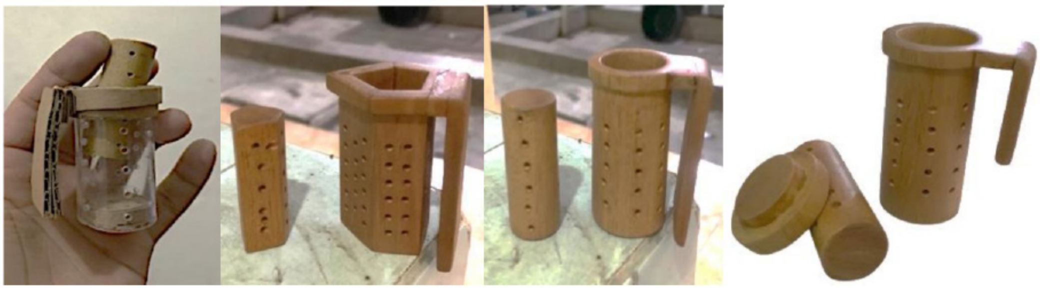

Image 6 Prototype Progress. (Source: Personal Documentation, 2023)

The final prototype aimed to increase the independence and quality of life of blind users in their daily activities. Involving users in product development can ensure that drinking aids are truly effective and suit their needs. Table 4 provided details of product specification according to blind users' need, the material potentials and the activity demands.

Table 4 Design Specification (Source: Personal Documentation, 2022

Product Name	Tacjuk
Types of products	Visually Impaired Aids
Product Function	Water-level detector for a glass or mug (D 76 – 85 mm); No electricity; Wooden floater gives tactile feedback through the user's thumb
Material	Mahogany
Product Colour	Natural mahogany colour
Dimension (ØxT)(mm)	33x68
Type of joint	bird's tail
Product componenents	A floater container with built-in clamp; a floater with 24 holes; clamp; a lid

Usability Testing

All users (n=4, 15±1,83 yr) preferred the "Tacjuk" product over battery-powered drinking aids. The development process successfully created a safe and hygienic non-electric drinking water volume detection aid. The Archimedes principle could successfully be implemented into a mahogany wooden floater (Image 7).

Image 7 The Final Prototype When It Is Used. (Source: Personal Documentation, 2023)

The components of the product could be identified and used as its function by all participants. The lid should be open and the container contains a floater inside. The users use the product by hanging the container's clamp against the mug's edge. The users could hold the mug by its handle and put their thumb on the top of the container's opening. The water is poured into the mug as usual. The wooden floater would float up and make contact with the users' thumb when the water reaches the safe water-level. For user comfort, the diameter of the product's hole should be set at D280 mm, as it is suitable for both teenagers' and adults' thumb anthropometry in order to receive optimum tactile feedback of the floater.

During the usability testing, all participants chose Tacjuk as the non-electric water-level detector over the electric ones as it is affordable and low maintenance, (Image 7). All participants claimed that they were confident to use the "Tacjuk" and do the maintenance independently. 'Easy' for users who are blind means immediate feedback and involves a simple sub-task. In addition, they claimed that Tacjuk could help them in public situations because it will not give any audio feedback and will draw any additional attention in a public environment.

"It's easy to use! I prefer to use this one rather than the sound sensor one" (P2)
"It's easy and you don't need to use batteries. For electronic ones you have to use batteries. The batteries can run out at any time and this can be made anywhere" (P4)

Image 7 Usability Testing. (Source: Personal Documentation, 2024)

CONCLUSION

The design development process aims to enable visually impaired individuals to measure water accurately and create a water volume measuring aid for glasses using hygienic waste wood materials. All users (100%) preferred the "Tacjuk" product over battery-powered drinking aids. The development process successfully created a safe and hygienic non-electric drinking water volume detection aid.

Visually impaired individuals often face difficulties detecting water levels in glasses, leading them to insert their fingers to gauge fullness. This practice can be replaced by a special tool that uses the principles of Archimedes and tactile indicators to measure water hygienically and adhere to safety standards.

Additionally, leftover wood from production in factories often ends up as firewood or piles up unused. To address this waste, the author developed a drinking aid for visually impaired individuals using mahogany, which is small and lightweight. Utilizing Archimedes' principle, this waste wood can be transformed into an ideal material for making drinking aids. Furthermore, the dovetail joint technology enhances the strength of the drinking aid. For user comfort, the diameter of the aid's hole should be set at Ø 280 mm, suitable for the fingers of both teenagers and adults to meet users' hand ergonomics.

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