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An Inclusive Science Laboratory for Visually Impaired Students

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Abstract : Education is a powerful tool that has the potential to improve the social and economic condition of a person in a developing country like India. The greatest challenge for the Government is the accomplishment of quality education in inclusive and accessible arrangements for persons with disabilities. The teaching techniques adopted in traditional classrooms aren't usually designed to cater to the need of visually impaired students. Visually impaired students are usually held back from pursuing STEM (Science Technology Engineering and Maths) education and are encouraged to take up humanities and commerce. The lack of resources is mostly responsible for holding back visually impaired students from pursuing Science along with other factors such as the incompetence and attitude of the facilitators. In this work, an inclusive science laboratory for visually impaired students is envisaged using assistive technology that can facilitate them in performing lab experiments. Assistive technology plays a crucial role in the shift of the education system for visually impaired students to an inclusive model. Low cost, easy to use and store, hardware modules with talkable features has been designed to measure temperature, time, to detect contrast and color using Arduino UNO. With the help of these modules, a visually impaired student can be assisted to perform laboratory experiments effortlessly, which otherwise is not made accessible to them.

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1. Introduction

The economic status of a citizen has its dependence on access to education. Educated youth is incredibly skilled to mold and reinforce growth prospects. Education can enable a person to make an informed decision and further can result in participative citizenship in a democratic environment. The Constitution of India guarantees equality of all its citizens in every respect and this is pertinent to education as well. The right to Education Act was passed by the parliament of India in 2009. It made education, a fundamental right of all children of the age group 6-14 years irrespective of their caste, creed, social status, and even physical disability. To date significant steps have been taken by the Indian Government, both at the central level and at the state level, to promote education amongst children. The Central Government has supported many schemes like District Primary Education Programme (DPEP), Sarva Shiksha Abhiyan (SSA), Rashtriya Madhyamik Shiksha Abhiyan (RMSA), Samagra Shiksha to achieve the mission of providing elementary education to all. The government has also introduced a centrally funded scheme- Integrated Education for Disabled Children (IEDC) with an objective of "Education for all". Under this scheme, persons with disabilities are integrated as equal members in the mainstream society. The overall aim is to inculcate courage and self-confidence in such persons to face daily life challenges.

The SSA was introduced at the end of the Ninth Five Year Plan, to uplift the education status of the country. It is designed through the intercessions to improve quality of teaching-learning, to increase accessibility, and to reduce gender and social gaps for students under the age group of 6-14 years. SSA also seeks to ensure that every child in the age group of 6-14 years with special needs, irrespective of the kind, category, and degree is conferred with desired education.

Despite all these schemes for reforming the education system of the country, a vast majority of children are still out of the reach of education due to various administrative, social, and economic reasons. Though the Constitution of India assures education of equitable quality for all, persons with disabilities have been facing discrimination in education and abandonment due to socio, psychological and cultural reasons. For the overall progress of the country, this discrimination must be eliminated and students with disabilities should be conferred with opportunities to pursue education, especially Science.

Science has always been an important subject from an academic point of view and requires a thorough understanding of concepts, scientific reasoning, and logical thinking. Traditional science teaching mostly involves visual instruction to explain a concept and relies on illustration of concepts such as light, chemical reaction, temperature measurement, etc., which require visual demonstration. So, it becomes more challenging for visually impaired students to adapt to traditional classroom teaching. They often feel excluded during science practicals due to the taboo that students might injure themselves or they may not be able to perform experiment (Taraporevala, 2016; Supalo, 2013). Therefore, it is necessary to incorporate a different approach to teaching visually impaired students which exploits the use of their other senses such as smelling, hearing, and touching (Sahin & Yorek, 2009). The development of inclusive lab space equipped with assistive technology-based devices capable of converting visual results into tactile or audio format should be encouraged. Besides this, it is important to train teachers and lab assistants by an inclusive model of education and to change their attitude towards blind and low-sighted students (Kumar,2019).

The Right of Persons with Disabilities Act, 2016 which grants blind person reservations in educational institutions and workplaces along with the Right to Education Act, 2009 together mandate the incorporation of Inclusive Education into the mainstream education system. But the transition of schools from retrofitting education mode to inclusive education model involves huge transformation (Source: https://www.thebetterindia.com/98146/science-accessibility-visually-impaired-students/). Assistive technology plays a crucial role in this transformation and helps in empowering visually impaired students (Senjam, 2019). It uses sight and other senses like sound, touch, smell, and vibration for accomplishing a task. It makes them independent individuals capable of pursuing vocational training in various fields even after completion of their school and high school education. Most of the current assistive technology equipment makes use of Braille, audio formats, and tactile as an indicator of results. Some of the popular equipment are audiobooks, tactile scales, braille embosser, text-to-speech converter, etc. Thus, with the use of assistive technology, it is possible to design tools that may satisfy the needs of all visually impaired students irrespective of their condition. In this work, an inclusive laboratory for a visually impaired student is proposed which consists of economical and robust modules for measurement of temperature, time, water level, detection of contrast, and color.

2. Literature Review

The attitude of people towards the specially abled has not always been a positive one. The change in the attitude has been a gradual progression from a feeling of indifference to pity, to finally their acceptance. The current mindset of people is to make them more self-reliant and integrate them as equal members of society.

Earlier, for visually impaired students, the lack of sight led to a wrongful belief that they are incapable of reading, writing, and learning. To read or write they had to be dependent on their relative or a helper. John Milton, the famous poet, for example, had to write using his daughter's help (Sylvester, 2020a). When "Letter on the Blind for the Use of Those Who Can See" was published by Denis Diderot in 1749, people began to realize that the visually impaired are capable of learning and working like other members of society. As a result, society became actively involved in making efforts to empower visually impaired individuals. Initial attempts to educate them were based on hiring private tutors for wealthy students. However, a formal educational institute was established later in the 18th century.

The National Institution for The Young Blind (L'Institution Nationale des Jeunes Aveugles) was established in Paris in 1784 by Valentin Haüy. Followed by the opening of schools for the blind in Liverpool, England in 1791 and Massachusetts, the United States in 1829. This led to the foundation of Perkins School for the blind. Eventually, the common trend in these schools was that their Graduates became teachers. This was due to the belief that only the blinds will know how to teach other blind students. These schools made sure that blind students became self-reliant and competent individuals of society. Various new teaching techniques were adopted in these institutes. In India, the Sharp Memorial School for the Blind, named after its founder, Annie Sharp became the first special school for the blind and was established in 1887 at Amritsar. Eventually, more special schools like the Calcutta School for the Blind and The Dadar School for the Blind enabled vocational rehabilitation of students through education and vocational training.

The old model of teaching was broadly based on residential education for students with wealthy socioeconomic backgrounds and isolated schools in the outskirts for underprivileged children. Both these modes led to the isolation of these students from mainstream society. The integration of sighted and visually impaired students through inclusive education was the key to the acceptance of blind students as equal society members. The invention of the Braille script in the 1820s played a vital role in this direction (Sylvester, 2020b). Braille empowered blind and visually impaired students with the skill of reading, writing, and typing. It became widely accepted towards the 20th century by the visually impaired and sighted communities. Helen Keller empowered herself with the braille and became the first deaf-blind person to graduate from college and shared her struggles and triumphs in achieving education in her memoir, The Story of My Life.

At present, science teaching, including both theory lessons and practical hands-on, depend a lot on visual and physical observations. Sighted people acquire information by observing things and people's actions around them. This observational learning is however not possible with the visually impaired person. To understand the object or concept they need more concise training and practical experiences by using their sense of touch along with other sensory perceptions. Thus, for teaching science to visually impaired students, tactile resources and audible diagrams are used (Zebehazy & Wilton, 2014; Supalo, 2016). The science textbooks are also adapted into braille for facilitating them (Toenders et al, 2017). The use of optical devices and providing handouts of the concepts or experiments pre-requisite has also eased out their struggle (Bishop et al, 1996). Audiotapes of the lecture and preferential instruction for performing experiments further can help them in understanding the subject.

Further, with the advent of assistive technology, students can independently carry out their tasks which otherwise may be difficult to accomplish. Science practicals depend on the observation of results obtained while performing experiments in the laboratory. These laboratories need to be modified for visually impaired students by using alternates that will simulate a similar experience. Assistive technology can be used as a bridge to mend this gap. The adoption of assistive technology in schools becomes easier if these pieces of equipment are low cost, easy to use,

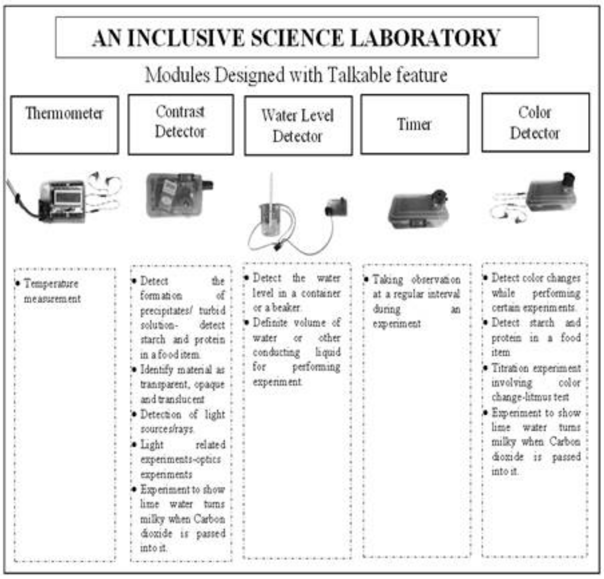


Fig. 1:Proposed inclusive laboratory for a visually impaired student.

require minimum instructions, easy to store, and most importantly can be used independently or utmost with the help of a student partner by the visually impaired students. (Gupta & Singh, 1998; Supalo et al, 2016; Supalo, 2012).

Over the recent years, various methods have been adopted to teach visually impaired students. Besides the use of assistive technology-based teaching, activity-based instruction is another great mode of science teaching. Activity based instruction (Kızılaslan & Sözbilir, 2019) enables students to enhance their problem solving and reasoning skills. Activities related to concepts of insulation (Kızılaslan et al, 2019), heat, and temperature have been conducted for visually impaired students. Hardware devices like SciVoice Talking LabQuest (Kroes et al, 2016) can be connected to various sensors for measuring temperature, pH, gas pressure, light, color, etc. without the help of a teaching assistant. Additionally, computer-based science has become accessible with the help of software like Logger Pro and JAWS (Supalo et al, 2007). Some of the recently designed devices for assisting visually impaired learner makes use of Arduino (Rodríguez et al, 2018; Salama et al, 2022) as they reduce the overall cost of the circuit and require low maintenance. The Arduino-based pH sensor was made that could sense the change in the color of the indicator paper using an RGB color sensor (Qutieshat et al, 2019). The color change is perceived by the visually impaired person as a distinct audible tone. However, there was no provision for speech output which helps in the better and clear interpretation of the obtained result by the visually impaired learner. An Arduino based talking calorimeter for an inclusive laboratory has also been described by Gomes et al (Gomes et al, 2020). An electronic interface using a Wheatstone bridge, thermistor, or an op-amp was designed. The thermistor is a nonlinear device that requires voltage for its operation and a current sensing resistor in series for obtaining a reading proportional to the temperature being measured. Thus, it requires calibration via a microcontroller before its usage.

In this work, an inclusive laboratory for visually impaired students is proposed making use of hardware modules designed with the talkable feature. The developed modules namely the talkable thermometer, color detector, and water level detector have been designed using microcontroller ATMega 328 IC. The talkable thermometer makes use of linear IC LM35 that doesn't require tedious calibration of the microcontroller prior to its usage and can provide a stable output. It is also augmented with LCD along with the talkable feature for displaying the measured temperature. The color detector module designed in this work apart from sensing the pH of the solution can also be used for other titration experiments involving color change and where the precise volume of titrant from the burette is needed. The timer and contrast detector modules make use of the IC 555 timer.

3. Research Methodology

The use of assistive technology as an integral part of inclusive education has gained popularity in recent years. In this view, an inclusive laboratory is planned which consists of devices designed to aid the visually impaired students to carry out their lab work independently. Most science experiments conducted in the laboratory are not tactile in nature (Baughman & Zollman, 1977; Hamed & Aljanazrah, 2020). A phenomenon like light cannot be sensed directly by visually impaired students. The devices designed under this smart lab convert the data/result to sound files that can be easily comprehended by the visually impaired student. The modules designed include a talkable thermometer, contrast detector, water level detector, stop timer, and color detector as shown in Fig. 1. These modules have been designed to provide an easy measurement of temperature, time, level of water, and color while performing various experiments in a laboratory. The designed modules are cost-friendly and are easy to use as they can either be used independently or with minimal help from teaching assistants.

The temperature module can be used to measure temperature ranging from −55°C to 150°C. The contrast detector can distinguish between the ambient light and the light rays coming from sources like laser, bulb, or candle and produces different intensity sound beeps. The module can detect the turbidity of the solution and can also help in the identification of transparent, translucent, and opaque material. It can further facilitate the visually impaired students in performing optics experiments. A water level detector is designed that can help a visually impaired student to take an adequate amount of water required for any experiment. A rod with a calibrated marks for volume is inserted inside a beaker with a tactile marking for different volumes like 10 mL, 20 mL, and 50 mL respectively. Whenever the water level reaches these marks inside the beaker, the beeps are produced. The module is designed in such a way that for 10 mL a

Table 1 : Details of Learners and the Practical Experiments that Can Be Conducted Using the Developed Modules

Age Group	Standard or Class	List of Experiments [a]
12-16 years	VI -X	1. Identification of the acidic/basic nature of the salt solutions. 2. Observation of temperature of water when it is being heated, when it is boiling and when it is cooling. 3. Verification of reflection of light. 4. Trace the path of the rays of light through a glass prism and glass slab. (Refraction) 5. To find the image distance for varying object distances in case of a convex lens 6. Differentiate between true solution, colloidal solution and suspension. 7. Food Sample Test for Starch and Adulteration.
16-18 years	XI-XII	1. Determination of the boiling and melting point of an organic compound. 2. To study the relationship between temperature of hot body and time by plotting the cooling curve 3. Find the focal length of a concave lens, using a convex lens. 4. Find refractive index of a liquid by using convex Lens and plane mirror. 5. Determine the strength of a given potassium permanganate solution against a standard ferrous ammonium sulphate (Mohr 's salt) solution. (Titration)
Above 18 years	Under Graduation	1. Determination of **acceleration** due to Gravity by Bar Pendulum. 2. Effect of impurities on the melting point – mixed melting point of two unknown organic compounds. Determination of boiling point of liquid compounds.

single beep, for 20 mL double beeps, and 50 mL three beeps are produced. A stop timer has been designed that can help a visually impaired student to take observations at a regular interval of time. The timer is designed in such a way that it produces a beep after every 30 seconds that signals the student to take an observation. The time interval can be extended as per the need of the student with fewer changes in the circuit components. The inclusive laboratory also includes a color detector that can enable a visually impaired student to know color change while performing certain experiments. With the use of a color detector, a visually impaired student can perform various titration experiments that involve changes in the color of the titrand. Starch and protein detection in the food item is also possible with this color detector.

The device modules made under the projected inclusive science laboratory can enable students at the school and college level to perform various science experiments, which are either explained orally by the instructor or not performed at all for visually impaired learners. These designed modules provide the result to the students by converting them in the form that can be identified by the visually impaired students by the sense of sound or touch. Table I shows the details of learners for whom the products have been developed and the practical experiments that can be conducted using the developed modules.

The detailed description and working of various modules designed as part of this inclusive laboratory are given below:

A. Talkable Thermometer

In this device, an Arduino-based talkable thermometer has been designed to display the ambient temperature and change in the temperature of the medium in which it is placed, in real-time on an LCD. Fig. 2(a) shows the components required for the device along with its circuit diagram. The temperature sensor is connected directly to Arduino UNO as can be seen in Fig. 2(a). The moment a change in temperature is detected, the sensor sends a signal to Arduino UNO which processes the data and the result is converted to a Celsius scale. The output is then displayed in numerical form on LCD and is heard aloud using audio jack. The talking mechanism in output is synthesized by Arduino UNO using pulse width modulated (PWM) signal.

The module comprises three sections:

1. Temperature sensing unit: In this unit, the LM35 sensor is used for temperature sensing. The main use of LM35 is to convert analog signals directly proportional to instantaneous temperature. The output temperature will be in Celsius. The typical accuracy of LM35 is ±0.25 °C at room temperature and ± 0.75 °C over −55°C to 150°C temperature range. It gives 10 mV output for every 1°C change in temperature (source: https://www.ti.com/lit/ds/symlink/ lm35.pdf). The output pin of LM35 is connected to the analog pin of Arduino Uno for further processing.

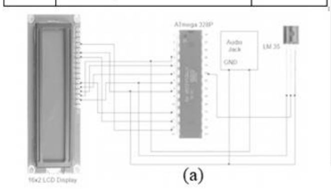
2. Arduino UNO board: Arduino Uno is a microcontroller board based on Atmega328p. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header, and a reset button (Source: https://www.arduino.cc/). It contains all the

necessary mechanisms required to support the microcontroller. It can be turned on using a USB cable or power from an AC-to-DC adapter or a battery.

3. LCD unit: The 16x2 LCD unit used in this device is cheap, easily available, small in size, and easy to interface with. The 16x2 LCD has two rows and 16 columns, i.e. it consists of 16 blocks of 5x8 dots. Out of the total 16 pins for connections, 8 of them are assigned as data bits D0-D7, 3 of them are control bits namely RS, RW, and EN, while the rest of the pins are used for supply, brightness control, and backlight control. The 16x2 LCD unit is directly connected to Arduino in 4-bit mode. Data pins of LCD namely RS, EN, D4, D5, D6, D7 are connected to Arduino's digital pin numbers 7, 6, 5, 4, 3, 2. After processing, Arduino sends temperature data to 16x2 LCD units by using appropriate commands of LCD.

This device finds its application in experiments involving the measurement of instantaneous temperature or change in temperature. Its talkable feature will aid a visually impaired student in taking reading independently. Its robust design enables it to be used in different mediums. A simplified flow chart explaining the working of this module is shown in Fig. 2(b). Upon pressing the start button, the temperature sensor probe starts reading the temperature of the environment or surroundings in which it is placed. The sensed data is then sent to Arduino. The programming is done in such a way that the probe senses the temperature for at least 5 seconds to get stabilized reading, before giving out the result onto the LCD and head phones. The probe temperature is continuously monitored on LCD and heard on ear phones while the device in ON

S.No.	Component	Quantity
1.	Arduino Uno	1
2.	LM35 Temperature Sensor	1
3.	16x2 LCD Display	1
4.	Audio Jack	1
5.	9V Battery	1


(a)


(b)

Fig. 2(a):Component required and circuit diagram for talkable thermometer (b) Flow chart of working of talkable thermometer module.

A. Contrast Detector

The contrast detector module has been designed to detect the change in intensity of light falling on the probe of the device. The module consists of IC 555 and Light Dependent Resistor (LDR) along with other components as shown in Fig. 3(a).

1. Light Dependent Resistor (LDR): LDRs are a type of resistor which are made up of semiconductor materials that have light-sensitive properties. The most common material used in the making of LDRs is cadmium sulphide (CdS). LDR works on the principle of photoconductivity which is an optical phenomenon. In it, the conductance of the material increases when the light falls on the surface of the material. Thus, when LDR is kept in dark it has maximum resistance and when it is exposed directly to light, lower resistance is obtained.

2. IC 555 Timer: The 555 timer IC is an integrated circuit (chip) used in a variety of timer, pulse generation, and oscillator applications. The IC 555 can be used to provide time delays, as an oscillator, and as a flip-flop element.

The IC 555 has the following operating modes:

1. Astable mode

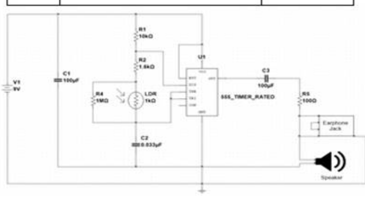
2. Monostable mode

3. Bistable mode

4. Schmitt trigger mode

In this device, LDR is connected with 555 timer IC in ASTABLE mode in such a way that it generates

S. No.	Component	Quantity
1.	LDR (light dependent resistor)	1
2.	IC 555 Timer	1
3.	Resistors and Capacitors	1
4.	Buzzer	1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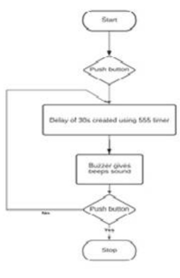
(b)

Fig. 3(a). Component required and circuit diagram for contrast detector (b) Flow chart of working of contrast detector module.

square waves when the light intensity goes above a certain level. The sound associated with it varies with the intensity of light falling on the LDR. When a very low-intensity light falls on the LDR, the sound produced is also quite low, and increases as the intensity of light increase till it attains its peak value.

A simplified flow chart explaining the working of contrast detector is shown in Fig 3(b). When light falls on LDR, it changes resistance and the 555 timer IC gets activated and deactivated as per the intensity of light falling on LDR. The in-built comparator in IC 555 timer compares the voltage between the input voltage applied at reset pin and 1/3rd of the power supply voltage (Source: https://en.wikipedia.org/wiki/555_timer_IC). Thus, if the light intensity is low, the LDR's resistance increases, and the voltage at the voltage divider drops below 0.8 V, which triggers the IC 555 to turn OFF. When the intensity of the light is high, the voltage at the reset pin goes above 0.8 V and the IC 555 turns ON. The output pin of IC 555 is connected to the buzzer. So, depending on the intensity of incident light on the LDR, the buzzer of the contrast detector turns ON and produces sound as per the intensity of light.

C. Water Level Detector

In this device, an Arduino UNO-based water level detector has been designed to measure the water level. Distilled water is a good insulator. However, distilled water was not used for the experiment. This device is based on the ability of water to pass current. Fig. 4(a) shows all the components and circuit diagram of the module. Here, resistors are used as pull-down resistors for sensing purposes. These resistors are connected directly to Arduino UNO.

The module comprises of

1. Resistor: In this module, resistors are configured as pull-down resistor in such a way that it acts as water level sensing probe. There are four levels on which pull-down resistors are connected. One end of these resistors is commonly grounded, while the other end is connected to a microcontroller as well as on different levels for sensing the presence of water.

2. Arduino UNO board: The four levels from the sensing probe are interfaced to the analog pins 23, 24, 25, and 26 of the micro-controller ATMega 328 IC. The power supply is connected directly at bottom of the probe. When the water rises to one of the assigned sensing levels and touches the sensing probe, conducting path between them is completed and output in the form of beeps is heard from the buzzer. The buzzer is connected to the digital pin 14 of the micro-controller. The micro-controller is programmed to beep once when the 1st water level is reached, twice when the 2nd level is reached, and so on.

The device has three levels on which sensing probes are connected which act as gradation on the container. These levels can be adjusted for a definite volume as per the volume levels marked on the measuring container. More levels can also be added depending on the requirement. When the measuring device is empty there is no conductive path between the probe (pull-down resistor) and the power supply of the circuit. Thus, no output in the form of sound will be obtained from the buzzer. As water is poured into the measuring container, the sensing probe at each level makes contact with the power supply probe. This

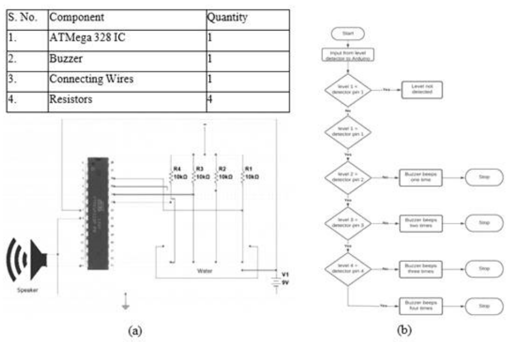

Fig. 4(a) : Component required and circuit diagram for water level detector (b) Flow chart of working of water level detector module.

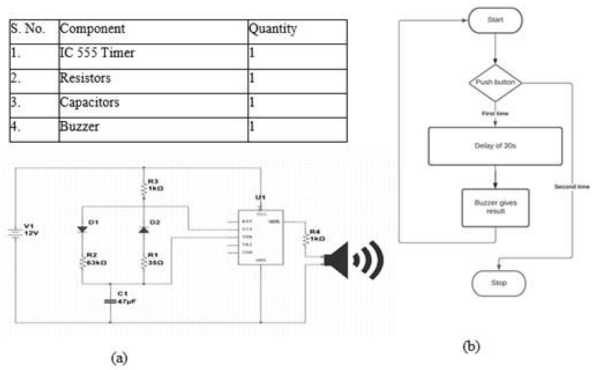

Fig. 5(a) : Component required and circuit diagram for timer (b) Flow chart of working of timer module.

completes the conductive path in the circuit and the corresponding output as sound is heard from the buzzer. Here, the number of beeps from the buzzer indicates the increasing levels of water. The first level will give one beep, the next level two, and so on. A simplified flow chart explaining the working of this module is shown in Fig. 4(b).

D. Timer

The Timer has been designed using IC 555 and it is used to measure instantaneous time and is also capable of beeping at fixed intervals of time. The components and the circuit used in the making of the module is given in Fig. 5(a). A delay in the form of oscillations or pulses of 0 and 1 is produced by charging and discharging the capacitor through the resistors. The flow chart explaining the function of designed timer is shown in Fig. 5(b). On pressing the push button, IC 555 starts counting the delays, and when the specific time occurs, the output is sent to the buzzer which in turn beeps. To stop the timer, press the push-button again.

IC 555 Timer: IC 555 is used in an astable multi-vibrator mode for producing 30 seconds delay. The output of the astable multivibrator is directly applied to the buzzer to create a beeping sound after every 30 seconds. The calculation formula for generating the desired delay for an astable multivibrator is given below

$$F=1/T= 1.44/(R1 + 2R2)\ C1$$

E. Color Detector

An Arduino UNO-based color detector has been designed to detect different colors using a TCS3200 color sensor. Fig. 6(a) shows the components required and circuit diagram of the designed module. The module consists of Color sensor, TCS3200, which is a programmable color to frequency converter that can detect a large array of colors. It consists of RGB (Red Green Blue) arrays in the form of square boxes of the RGB matrix. Each of these boxes contains three sensors- RED, BLUE, and GREEN. The sensor array in these three arrays can be selected separately depending on the requirement. The module can be designed to sense a particular color and disregard the others. It contains filters to perform the selection as shown in Table II. and a fourth mode is also there i.e., no filter mode, to detect the white light. Pins S2 and S3 are used to select the particular group of photodiodes. The output from this sensor is a square wave with frequency directly proportional to light intensity it senses. The full-scale output frequency can be scaled by one of three pre-set values via two control input pins S0 and S1 as shown in the Table II. The scaling of

Table 2 :Pin Configuration Of Tcs3200 Color Sensor For Filter Selection And Scaling Of Output Frequency

S0	S1	Output Frequency scaling (f_0)	S2	S3	Photodiode Type
L	L	Power Down	L	L	Red
L	H	2%	L	H	Blue
H	L	20%	H	L	Clear (no filter)
H	H	100%	H	H	Green

(https://www.mouser.com/catalog/specsheets/tcs3200-e11.pdf)

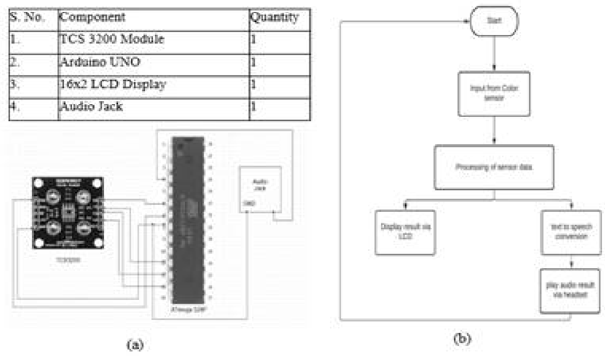

Fig. 6(a) : Component required and circuit diagram for color detector (b) Flow chart of working of color detector module.

outputs is done to optimise the measurement for slow frequency counters used in low-cost microcontrollers.

When an object whose color is to be detected is placed on top of the color sensing probe, white LEDs from the color sensor emit light. This light is then reflected from the surface of the object. This reflected light is analyzed by the photodiode present in the color sensor. The intensity data detected by the color sensor is sent to Arduino UNO for processing. The data is converted in the text as well as speech format. The text data is displayed via 16x2 LCD and speech data is made audible through an audio jack. The working of the designed color detector module is shown in Fig. 6(b).

These device modules developed for inclusive science laboratory can equip a visually impaired learner to perform various science experiments

Table 3 : Cost Estimate of the Developed Module and Commercially Available Products

Module	Estimated Cost of the developed module in Indian Rupee (INR)	Cost of the commercially available Product in USD and its exchange rate in Indian Rupee (INR) as of January 17, 2022.
Talkable Thermometer	Rs 750/-	25 USD (~ Rs 1854/-)[a]
Contrast Detector	Rs 100/-	150 to 200 USD (~ Rs 11123/- to Rs14830/-)[b]
Water level detector	Rs 280/-	12 USD (~ Rs 890/-)[c]
Timer	Rs 90/-	10 USD (~ Rs 742/-)[d]
Color detector	Rs 950/-	150 to 200 USD (~ 11123/- to 14830/-)[b]

[a] https://www.maxiaids.com/talking -digital-cooking-thermometer
[b] https://www.maxiaids.com/the -talking-color-detector
[c] https://www.maxiaids.com/liquid -level-detector
[d] https://cobolt.co.uk/products/index/talking -timer1590762961, https://www.maxiaids.com/oval-talking-alarm-clock-keychain-white

effortlessly with the inclusion of talkable features. These modules are cost efficient as compared to the commercially available product as can be seen from Table III. The products available in the market are mostly general purpose and are not customizable for a visually impaired person to perform laboratory experiments. They mostly support the English language and the components are not easily replaceable

4. Results

To date, studying science is an enormous struggle for a visually impaired student at school and college levels. The necessity of additional material to facilitate the learning process and ample expanse of time makes it even more challenging. In teaching, representations in the form of graphs and pictures, are generally used for conveying the intended information. A visually impaired student is unable to understand the printed information until and unless it is provided with some other means to intercept. With the extra effort of the teacher and additional resources, and exploiting the other senses of the visually impaired, the same can be conveyed. In this proposed inclusive laboratory, five modules namely talkable thermometer, contrast detector, water level detector, stop timer and color detector have been designed and tested.

The talkable thermometer is tested for varying temperature ranges by immersing the setup in ice, normal water, boiling water, and super-heated solutions to check its accuracy. It has been observed

Table 4 : Difference In Readings of Designed Digital Talkable Thermometer and Ordinary Laboratory Thermometer

Sample	Temperature using a temperature sensor (C)	Temperature using mercury thermometer (C)	Relative Error (%)
1.	24.52	24	2.10
2.	38.67	39	0.85
3.	50.26	50	0.52
4.	62.21	62	0.39
5.	78.19	78	0.25
6.	12.40	13	4.60
7.	5.24	5	4.80

that it could sense the correct temperature reading which was heard aloud using the designed talkable feature with almost 95% accuracy and maximum relative error of 4.8% as mentioned in Table IV. The difference in the readings while measuring temperature using mercury thermometer and the digital talkable thermometer is due to the fact that in ordinary thermometers temperature is measured with respect to mercury level where precise measurement is not possible. The high relative error in the readings of the talkable thermometer is due to differences in the least count of the devices. The least count of the mercury thermometer used for measurement is 0.1 ℃ whereas it is 0.01 ℃ in the developed module. It is due to this difference in the least count of the two thermometers, readings somewhat differ in values and relative error exists. Moreover, the possibility of parallax error while taking measurements in a mercury thermometer cannot be ruled out. Also, certain precautions need to be taken while using a talking thermometer to ensure correct measurement. The talking thermometer must be given an appropriate time for measuring temperature and also the temperature probe must be held still while taking readings.

The contrast detector module designed in the proposed inclusive laboratory helped in performing many experiments. By using the contrast detector, different intensity tones were heard for transparent, opaque, and translucent material and the results obtained are 100% accurate. These tones are easily intercepted by normal persons as well. With this contrast detector module, even the experiment whereupon blowing CO2 lime water turns milky could be successfully performed. The sound of the detector was drastically changed when the lime water turned milky. It could also help the visually impaired students in performing light-related experiments as

Table 5 : Difference In Readings of Designed Digital Talkable Thermometer And Ordinary Laboratory Thermometer

No. of Samples tested	Levels	Level detection
5	10 mL	Single beep was obtained
	20 mL	Two beeps were obtained
	50 mL	Three beeps were obtained

the detector could distinguish between the ambient light and light from a source like a bulb, laser, or candle. The students could verify the law of reflection and other ray optics experiments using laser as a source and this module as a detector.

The water level detector module was tested for taking a definite amount (10 mL, 20 mL, and 50 mL) of water for an experiment as shown in Table V and it could detect the different levels accurately with a success rate of 100%.

Table 6 : Relative Error In The Readings Obtained Using Designed Stop Timer and Commercial Stop Watch

Sample	Stop timer	Timer using a digital stopwatch	Relative Error (%)
1.	30 sec	29.45 sec	1.83
2.	30 sec	29.52 sec	1.60
3.	30 sec	31.20 sec	0.67
4.	30 sec	29.66 sec	1.13
5.	30 sec	29.32 sec	2.26

The stop timer was tested for conducting experiments where observations were to be recorded after a fixed interval of time.

The module worked extremely well with an accuracy of above 97%. The student could successfully record the readings for these experiments at an interval of 30 sec using this stop timer module. Table VI shows that relative error in the reading obtained using designed stop timer as compared to that measured using a commercial stop watch, is not more than 2.26%. The module can be further extended to provide time intervals of 1 sec or 2 sec as per the need of the experiment. In stop timer, accuracy depends strongly on the capacitor used in its design. A low leakage capacitor is required to enhance the efficiency of the timer and to reduce errors. The relative error in the developed stop timer module can further be reduced using a thin film capacitor instead of an electrolytic capacitor as the former is having a low leakage current.

The experiments involving a change in color of materials or substances were performed and the color detector module was used to obtain the result. The designed color detector module can detect the colors in the liquid samples also. An experiment to detect the presence of starch in potatoes was performed. Iodine solution was put on a piece of potato using a dropper and the amber-colored iodine solution turns blue-black as seen on the potato. This color was successfully detected by the module. Even the presence of protein in food items could be tested using the color detector. To the given food sample extract,

Table 7 : Summary of the Profile of the Subjects for the Research

Parameters	Detail	No. of Respondents
Age	Below 12 years	Nil
	Between 12 -18 years	9
	Above 18 years	12
Gender	Male	13
	Female	8
Teachers		3
Students		18

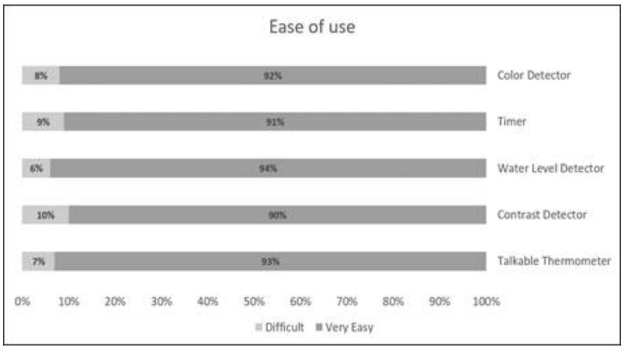

Fig. 7 : Response for the ease of use of the developed device modules.

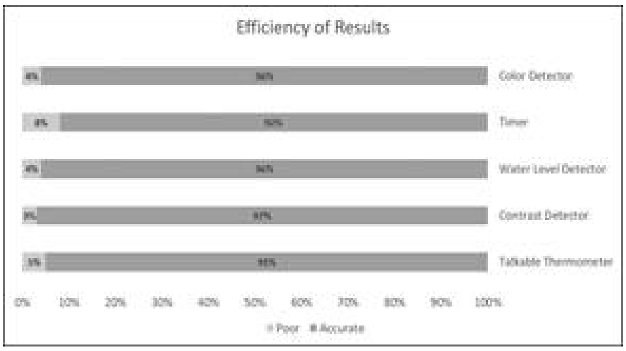

Fig. 8: esponse for the efficiency of the developed device modules.

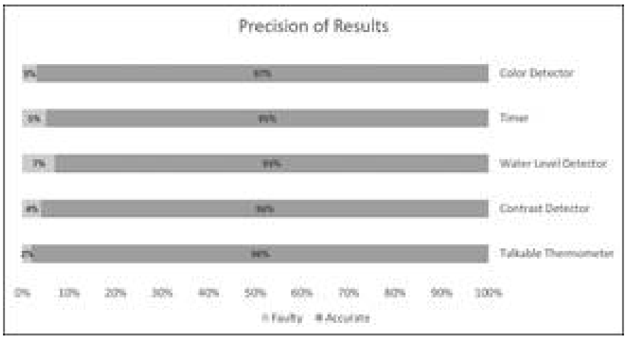

Fig. 9 : Response for the precision of the results obtained using the developed device modules.

the aqueous copper sulphate was added and the solution turned violet in color, thereby confirming the presence of protein in the food sample. The same was successfully conveyed by the detector and the student could confirm the presence of protein.

These modules together can equip the visually impaired student to perform various experiments not only related to physics subjects only but could be useful in experiments of another discipline as well.

5. User Testing and Validation of Modules

To evaluate the performance and features of developed modules under the inclusive science laboratory, a sample of students and teachers was taken into consideration. Due to the prevailing covid-19 pandemic, the developed modules could not be tested by visually impaired students. However, the modules were physically tested by 4 students and 2 teachers with their eyes blindfolded and were demonstrated to a set of 15 students and teachers. The responses were taken using a feedback form given in Appendix 1 and the same were analyzed sing Content Analysis. The details of the sample are given in Table 7

The developed modules were demonstrated and tested by students from class VI–XII, undergraduate, post-graduate students and teachers, and nearly 90% of the respondents found the device easy to use, understand and handle as shown in Fig. 7. The modules worked efficiently and precise values of the desired quantities - temperature, level of liquid, time, color and contrast are obtained through them, as per more than 92% of the respondents as shown by the bar chart given in Fig. 8 and Fig. 9. The modules were recommended for usage at the school and college level to perform the experiments.

Appendix

Participant Feed-back Form for the assessment of developed module under Inclusive Science Laboratory

* Required

1. Email *
2. Name
3. Age *
4. Standard / Year *

Talkable Thermometer

5. How effectively the device could translate the result to speech/audio? *

   1 2 3 4 5

   Poor ○ ○ ○ ○ ○ Accurate

6. How easily are you able to record the observation using the experimental set-up? *

   1 2 3 4 5

   Difficult ○ ○ ○ ○ ○ Easy

7. How precise are the results of the experiments? *

   1 2 3 4 5

   Faulty ○ ○ ○ ○ ○ Accurate

Contrast Detector

8. How effectively the device could detect the presence of light? *

   1 2 3 4 5

   Poor ○ ○ ○ ○ ○ Accurate

9. How easily are you able to record the observation using the experimental set-up? *

   1 2 3 4 5

   Difficult ○ ○ ○ ○ ○ Easy

10. How precise are the results of the experiments? *

    1 2 3 4 5

    Faulty ○ ○ ○ ○ ○ Accurate

Water Level Detector

11. How effectively the device could measure the water level? *

    1 2 3 4 5

    Poor ○ ○ ○ ○ ○ Accurate

12. How easily are you able to record the observation using the experimental set-up? *

    1 2 3 4 5

    Difficult ○ ○ ○ ○ ○ Easy

13. How precise are the results of the experiments? *

	1	2	3	4	5	
Faulty	○	○	○	○	○	Accurate

Timer

14. How effectively the device measured instantaneous time? *

	1	2	3	4	5	
Poor	○	○	○	○	○	Accurate

15. How easily are you able to record the observation using the experimental set-up? *

	1	2	3	4	5	
Difficult	○	○	○	○	○	Easy

16. How precise are the results of the experiments? *

	1	2	3	4	5	
Faulty	○	○	○	○	○	Accurate

Color Detector

17. How effectively the device could identify color? *

	1	2	3	4	5	
Poor	○	○	○	○	○	Accurate

18. How easily are you able to record the observation using the experimental set-up? *

	1	2	3	4	5	
Difficult	○	○	○	○	○	Easy

19. How precise are the results of the experiments? *

	1	2	3	4	5	
Faulty	○	○	○	○	○	Accurate

20. Do you recommend the use of these modules at school and college level to perform the experiments.? *

Yes ○ No ○ May be ○

6. Conclusion

In this work, an inclusive science laboratory for visually impaired students is foreseen using assistive technology. With the developed modules, one can facilitate such students in performing lab experiments easily and at a low cost. The work utilizes the sense of hearing of such students and augmented the developed module with a talkable feature for measuring temperature, time, to detect contrast and color. These developed modules can help the visually impaired student in performing various science experiments where measurement of the above-mentioned physical parameters is involved. Thus, with the use of such assistive technology tools, an inclusive model of education can be made a reality.

The inclusive laboratory presented in this paper can be further extended with more affordable modules for measuring other parameters like weight, volume, pressure, dimensions of the solids, etc. The modules can also be refined to improve their accuracy, steadiness, and robustness using new technologies.

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