CHAPTER V

SUMMARY AND CONCLUSION

5.0 Introduction

The present study entitled **"Development of *Science Lab Talking Device (SLTD)* and its Effectiveness for Laboratory Experiment for Students with Visual Impairment** "is related to designing and development of *Science Lab Talking Device* using hardware and software to perform Science Experiments by the Students with visual impairments. Science Lab Talking Device has been developed using the hardware called Arduino Mega 2560 which is compatible with all sensor operations. In the present study, sensors such as load cell sensor, current sensor, voltage sensor, colour sensor and temperature sensor were used. Thus the device has both hardware and software system. The study had two stages: Designing and Developing the Science Lab Talking Device and Study the effectiveness of the Device by introducing the device to the students with visual impairments to perform various Physical Science Experiments.

5.1 Rationale

Science education is less accessible to students with visual impairments due to the fact that it includes many abstract concepts. These students typically need a variety of opportunities to explore and examine real materials or models by touch or putting across through residual visual observation (Gast, Winterling, Wolery, & Farmer, 1992; Wright & Wright, 1998).

Exposure to science education contributes to the development of an interest in the science subject. Young people with disabilities who lack exposure to science may never have the opportunity to develop this interest. A lack of teacher training around appropriate accommodations in the sciences, particularly in the laboratory environment, may create barriers for students with disabilities (Moon, Todd, Morton, & Ivey, 2012).

Students with visual impairment are required to complete the same curriculum and examinations as sighted students. However, due to the nature of science and mathematics, the majority of the education resources and instructional methods are based on vision, which is not accessible at all by students with visual impairments. One of the primary reasons for exclusion of students those who are blind from the sciences is their inability to perform practicals. In the case of students those who are blind, the practical component of science proves to be rather impractical (Sam Taraporewala, 2013).

There is a need for adaptation in the educational resources and methods for the needs of individuals with visual impairment. Although there are some guidelines (i.e. Dion, Hoffman, & Matter, 2000) how to adapt educational resources to the needs of students with visual impairments, there is still a huge gap in how to adapt educational resources and instructional methods to the needs of the students with visual impairments as they are a heterogeneous group. Students with visual impairments differ in intellectual ability, development rate, social competence, and other factors. In addition, they differ in terms of their impairments, the extent of their visual acuity, and their ability in using the vision if they have.

Labs do not have technology that enables access, or devices that convert visual material into audio or tactile formats. The teachers and laboratory assistants also have little inclination to extend their imagination beyond the existing practices that prove tedious even for sighted students. Instead, authorities should focus their attention on evolving science assessment beyond standard practical formats. This will allow for inclusive lab spaces where students can use different modes of access to study concepts and conduct experiments.

Retrofitting lessons might not always be the best way out. For students those who are blind to be able to compete with their sighted counterparts on an equal footing, teachers need to extend the boundaries of their syllabus and classroom beyond heavily sight-dependent methods. They must be diligent about providing students study materials in accessible formats such as Braille, large print, digital, tactile, or audio.

Schools require is fresh and non-visual thinking. They need to incorporate experiential and immersive learning with planned visits to the field, museum, factories, etc. into the curriculum. Adapting lessons for students those who are blind also gives sighted students the opportunity to learn beyond sight. Current trends in pedagogy encourage practices that are student-centric. Teachers can no longer expect students to constantly adjust to classrooms. They too will have to make concerted efforts to understand and integrate the child's needs and modes of learning.

Around the globe, there is a growing awareness about the need to make science accessible to the students those with low vision and those who are blind. There is an attempt to shift away from purely visual ways of learning and studying science.

The National and International Policies and legislations reiterate equality of education to persons with disabilities on par with persons who do not have disability. The Sarva Shiksha Abhiyaan attempts to uphold the Right to Education Act,2009. It promises to supply accessible textbooks and teaching-learning resources to students those who are blind and students with low vision enrolled in schools.

The Indian RPWD Act 2016 prescribes to provide learning materials and appropriate assistive devices to students with benchmark disabilities in addition to make suitable modifications in the curriculum and examination system. It also suggests Institutions need to gear themselves to not only admit, but also adapt to the varying needs of diverse student bodies. But even after legal binding, students with visual impairments are deprived of many learning experience particularly when the concept is visually oriented. In Western countries, students with visual impairment are exposed to many adapted devices and gadgets helping them get desire to learn science subject. In Indian context, the survey of literature revealed that there is hardly any device available to help students with visual impairment to participate in the science laboratory experiment. Hence an attempt was made in the study to develop a quest which is named as Science Lab Talking Device. The device is designed with the support of Arduino Mega 2560 as hardware and five types of sensors namely Temperature, Colour, Current Measurement sensor with Light Detection, Volte Measurement and Weight sensor.

This device was developed mainly to perform physical science experiments which were in the Grade VI to X Science curriculum of Tamil Nadu Secondary Board. This device would help the visually impaired students to be involved in the physical science laboratory experiments and also help them collect the live data and interpret.

Here, the effect of the device was examined with the help of students' participation and performance in doing the science experiment in this Experimental Study.

5.2 Objectives

1. Develop a Science Lab Talking Device (SLTD) for students with visual impairment to participate and perform Physical Science Experiments.
2. Study the efficiency of the device based on power (energy) and time.
3. Analyze the efficiency of the device based on its error free software programme.
4. Examine the efficiency of the device on its time complexly and space complexity.
5. Analyze the level of acquisition of Physical Science concepts by the students with visual impairment before and after the introduction of Science Lab Talking Device.
6. Find out the effectiveness of the newly developed Science Lab Talking Device on the efficiency of the students with visual impairment in performing the Physical Science Experiments.
7. Identify the effectiveness of the newly developed Science Lab Talking Device on the efficiency of the students with visual impairment in performing the Temperature Measurement Experiment.
8. Identify the effectiveness of the newly developed Science Lab Talking Device on the efficiency of the students with visual impairment in performing the Acid and Base Experiment.
9. Identify the effectiveness of the newly developed science Lab Talking Device on the efficiency of the students with visual impairment in performing the Electricity Experiment.
10. Find out the effectiveness of newly developed Science Lab Talking Device in performing the overall procedure involved in the Experiments viz., Listing the items for Experiment, Identification of Items, Setting Apparatus and Conducting Experiment in the selected Experiments.

5.3 Method

The method of the present study has two stages

Stage I : Design and Development of Science Lab Talking Device (SLTD)

Stage II: Study the Effectiveness of Science lab Talking Device

5.3.1 Stage I: Design and Development of *Science Lab Talking Device (SLTD)*

Science Lab Talking Device has been developed using the hardware called Arduino Mega 2560. The Arduino Mega 2560 is a microcontroller board based on the Tmega 2560 (datasheet). It has 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. The developed device can function with a AC to-DC adapter power. The critical part of the Arduino Mega 2560 is that it is compatible with all sensor operations.

Arduino Mega 2560 directly runs the programme in micro controller which in turn converts the sensor reading with minimum time and maximum speed. The investigator used six sensors connected to the Arduino Mega 2560. The sensors used for various science experiments include: Temperature, Colour, Light Detection, Current Measurement sensor, Volt Measurement and Weight sensor. For each sensor operation, separate push buttons have been fixed on the board. The device works with embedded C program. The Embedded C program interface technology is used for real time data collection and converting the output in voice reading to enable students with visual impairments to get the real time data in voice form. The voice output is read both in Tamil and English language. The output is heard through an ear phone/head phone connected with the device.

5.3.2 Stage II: Study the Effectiveness of the Science Lab Talking Device

To study the Effectiveness of the SLTD, samples from students with visual impairments population have been selected.

5.3.2.1 Site Selected

The study was conducted in Secondary Schools in Coimbatore and Madurai district of Tamil Nadu. The students with visual impairments from Grade VI to X were selected.

5.3.2.2 Selection of the Sample

The sample comprised of 60 students with visual impairments with 24boys and 36 girls. The sample consisted of two groups of students viz. Group I (VI-VIII Grade) and Group II (IX& X Grade).The two groups were independent groups. The samples were selected from Special Schools for the Students with visual impairments and Inclusive Schools.

5.3.2.3 Design of the Study

The design adopted in the study is Quasi experimental design. It is a single group design. Here Pre observations/ test and Post observations/ test were made besides Treatment.

5.3.2.4 Tool

i. Personal Data Bank

To collect general information regarding Gender, Type of School Programme and Grade, Personal data bank was developed.

ii. Assessment of Level of Acquisition of Science Concept before and after Introduction of Science Lab Talking Device

The test was aimed to measure the acquisition of the Physical Science Concepts. Multiple choice questions were selected from the curriculum for three concepts viz. Temperature, Acid & Base and Electricity. There were three choices for each question which had very minimal differences between choices.

For Group I students (Grade VI to VIII),15 Multiple Choice Questions and for Group II, (Grade IX & X), 30 Multiple Choice Questions were given. This test was administered as pretest and posttests.

Scoring: For each correct response, One score and Zero score for incorrect response.

iii. Assessment of Performance in Experiments

The test was aimed to measure the Performance of students in the following Experiments.

a. ***Experiment for Group I***

1. Temperature Measurement Experiment
2. Acid & Base Experiment
3. Light Detection -Electricity Experiment

b. Experiment for Group II

1. Temperature Measurement Experiment
2. Acid & Base Experiment
3. Electric Current - Ammeter Experiment
4. Electric Force - Voltage Experiment

c. Measurement criteria

The measurement criteria for both Group I & Group II include:

1. Stating the items/Materials required (aware of the required items/ Materials for the experiment)
2. Identification of Material by exploration except Acid & Bases
3. Setting the Apparatus
4. Performing the Experiment

d. Scoring procedure:

Total Score for each experiment for Group I& Group II is 25 & 30 respectively. The score was done on task basis and the level of difficulty of the task.

iv. Measuring Internal Consistency of Tool

A rating scale describing the device in terms of appropriate feature, usability and accessibility of the device was developed to get the rating of device from the Teachers of students with visual impairments and students with visual impairments themselves.

For students' rating 15 questions and for Teachers' Rating, apart from 15 questions 10 more additional questions were included. A four point rating was given as 4 –Strongly Agree, 3-Agree, 2-Disagree, 1-Strongly Disagree.

5.4 Implementation of the Intervention

The intervention was given to Students with visual impairments in four major areas

1. Orientation to Basic Science Concepts

Prior to the actual study intervention was given to students for acquisition of basic concepts related to Temperature, Acids & Bases, and Electricity.

2. Introduction of Existing Science Lab Materials/Instruction & the Adaptation made in Materials/Instruction

The most common materials used in the Science laboratories were introduced to the students with visual impairments. The purpose of each materials and the procedure on how to use it was taught to the Students with visual impairments. Thus safety precautions, skills, and tools were the considered.

3. Instruction for Using the Device for Various Experiments

The Science Lab Talking Device was introduced to students with Visual Impairment. The students were allowed to explore the device with their hands and each part of the device was introduced with its features.

4. Procedure for Introducing to Science Experiment using SLTD

Students with visual impairments were exposed to various laboratory activities and experiment using SLTD. During intervention Phase time duration of six months was spent to teach lab experiments and activities.

5.5 Findings

The major findings emerged out of the study are:

5.5.1 Results pertaining to Efficiency of the SLTD

1. As regards the efficiency of the system based on power, the device operation sustains upto the appropriate power supply.
2. The device works to the maximum time period without bugs, when the external factors like dropping the device, slip of liquids or any such factors are controlled.
3. The Software component of the SLTD is error free.
4. As regards, the Time complexity, each Module of the programme performs linear searching.
5. The algorithm uses constant memory space during the run time hence space complexity is also linear.
6. As regards to display features, the audio output of the device is accessible but visual output is not displayed
7. In analyzing the interview data from the special teachers, the teachers opined that the SLTD has simple features to perform Physical science experiments by the students with visual impairments independently.

5.5.2 Results pertaining to efficiency of the SLTD in acquisition of Science Concepts

1. Pertaining to Science concepts acquisition before and after introduction of SLTD, students in Group I and Group II secured highest score in posttest than pretest : Group I - Pre Mean **2.97**; Post Mean **12.97** and Group II - Pre Mean **6.33**; Post Mean **27.50.**

5.5.3 Results related to the efficiency of SLTD in conducting experiments

1. When analyzing the students' score on acquisition of Science concepts viz., Temperature Experiment, Acid & Base Experiment, Electricity Experiment, the students in both Group I and Group II secured higher score in posttest than pretest impacting the effective intervention with the usage of SLTD.

2. In the Temperature Experiment, the overall performance of students in Group I showed significant improvement from pretest to post test and then to delayed posttest (Mean: Pre - **6.17**; Post - **11.53**; Delayed Post – **22.73**)
3. When analyzed the overall score for the Acid & Base Experiment for Group I students, the results indicate that the delayed post score (M=**23.00**) is higher followed by post (M=**11.83**) and then pre score (M=**3.80**).
4. In the Light Detection Experiment, the overall score of students indicates that students in Group I secured higher score in the delayed post score (M=**17.33**) than pre score (M=**3.10**) and post score (M=**10.47**)
5. For Group II, the overall results of Measurement of Melting Point of Wax showed, the delayed post mean score has significantly scaled up to **19.90** when compared to post score which is **11.90** and the pre score **9.05**.
6. When analysis done for Acid & Base Experiment for Group II students, similar findings are noted as they are in other experiments. The delayed post score is significantly higher (**M=28.00**) followed by post score (**M=13.07**) and then pre score (**M=8.05**)
7. When compared the scores of pre, post and delayed post scores for Electricity Ammeter Experiment for Group II students, the findings showed that delayed post score is significantly higher (**M=20.03**) than in post score (**M=10.77**) and then the pre score (**M=4.77**)
8. The results of Current Voltmeter Experiment for Group II and the overall score revealed that the delayed post score is significantly higher (**M=19.13**), then post score (**M=9.84**) and pre score (**M=4.87**)

5.5.4 Results related to the Four Components involved in each experiment viz., Listing of Materials, Material Identification, Setting Apparatus and Performing Experiment - Group I

1. Considering the four aspects of Temperature Experiment, the scores of students in delayed posttest is higher followed by post score and then the pretest score. The comparative scores are
   a. Listing of Materials : Mean: Pre - **2.15**; Post - **3.6**; Delayed Post - **3.5**
   b. Material Identification : Mean : Pre - **2.62**; Post - **3.23**; Delayed Post - **3.67**
   c. Setting the Apparatus : Mean : Pre - **1.37**; Post - **2.83**; Delayed Post - **7.10**

   d. Performing Experiment : Mean : Pre - **0.03**; Post - **1.87**; Delayed Post - **6.87**

2. The analysis of component wise score for the Acid & Base Experiment of Group I students, the results showed that the delayed post scores are higher in all the components.
   a. Listing of Materials : Mean: Pre - **1.63**; Post - **3.53**; Delayed Post - **3.6**
   b. Material Identification : Mean : Pre - **1.4**; Post - **2.9**; Delayed Post - **3.5**
   c. Setting the Apparatus : Mean : Pre - **0.67**; Post - **2.73**; Delayed Post - **4.87**
   d. Performing Experiment : Mean : Pre - **0.10**; Post - **2.67**; Delayed Post - **9.10**

3. Component wise analysis of the Light Detection Experiment presented that that the delayed post score is higher than intermittent and then pre score.
   a. Listing of Materials : Mean: Pre - **0.93**; Post - **3**; Delayed Post - **3.7**
   b. Material Identification : Mean : Pre - **2.17**; Post - **3.40**; Delayed Post - **3.80**
   c. Setting the Apparatus : Mean : Pre - **0**; Post - **2.10**; Delayed Post - **4.27**
   d. Performing Experiment : Mean : Pre - **0**; Post - **1.97**; Delayed Post - **5.57**

5.5.5 Results related to the Four Components involved in each experiment viz., Listing of Materials, Material Identification, Setting Apparatus and Performing Experiment - Group II

1. In the measurement of Melting Point of Wax Experiment, the analysis was done separately for each component and the results indicate that delayed post score is higher than post and pre score.
   a. Listing of Materials : Mean: Pre - **1.87**; Post - **3.77**; Delayed Post - **4.55**
   b. Material Identification : Mean : Pre - **1.82**; Post - **3.30**; Delayed Post - **4.62**
   c. Setting the Apparatus : Mean : Pre - **1.10**; Post - **2.63**; Delayed Post - **5.20**
   d. Performing Experiment : Mean : Pre - 0**.26**; Post - **2.20**; Delayed Post **- 5.53**
2. Component wise analysis for the Acid & Base Experiment, the results showed that in all the four components the delayed post score is higher impacting the effect SLTD used for experiment
   a. Listing of Materials : Mean: Pre - **1.87**; Post - **3.23**; Delayed Post - **3.63**
   b. Material Identification : Mean : Pre - **1.57**; Post - **2.87**; Delayed Post - **3.67**
   c. Setting the Apparatus : Mean : Pre - **0.80**; Post - **2.53**; Delayed Post - **5.73**

   d. Performing Experiment : Mean : Pre - **0.13**; Post - **4.43**; Delayed Post - **11.13**

3. Component wise analysis for the Electricity Ammeter Experiment revealed that in all four components, the delayed post score is higher revealing the effect of SLTD usage for Science Laboratory Experiment.
   a. Listing of Materials : Mean: Pre - **1.90**; Post - **3.29**; Delayed Post - **3.81**
   b. Material Identification : Mean : Pre - **2.71**; Post - **3.39**; Delayed Post - **3.87**
   c. Setting the Apparatus : Mean : Pre - **0.16**; Post - **2.29**; Delayed Post - **4.94**
   d. Performing Experiment : Mean : Pre - **0**; Post - **1.81**; Delayed Post - **7.42**
4. Component wise analysis for the Current Voltmeter Experiment showed that in all four components, delayed post score is higher.
   a. Listing of Materials : Mean: Pre - **2.03**; Post - **3.23**; Delayed Post - **3.81**
   b. Material Identification : Mean : Pre - **2.74**; Post - **3.42**; Delayed Post **- 3.87**
   c. Setting the Apparatus : Mean : Pre - **0.10**; Post - **1.97**; Delayed Post - **4.74**
   d. Performing Experiment : Mean : Pre - **0**; Post - **1.23**; Delayed Post - **6.71**

5.6 Discussion

Assistive technology for students with visual impairments and students who are blind people is a research field that is gaining increasing prominence owing to an explosion of new interest in it from different disciplines. Research on assistive technology for the students with visual impairments and people who are blind has traditionally focused on mobility, navigation, and object recognition; but more recently on printed information access and social interaction (Terven, Salas, & Raducanu, 2013). Exciting and emerging topics associated with this field include sensory substitution, visual prostheses, visual neuroprostheses, brain plasticity, brain-computer interfaces (BCI), artificial vision, tactile human-machine interfaces (HMI), accessible computing, and human factors research. Since Bach-y-Rita's pioneering work on tactile vision substitution systems (TVSS) to translate visual information into tactile cues, major advancements over the decades have followed based on this formative work and have steered the field into many offshoot areas of research (Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969). Another central theme of research over the decades has been the accessibility and inclusion of persons with visual impairment and people who are blind individuals into mainstream society.

In the early 1980’s, research led by William J. Skawinski at the New Jersey Institute of Technology developed a project known as, “Macrolab” (Cochin & Herman, 1981). This effort developed a series of talking laboratory probes such as pH, balance, and temperature sensors to be used in the science laboratory. Although these tools were innovative for the time, they were never mass-produced due to the high cost to replicate. Later, (Lunney & Morrison, 1981) successfully interfaced with a portable electronic notetaker referred to as Braille ‘N Speak distributed by Blazie Engineering in the early 1990s with common electronic laboratory equipment equipped with RS-232 ports & ASCII output capability. This interface, although far more cost-effective, was difficult to replicate due to customization needed in pin configurations on connector cables between laboratory equipment and the Braille ‘N Speak device. Later, Supalo et al obtained a National Science Foundation Research in Disabilities Education (RDE) grant to found the Independent Laboratory Access for the Blind (ILAB) project (Cary Alan Supalo, 2010; Cary A Supalo et al., 2009; Cary A Supalo et al., 2007). This initiative sought to develop a suite of talking and audible laboratory tools to be first used in high school chemistry and later other science courses. The ILAB team partnered with Vernier Software & Technology to incorporate text-to-speech accessibility support for one of the largest laboratory sensor computer interfaces to be used in secondary science laboratory classrooms across the United States. The Vernier hardware interfaced with a scientific data collection software package known as Logger Pro. This software-driven interface empowers students to obtain highly quantifiable data sets. Further, it enables all students to perform higher functional statistical analysis on multiple data sets. Having quantifiable data enhances student laboratory learning experiences to more fully explain the science concepts being taught.

In 2007, Vernier Software & Technology launched a new product known as the Lab-Quest. This handheld computer serves as one of the first portable scientific data collection devices. This handheld computer successfully interfaces with most of the Vernier product line of laboratory sensors. Students no longer need a laptop computer to collect and analyze scientific data. The Lab- Quest is a powerful tool in an informal science learning setting and allows students to take quantifiable data in the field. This new innovative piece of hardware is equipped with a touch screen, microphone and headphone jacks, onboard rechargeable battery, and USB, USB mini, and SD card slots for expanded data storage. Additionally, there are four analog and two digital probe ports for Vernier sensors. There is also an internal microphone and speaker. Supalo, when he first saw the LabQuest, had the idea of wanting to develop a text-to-speech screen reader for the LabQuest. This would create the first accessible portable scientific data collection device for students with visual impairment.

In 2009, Supalo's firm Independence Science applied for and successfully obtained a National Science Foundation Small Business Innovation Research (SBIR) grant to develop an alpha version of a text-to-speech screen reader for the LabQuest (M. Isaacson, Supalo, & Lloyd, 2013). An educational research study was conducted at a residential school for the students who are blind to field test the alpha version of this software application. A large majority of students with a visual impairment from the sample of 27 participants indicated positive feedback towards the use of text-to-speech as compared to non-talking LabQuest technologies. Various projects have been developed over the decades to empower persons with visual impairment towards accessibility, inclusion, and participation.

The methodology employed in LabQuest was inspiring to the present researcher and has been prompted to develop a prototype of the Science Voice Talking Device indigenously in a cost-effective manner. While reviewing the research in this area, Arduino was found to be potential technology in the development of educational and navigational devices and the same has been used in device development. The focus of this research study was mainly on the past, present, and future of assistive technology for persons with visual impairment persons particularly technology for educational enhancement. The newly developed device would address practical utility and cost-effective manner.

Literature review revealed that in countries like the United States, common Science experiments have been modified to the needs of students with visual impairment. But in the Indian context, such modification/adaptation or development of new devices for science experiments is rarely noted. In the present study, the newly developed Science Lab Talking Device helps students with visual impairments to conduct seven physical science experiments independently.

In the development stage of the device and while the introduction of the device for field testing, the investigator noted that there would be improvements in the device and its functioning. Some of the suggested improvements are visual display along with the available auditory output so that the student can be independent in performing the experiment. Otherwise, she/he needs the assistance of a sighted person to write the output when dictated by the students with visual impairments or write the result in Braille and then interpret it to the teacher/ instructor.

In the designing process, the investigator involved persons with visual impairment person for the design and development to be effective. This idea is in line with the philosophy of the user should be involved in the design process at specific times such as prototype development, observations, and interviews (Abras, Maloney-Krichmar, & Preece, 2004).

It is common that students who are a person with visual impairment are not allowed to perform experiments in the laboratory, instead, they are paired with a sighted student who performs the experiment and shares the information on the experiment that is taking place (M. Isaacson et al., 2013; Pence, Workman, & Riecke, 2003). The same scenario was noted in the Indian context. The efficacy of the device proved when a majority of the students selected for the study participated independently in science experiments

The newly developed Science Lab Talking Device has its base with Talking Sci Voice developed in the United States. Arduino-based device is simple to construct and suitable for adoption in school chemistry laboratories because of its miniature size, user-friendliness, and flexible coding (M. D. Isaacson, Supalo, Michaels, & Roth, 2016; Kroes, Lefler, Schmitt, & Supalo, 2016). This finding is in line with the newly developed Science Lab Talking Device in this investigation.

Promoting Inclusive Chemistry Teaching by Developing an Accessible Thermometer for Students with Visual Disabilities discussed the construction and evaluation of a digital thermometer specially designed to be operated by people with visual disabilities (Vitoriano, Teles, Rizzatti, & de Lima, 2016). The accessibility thermometer can be used as an educational tool in science laboratory practical activities in classes for sighted and students with visual impairments, with the aim of helping those with special needs gain better access to the scientific world. Tests carried out with students who are blind showed that this instrument could be an important tool in helping them to better understand the proper scientific concept of temperature. Besides being low cost, the device is user-friendly and provides quick response and good reproducibility. A similar finding is noted in this present study that students while doing Temperature experiments using the newly developed device understood the temperature concepts and performed the temperature experiment independently. Thus the study results showed that a majority of the studies related to adaptation and assistive technology for Science experiments are supporting the present investigation and generalizing that even a simple device with Arduino as hardware with sensors and flexible coding is useful to conduct physical science experiments in an inclusive environment.

5.7 Suggestion for Further Research

1. Further study will be necessary to develop technological interfaces for students with visual impairments to participate and perform biological laboratory experiments. Hardware and some of the software used in this study may be transferrable to design assistive technology to do biological science experiments.
2. Innovative investigations need to be pursued regarding how students with visual impairments can successfully participate in laboratory experiments on par with their sighted peers and for which various assistive technologies are required to be created to aid the students with visual impairments in science laboratory. This kind of research will continue to add to the body of research in the realm of Assistive Technology for the students with visual impairments in Science subject.
3. In the present study, colour sensor is used for detecting four colours. Further study is needed to employ compatible sensor to detect more colours so that many experiments can be conducted for students with visual impairment.
4. New Investigations are required to make the newly developed device by integrating more sensors, text -speech - assistive technology, keyboard and

computer monitor to display the live data and data server in a standalone but a compatible device so that students with visual impairment can eliminate the assistance of sighted and perform experiments independently

5. In the era of Artificial Intelligence (AI), research can be pursued in the use of AI in developing Assistive technology in the education and rehabilitation of persons with special needs

5.8 Recommendation

1. The study recommends that Government and educational personnel may take initiative to integrate Assistive technology in the existing science laboratory so that students with visual impairment can participate in the laboratory experiments.
2. The newly developed prototype of the SLTD may be refined and industry and technical personnel can be explored to make the prototype in to product
3. The Government may take effort to setup an Research Innovation Incubation Centre for STEM (Science, Technology, Engineering &Math) subject for persons with special needs focusing development of assistive technology, research on the efficacy of the device/ equipment, facilitating production, and thereby providing opportunities to persons with special needs particularly students with visual impairment to pursue education in STEM subjects as many students in industrial countries have successfully complete STEM courses due to the avenues available to them.
4. Incorporation of training to the in-service teachers and in the curriculum of pre - service teachers on the application of assistive technology for students with visual impairment.

5.9 Implications

1. Theoretical Implications

In the present research, the anticipated outcome that students with visual impairment to perform the science laboratory experiment independently has happened. The procedure of using the SLTD device for experiments might be used as a set of guidelines for application by teachers and students with visual impairments. The guidelines can be in the form of Print and Braille. The training institutes may incorporate a component of Assistive technology for the students with visual impairment in the curriculum. The study outcome might help the Teachers and Teacher educators to get reoriented to enrich their knowledge in the latest development in the field.

Practical Implications The students with visual impairment are mostly deprived of science laboratory experiments due to its visual orientation. This study proved that students with visual impairment can do most of the laboratory experiments at the high school level independently. Another practical implication is that this device is designed to use it inclusive school. The inclusive classroom teacher can use the device to demonstrate experiments to the other students in the classroom. This can change the attitude of the inclusive classroom teachers and peers towards students with visual impairment and they consider this device as an effective learning device for all.

2. Implication to Textbook Writers

The application of technology to education particularly to laboratory experiments is a recent phenomenon in Special Education in the Indian context. Books by Indian authors in Special Education are being slowly emerged. The development of this device and its efficacy in performing laboratory experiments by persons with visual impairment evidenced in the study have implications to book writers. The writers can incorporate this indigenous development in their writings.

3. Implication for Product Development

The user and the special teachers in the study expressed the usability and the advantage of this device. The prototype developed in the research has scope for product development and the developers can get detailed guidance from the research team on how to design user-friendly devices for wider usage.

5.10 Conclusion

The study results revealed that when Science Lab Talking device (SLTD) was used, a conspicuous change was noted in most of the students in conducting the experiments. They were independent, their performance score scaled up and they presented competitive spirit thus indicating the efficacy of the device for their autonomy in science education in inclusive environment. Nevertheless, the development of the device and its introduction among students with visual impairments provided information on how to improve the hardware and software system and make the device more effective. This development is an attempt to provide more equity to the students with visual impairments keeping in mind the philosophy of inclusive growth for nation building set forth in Inclusive Growth: Vision and Strategy (2002). But a long way to go! We look forward to meet challenges in our future initiatives in the realm of Science Education for the students with visual impairment thereby providing full inclusion in the mainstream education.