Creating an Accessible Technology Ecosystem for Learning Science and Math: A Case of Visually Impaired Children in Indian Schools

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Abstract

In India, hardly any visually impaired (VI) person pursues Science and Maths beyond the seventh grade or takes up a career in the Science, Technology, Engineering and Math (STEM) fields. This is despite the country producing more STEM graduates than any other in the world or being home to the largest population of VI persons. While Information and Communication Technologies (ICT) products are increasingly being used in improving education and professional activities, the inherent visual bias in ICTs forces VI persons to depend on other Assistive Technologies (AT), which are seen to have a huge potential in making their personal and professional lives more accessible. We, however, do not find much evidence of ICTs/ATs being designed or used to address the above incongruity in the Indian education and professional space where VI persons continue to be excluded. Through this study, we seek to understand the motivations behind the existing design focus of ATs and the reasons behind their low relevance in STEM education for VI persons in India. Through an ethnography involving both the demand and supply side stakeholders in this space, over a 9-month period and close to 100 interviews with both VI and sighted persons in formal and non-formal schools, teacher training centers, technology design labs etc. and using a multidisciplinary approach to disability, we find an absence of integrative principles and structures guiding ICTs/ATs design and use. In conclusion, we distill our findings to propose recommendations which lead to the creation of an assistive technology ecosystem that can bridge the existing gaps in practice by allowing different players to transcend their traditional disciplinary orientations.

Keywords

Disability, visual impairment, assistive technology, STEM Education, accessibility, bio-psycho-socio framework.

1.0 INTRODUCTION

According to the World Health Organization (WHO), over a billion people are estimated to live with some form of 'disability' (World Health Organization, 2018). This corresponds to about 15% of the world's population. Of the 285 million people in the world who are visually impaired, 90% are in developing countries. While 39 million people are blind, 246 million have severe or moderate visual impairment (India Today, 2018). The United Nations Convention on the Rights of Persons with Disabilities (CRPD) states that "Persons with Disabilities include those who have long-term physical, mental, intellectual or sensory impairment which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others" (Un.org, 2018). India ratified the CRPD in the year 2007 and a new Rights of Persons with Disabilities Act (RPD) was passed in December 2016 (Ncpedp.org, 2018).

Persons with disabilities, especially the visually impaired persons, are widely using Information and Communication Technologies (ICT) products in recent years for improving their personal and professional lives (Neff et al., 2009). Visually impaired persons could, however, be at a disadvantage because of an inherent visual bias in many ICT products (Chaudhry and Shipp, 2005). People with visual impairment may further require Assistive Technologies (AT) to access these ICT products. According to Assistive Technology Industry Association (ATIA), an AT is "any item, piece of equipment, software or product system that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities". For persons with visual impairment, these include screen readers, smart canes, mobile applications such as TapTapSee, Refreshable Braille Displays and products such as Kurzweil Education to scan and convert the printed material to accessible formats.[1]

The increasing professional aspirations among the visually impaired due to availability of ATs has been studied by many researchers (Pal and Lakshmanan, 2012). However, it has also been found that most of the visually impaired persons do not opt for STEM (Science, Technology, Engineering and Mathematics) related professions (Pal and Lakshmanan, 2012). In India, visually impaired people are often influenced and directed by educational institutions, governmental agencies, or non-profits towards specific careers. They are frequently encouraged to work in teaching or in human resource functions. Other popular career areas include medical transcription and telemarketing. Underemployment is particularly high among visually impaired who have higher technical skills. In general, they are either offered jobs related to technology training, accessibility testing or have to work in positions with much lesser technical responsibilities than they are capable of. Blind programmers are offered salaries much lower than their sighted colleagues (Pal and Lakshmanan, 2012).

On the education front, despite innovations in assistive technologies, visually impaired (VI) people are under-represented in STEM related areas even in developed countries such as the United States of America (Center, 2018). ATs can make the learning process accessible, and technologies such as talking calculators, tactile graphics, haptic devices, three-dimensional models and laboratory data collection aids such as TalkingLabQuest (Mulloy et al., 2014) can aid learning of STEM subjects by the visually impaired. Yet, students with vision impairments are encouraged to take on 'non-technical' areas of study that includes arts, social sciences and humanities instead of what may be their preferred choice (Pal and Lakshmanan, 2012).

In India, there are more than 1.1 million visually impaired children in the age group 5-19, 68% of who attend school (Censusindia.gov.in, 2018). Of the visually impaired children that attend school, very few continue with Science and Mathematics beyond the seventh grade (Taraporevala, 2016). Despite producing 2.6 million STEM graduates in 2017, which is among the highest in the world (Forbes.com, 2018), there is an apparent inadequate motivation among the visually impaired students (henceforth referred as VI students), for studying these subjects and taking up STEM related careers. Since ATs have been found to act as artifacts of capability enablement or enhancement and could help to create a positive impact on the aspiration of individuals with visual impairment (Pal et al., 2015), we inquire into the AT design process and the challenges of STEM education for the VI students in Indian schools.

The rest of the paper is organized as follows. In Section 2, we present a review of existing literature highlighting the predominant focus on medical aspects of disability, which have consequently guided the design of AT. We thereby justify our use of a multidisciplinary "biopsychosocial" framework (Engel, 1977) to structure and analyze our primary data gathered through ethnographic methods of research in India, from teachers and students in schools who create the demand for ATs and resource providers and technology designers, who are the suppliers of ATs, as highlighted in Section 3. In Section 4, we present our research findings classified based on three major challenges that emerge from the data gathered. In Section 5, we analyze our findings from the perspectives of both the demand side and the supply side stakeholders. We highlight the gaps from the supply side stakeholders in servicing some of the well-articulated needs of VI persons, as well as the probable gaps in articulation of needs by the stakeholders on the demand side. In conclusion, Section 6 presents a list of proposed recommendations based on the analysis, highlighting the need for a collaborative AT ecosystem and changes in the AT design process to create AT ecosystems which incorporate a holistic appreciation of the notion of 'disability'.

[1] http://guides.library.illinois.edu/c.php?g=526852&p=3602299

2.0 DISABILITY AND ASSISTIVE TECHNOLOGY DESIGN

Only a few studies concerned with disability identify and tackle the problem inherent in working with misplaced assumptions and attend to social and cultural issues. Fine and Asch (1988)'s piece on addressing social stigma attached to disability brings up five different myths plagued in disability studies and draw parallels with the "*racial oppression that Blacks or Hispanics have faced over the centuries, supported by reports which show that 45% of disabled people see themselves as a minority*". One of the most important assumptions in terms of disability studies and research is that disability is located solely in biology; the level of functional capability of persons determines their participation in society when, in fact, the converse could be equally probable. The level of adjustment and adaptation of the environment might eventually determine the level of participation and comfort of a disabled person.

Another assumption which affects disability studies is the perspective that a disabled person is always the "victim". It is assumed that the disabled person copes by suffering self-blame or by reinterpreting the suffering to find positive meaning. Studies show that this victimization of the disabled seems more vital to the non-disabled than the disabled because this treatment provides them both a sense of fear and power; fear because they remind them that no one is invincible and power because they are seemingly more functionally capable than the disabled person which instills in them a false sense of control. Most disability studies are carried out with an assumption that disability is crucial to the disabled person's "*self-concept, self-definition, social comparisons and reference groups*". Further, there is evidence of "*downward comparisons to current situations to preserve self-esteem*" (Fine and Asch, 1988). This is, in all senses, degrading to one's concept of self and survival. Fine and Asch (1988) further question the validity of such notions and voice their arguments that such states of "helplessness" wouldn't exist if our living environment and society were more accommodating and, if better and improved technological aid would be accessible by everyone.

Hahn (1988) expresses similar concerns of policies and research not being able to weigh in the "functional-limitations" and the "minority-group" concept of disability equally. He mentions how the current "functional-limitations" model is transforming into a "minority-group" model and this change in thinking can be traced back to the change in definitions, from a medical definition to a new socio-political approach. While the medical viewpoints focus on improving the functional capabilities of the disabled individual, from the socio-political vantage point, a strong need for policies and regulations can be seen important to battle discrimination. Hahn (1988) presents two additional corollaries which spring up due to the socio-political definition. First, that the architecture and social institutions present in today's world are designed by a non-disabled group of policy makers and these inevitably place "*stringent requirements on persons with different levels of functional skills*". Human expectation that everyone ought to achieve the highest levels of functional capacities blindfolds us from the potential alternative of tweaking the living environment to help achieve the desired levels of functionality. Hence, there is an urgent need to mold this design approach into a more suitable and accommodating one. The second corollary highlights the treatment of "*public/social attitude as a vital component of the society that the disabled person has to grapple with on a daily basis*". Hahn (1988) argues that the principle issue lies in societal and professional attitudes which entertain the view that the disabled people achieve their unequal status from their inability to achieve "normal" levels of modal functional capability instead of challenging it. Similar to other minority groups "*who possess characteristics that allow them to be victimized, like their skin color or their ethnicity*", disabled people also have such visible physical characteristics and research and technology should stop amplifying this view by retaining this in their works, but should help challenge such "*prejudicial attitudes*".

Keeping in mind these varied perceptions of disability, it is important to understand this concept through a multi-disciplinary framework, like the "biopsychosocial" framework developed by George Engel (1977) .The term "biopsychosocial" attributes equal weightage to all three known causes of disability: biological, which implies the functional limitation caused by the impairment, psychological is the personal or individual interpretation of one's own impairment and social, which refers to how impairment causes disability to the person when in a social setting or while interacting with various other environmental factors. We realize that such a multidisciplinary perspective, with its holistic and inclusive understanding of disability, can open up avenues for improving existing solutions, both technologically as well as socially.

Technology designs in the area of disability are found to be largely guided by most of the misplaced assumptions mentioned above. Shinohara and Wobbrock (2011), therefore advocate a much needed change in the design and outlook of ATs and propose an alternative, based on interviews they conducted on a sample of disabled participants with varying demographics of age, gender, disability and economic and employment status. They find that the aesthetics of design, which is influenced by both social and psychological needs of the user, are never given enough importance in designing AT, and this, according to the authors can be a possible reason for abandonment of AT. Pape et al (2002) found that people with disabilities were more likely to abandon the AT if the device socially excluded them or if it clashed with cultural values. Their research shows that although some participants claimed that with these devices, they could express to the world their equal capabilities, a lot more were self-conscious and desired to keep their disability hidden in the fear of embarrassment during social interactions. The research concludes that free choice to withhold or communicate something about their disability is, therefore, the prerogative of the user. Their approach to address this problem and misperceptions is to "Design for Social Acceptance". As designers of technology, it is pivotal, therefore, to remember that technology is used in a social context. Thus, designing technology that is either more accommodating of such marginalized groups or designing AT which molds into society less vigorously is a crucial requirement.

Studies on perceptions of ATs by the disabled as well as the legislative steps taken towards making these technologies accessible reveal a hopeful attitude in people with disabilities towards emerging ATs, but simultaneously a need for "neutral" technologies prevail, the design of which do not reveal the disability of the user unless they choose to (Boucher, 2018). Regulatory framework and policies also need to be redesigned to work towards the integration of the disabled in the society. Hence, while ATs might have a positive implication on their users, it is essential to embed them in an ecosystem fostering the aforementioned ideas of accessibility and inclusivity.

The high level of discordance between the issues faced by the disabled and the technological solutions and policies that are being offered as solutions to combat them is rooted in the basic understanding of what causes disability. As aforementioned, retaining prejudicial stereotypes while designing solutions may only cause perpetuation of those unwanted views and perspectives. We, therefore, suggest that looking at this socio-technical issue through a multidisciplinary "biopsychosocial" lens might be a useful way to come up with better solution designs. In the rest of the paper, we explore this aspect further by studying the existing system of Math and Science education for VI children in Indian schools and the manner in which its various constituents invoke ATs in their respective functions. This is intended to help us gain better insights into the question of how ATs should be designed to make STEM education more accessible to children with visual impairment.

3.0 METHODOLOGY

This research was a first step to create a social enterprise which focuses on education processes and technology requirements of VI students in the Indian state of Karnataka. The research was aimed to inform the strategy to address the grand challenge of low number of VI students taking up STEM education or STEM related professions in India.

We gathered data from public reports regarding VI persons, their education and the current processes and technologies being used by them in India. For the primary research, we used a mixed ethnographic approach of data gathering through participation and observation (Spradley 2016). These included participant observation (Dewalt and Dewalt, 2011), through constant interaction with stakeholders and field immersion exercises such as observing classroom lectures, conducting institutional workshops and participating in teacher trainings as active participants in a peripheral membership role (Adler and Adler, 1997). We adopted qualitative modes of study such as observations and structured questionnaire to understand the present scenario of STEM education of VI persons in India, in terms of availability of resources for education, employment opportunities, technology use, design of various technologies, support systems available such as resource providers and families/mentors.

Data was gathered through interviews with students, teachers, resource providers and technology design teams. Of all the respondents, 75 were VI persons and 22 were sighted persons. Respondents were identified largely using the snowball sampling technique. Of all the interviews, 6 were conducted in groups and 27 were one-on-one interviews, 13 of which were face-to-face and 14 were telephonic interviews. A structured questionnaire with 11 questions was sent out to an online group for VI persons in higher education to which 11 persons responded.

The details of the interviews are given below:

Table 1: Details of Interviews with Visually Impaired Participants

VI Persons	Total participant count	Interviews Count	Remarks
School students	30	5 individual; 2 focus groups (15; 10)	3 face-to-face individual interviews at school; 2 telephonic interviews; 1 focus group of 15 high school students; 1 focus group of 10 middle school students; Participant observation of middle school students from August 2017 - March 2018 at 4 hours per week.
College / University students	26	2 telephonic interviews; 9 survey responses	15 at focus group interactions at Hackathon event Jan 18-19 2017 at IIITB.
Working Professionals	9	5 face to face interviews; 2 telephonic interviews; 2 survey responses	5 interviews at IIITB with VI programmers on Jan 18-19, 2017; Telephonic interviews
Teachers	2	2 face to face interviews; 1 focus group (6 of 12: VI)	2 interviews at school with Math and Computer teacher; 1 focus group of 12 teachers at Teacher Training (Nov 7 - Nov 11 2017) at an NGO
Technology Designers/Resource Providers	2	1 telephonic interview ; 1 face to face interview	Telephonic interview on July 25 2017; Face to Face interview on Nov 20 2017

Table 2: Details of interviews with participants who are not visually-impaired

Non Visually Impaired persons	Total Participant Count	Interview Count	Remarks

Teachers	17	6 face to face interviews; 2 focus group (6;5) interviews	3 teachers at school; 3 teachers from coaching institute; Focus group at Teacher Training (6 teachers Nov 7 - Nov 11 2017) on Focus group at NCERT (5 teachers) on March 13-Mar 15 2017
Technology Designers/Resource Providers	5	5	5 face to face interviews on 5th April 2018, 12th March 2018, 13th March 2018, 6th Dec 2017, 20th April 2018

One or more authors interviewed all participants. All interviews were open in nature, and questions were formulated depending on the conversation. However, a questionnaire protocol with basic questions to direct the interviews was followed.

We observed participants in 5 different events, some of which had both visually impaired and non-visually impaired participants. These included i) Teacher Training for teachers from schools for the blind ii) Inclusive Hackathon of 12 teams: Each team comprising of 2 visually impaired programmers, 2 sighted programmers from industry, 1 engineering college student. ii) Student demonstration: Science projects at a private training center iv) Summer Camp: 10 VI students of fifth standard and 3 teachers v) Teacher and Textbook Authors Workshop. Participants were also observed in Science and Math lectures in a blind school with 10 students of fifth grade from August 2017 to March2018 for 1 hour per week during Science and/or Math periods and 3 hours of interaction time per week during which interviews and observations were made, and experiments such as tactile methods of teaching and activities for learning Science and Math was administered to the class. Some interviews were audio-recorded on approval of the interviewee, while field notes were taken for others. This allowed us to revisit the details of what the participants articulated and reflect more closely on their discourse. Transcripts of the conversations were made for easier analysis. These transcripts were then scrutinized multiple times to gauge patterns, and certain words or groups of words were highlighted as 'codes'. Entire sets of codes dealing with specific topics were then grouped into the categories elucidated in the Findings section and conclusions drawn from them using an interpretive approach.

4.0 FINDINGS

ATs and policies for their adoption have rarely included the lived experiences of the visually impaired, especially in the developing countries (Pal et al., 2015). To comprehend these lived experiences, our primary research adopted ethnographic methods and focused on stakeholders in the education system for the visually impaired, particularly in the southern Indian province of Karnataka. The key stakeholders include students, teachers, enabling agencies involved in providing resources to the VI students and technology designers in labs and corporate organizations. Our findings have been classified in terms of three major challenges being faced by the stakeholders and their views on the possible ways to address them:

- Accessible Science and Math content.
- Instructors for the VI students and their capacities**.**
- Infrastructure and technology aids for the visually impaired, and the process of their creation and use.

Accessible Science and Math content

We found that children in schools for the blind do not possess individual text books. There is usually one Braille book for the entire class which remains with the teacher. Before tests, most of the students refer to the notes which the teacher dictates in class. Students in lower grades depend largely on learning in the classroom and rarely do any additional homework. The text books are often authored by sighted persons and their descriptions are not always comprehensible by a blind student. *"I am blind by birth, I cannot understand a curve description which says L-shaped or V-shaped,"* said a student of ninth grade.[2]

The students in the school for the blind where we conducted our fieldwork were not exposed to 3-dimensional (3D) models or tactile diagrams. In an experiment designed to introduce tactile diagrams to the students of fifth standard, 70% of them were not able to relate to a tactile diagram of a flower or the sun, since they had never used such material earlier. Those who have taken Math in high school are exempted from learning Calculus, Geometry or Trigonometry for their exams - these subjects are, therefore, not taught in these schools. There is no equivalent for these topics and students often score low marks in the Class 10 Board examination since they cannot attempt those questions. On the other hand, VI children who attend inclusive schools face challenges in following class lectures and teaching methods which are largely visual and use the black board extensively. Even if a college or school admits the visually impaired, in most cases, no specific support is provided to help these students with their coursework. Most of their study material is not fully accessible since OCR software does not recognize them or screen readers do not read the content. Moreover, there have been limited efforts in making mathematical notations accessible. All our respondents shared that they had to frequently rely on volunteers, friends and family members for help with reading out the study material or recording them.

There are a few resource centers in the not-for-profit sector that provide Braille, Audio, E-Text and DAISY [3] format books on demand to the students. A doctor who heads a rehabilitation programme of a leading ophthalmologic research institute in India shared that their institute had created a large-print and Braille books library for non-curricular books in addition to providing accessible curricular resources such as tactile maps and Braille text books on demand. However, the doctor said that the demand for Math and Science books were very rare until very recently. An expert who heads such a resource center and is blind himself said, *"For the visually impaired student in India, S and M stands for Sanskrit and Music, and not Science and Math."*[4] Socio-technical issues such as the need for affordable braille displays and the need for creation of accessible Science and Math content for VI students are being highlighted at the behest of certain forerunners who are themselves visually impaired (Taraporevala, 2016). In a conversation with us, the Director of another resource center said, *"There is a great need to make the Science lab accessible through technology"*.[5] He also shared that he loved Science as a student, but could not study it due to lack of content and other resources. He therefore pursued Sociology for his higher education.

Since lack of access to diagrams in Science and Math is one of the key deterrents for the VI students, an AT research lab has created tactile diagrams along with the Braille printed NCERT[6] curricular books for all grades. The cost of each page of tactile diagram varies from INR 290 (USD 4.40) to INR 680 (USD 10.25) per page for a new design, creation of 3D moulds and thermoforming, depending on the degree of complexity and, at this rate, is not affordable by many special school students who come from lower-income households.

Instructors for the visually impaired and their capacities

Teachers in the schools for the visually impaired highlight the need for development of independent living and mobility skills for their students. The Principal of one such school shared that students also undergo additional vocational training such as on horticulture and dairy farming, to prepare them *"for*

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[2] Excerpt from an interview conducted with a 5th grade student on August 18, 2017.
[3] DAISY is an acronym for **D**igital **A**ccessible **I**nformation **SY**stem.
[4] Discussion with Head of a resource center on July 7, 2017.
[5] Discussion with Head of a resource center on November 17, 2017.
[6] National Council of Educational Research and Training (NCERT) is an autonomous organization of the Government of India which advises the Central and State governments on policies and programs.

employment with which they can easily cope".[7] While many of our student respondents from schools are interested in studying Science and Math, work beyond school hours is limited. *"They do not practice,"* said a Math teacher. *"Our teaching has no problems, but if they don't practice, they cannot score,"* he continued.

The classroom of a non-government organization for the blind which offers a 2 year diploma on special education for teachers was filled with tactile artifacts of maps, human body systems and models of urban structures. Supporting the use of sensorial teaching methods, the Principal of the school said, *"When we teach the children about plants, roots, branches, leaves...we make them touch plants...the Montessori sensory system of education is adopted for primary school".* However, when we spoke to the specific subject teachers and students, we found that chemical equations are skipped in high school Science lessons, laboratory experiments are entirely omitted and the students have no exposure to the experimental procedures. *"They will find lab work very difficult",* said a teacher.[8] There is also no effort to teach diagrams in Math and Science. There are no accessible and affordable 3D models or tactile diagrams for any of the topics in the classrooms which the children could relate to. Middle school students of a school for the blind shared that the Science lectures in their class are largely theoretical, and are conducted without the use of any sensorial artifacts. By contrast, in an international school in Bangalore, which is largely attended by students whose parents are employed in senior positions in multinational corporations, and is open to admit VI students, a designated teacher helps the VI student in the classroom during regular classes. She uses Wikki Stix (Mcdonald, 2018) to create tactile equivalents of board diagrams drawn by the class teacher on parchment paper. During exams, a school designated teacher copies the answers typed in by the student on a computer onto an answer sheet for correction by the subject teacher. The print-out of the student's Microsoft Word answer sheet and the teacher's handwritten answer sheet are together submitted for correction to the examiner.

Out-of-school coaches and mentors who are trained on special education strongly stressed the need to provide accessible resources for the VI students to help them comprehend Science and Math. They are confident that given the right tools and exposure, VI children can grasp concepts as clearly as their sighted peers. They suggest that it is critical that special skill learning for these students should run parallel to academic learning. They lament the stereotyping of visually impaired into professions which do not require much intellectual prowess. A group of teachers, who support VI students with their academics, demonstrated the use of various tactile models and toolkits which they use to ignite interest in Science and Math from a very early age. A center which employs such coaches has begun to create manuals for helping instructors teach Science and Math.

There are 27 organizations which train teachers on the pedagogy of special education in Karnataka with aid from the government (Studyguideindia.com, 2018). The government also runs one institute offering Diploma in Special Education for teaching VI students. The minimum requirement to join the course is completion of a Pre University Course (Karnataka.gov.in, 2018). In a workshop for teachers from schools for the blind, we found that all the participating teachers, both sighted and blind, were indeed qualified with this additional diploma. Yet, most of them were not graduates and some VI teachers of Math and Science had not studied these subjects beyond seventh grade. A Math teacher of a special school, who is a software engineer by training, shared that by teaching these VI children, she felt she was serving society. She said that the school has geometry kits and algebraic tiles which are used by the children for learning Math, though she was herself not trained to use the tiles and was learning their usage from her students. She considered *"geometry and algebra difficult for them".* Another Math teacher, who was blind herself, and had not been trained on Math or Science, expressed the urgent need to learn how to explain the basic Math concepts to the children. The Principal of a special school shared that lacking a qualified Science teacher to teach Science to high school children, he assigned the task to a Humanities graduate who was otherwise working as an office helper. In another school, the few Science and Math teachers often

[7] Discussion with Principal of a school on September 15, 2017.
[8] Discussion with Teacher of a school on October 6, 2017.

combine the students of eighth, ninth and tenth standards for Science and Math lessons. Teachers from one of the oldest schools for the blind in India said that they send their students to the district high school, while continuing to support them with resources, due to the dearth of qualified teachers for Science and Math with a willingness to take up these jobs. VI students who are pursuing STEM related subjects in higher education feel that teacher training and orientation towards the needs of VI students is critical.

Infrastructure and technology aids

Some resource centers in India provide advocacy support for VI students requiring print access, financial access, education access and independent living besides spreading awareness about the lives of persons with blindness and low-vision.

In schools for the blind, usage of AT is limited to screen readers such as Non-Visual Desktop Access (NVDA) on the computers. Students are taught to type on a QWERTY keyboard and use Microsoft products such as Word and Excel. The computers are not used as learning tools for other academic subjects and basics of programming is not included in the Computer lessons. By contrast, high school students in inclusive international schools use a computer to type in their notes. They use Braille for Indian languages, but rarely use Braille for English text. Upwards of sixth grade, they take subject tests on the computer. While students in schools for the blind do not get any reference material other than the school notes, caregivers of students in international schools create scanned copies of printed academic books and other reference material to complement their learning in school. For additional tactile diagrams for their specific needs, these students enlist assistance from private tutors trained in special education. Most students from schools for the blind belong to either rural areas or from urban low-income households and cannot afford such assistance. Talking calculators which cost three times as much as the normal scientific calculators are used by VI students for higher level Math in international schools. They are, however, exempted from performing lab experiments in Science. Instead, they are tested on their knowledge regarding the experiments and the findings. These students highlighted the need for technologies to make high school Science experiments accessible through devices which may help to record observations and measurement and provide audio output.

VI students who are now enrolled in higher education programs strongly condemn the limitations placed on VI students in schools and demand that they should be allowed to study any subject of their choice. In their view, VI students should be integrated with others at inclusive schools at the earliest. In fact, many such respondents feel that there is no need for special academic institutions for the blind. All schools should be aware of the needs of differently abled and use technologies that can make their studies accessible. Currently there is no standardization on the facilities available to blind students even if they are provided admission to institutes of higher education. *"In fact, some urban schools have better facilities for the blind than the engineering college I attend,"* said a VI engineering student. *"My biggest hurdle was the lack of awareness in terms of accessible technologies both on my part and that of others around me,"* said a student of Finance. While there are various categories of visual impairment, most ATs rationalize across their specific needs. Specific needs of a large number of low vision students, for example, are not met. Moreover, our respondents felt the need for Persons-with-Disabilities cells in colleges such as those available to students in leading universities elsewhere. University students seek an option to write their exams on computers instead of compulsorily taking the services of a scribe, who mandatorily has to be of lower academic qualification, and is difficult to explain to. In their views, with the advances in technology, a voice to text technology in exams is not too much to ask for.

While educational technology is a key area of research at a leading engineering college in the country, we didn't notice a specific focus on assistive digital technologies for education. However, some student startups have gained recognition by creating innovative haptic interfaces for VI school children. The founder of one such firm shared that after interacting with school children at various schools for the blind and interning at a resource center, she found it was extremely important to create a fun-filled learning environment and introduce more interactive games to foster healthy competition to motivate the VI students. She is working on creating a channel for schools to adopt the tactile products with haptic interfaces. The challenge she faces is affording expertise from multiple domains, so essential in creation of AT. For example, she was keen on collaborations with firms which had already developed expertise or the physical hardware ready to hold devices such as smart phones which are being effectively used for the camera enabled apps. However, such an alliance is not always a priority for the larger firms.

In a lab specifically dedicated to creation of ATs in another engineering college, technologists create solutions to address the challenges of mobility and education besides helping to create awareness among the youth towards the needs of the differently abled. Graduate engineers and research scholars engaged in the lab have created a range of products for the education of VI students. These include Braille readers, patented technology to create high resolution tactile graphics, a catalogue of 3D printed models and an audio labeller. The engineers also actively contribute to the NVDA screen reader platform through enhancements, while research scholars pursue projects on innovative ATs. In the same lab, a team comprising of mechanical engineers, hardware and software experts and CAD designers have dedicated more than six years to create a portfolio which is being moved to production through their commercial arm, in collaboration with industry partners in various states of India. Dedicated engineers are also working on two versions of refreshable Braille displays, which are being tested through various beta sites. In an attempt to remain competitive, the technologists originally created a largely trimmed down version of a product, only to find disparate acceptance criteria by the low cost users. This forced them to go back to the drawing board and recreate the design with inputs from users at the very outset. The products are now at various stages of acceptance testing and the lab is working closely multiple resource centers.

Assistive Technology is also a focus area of Corporate Social Responsibility (CSR) departments of a few technology firms in India. One such firm created an analog-digital interface computer access switch to help children with cerebral palsy to type on computer keyboards in collaboration with students at an engineering college. This product was priced attractively at INR.350 (USD 6) while the prevalent market price for such products at that time was about USD 150. The product was taken to the children after seven rounds of prototyping through four years of design with the help of a design firm and advice from physiotherapists who treated children with autism. According to the Program Director, the product was functionally complete and designed by technology experts and packaged attractively to look like a child's toy, yet the product was rejected by its targeted users, due to issues with the ergonomics of the device. These had to be corrected through various trial and error conditions and a "base lined approach" on the user story, to inform the optimum feature set requirements to be included in the product. Armed with the learning from its previous product, the firm initiated a product for the visually impaired in collaboration with a leading eye hospital. They designed a text to speech conversion device for libraries in rural schools, which would scan books and provide students with a way to access print material easily and on demand. However, since the market price of this device is far beyond the reach of most schools, the firm aims to bring down the cost drastically through innovative design principles.

In an inclusive hackathon organized in the course of this research, participants consisting of technology designers from industry, VI programmers and non-VI engineering students were teamed up to create product prototypes over a 48 hour period. Twelve prototypes were designed to near completion through this exercise, and each design was completely accessible. AT products were designed and demonstrated even in such a short exercise through collaborative effort of an inclusive team of designers.

5.0 ANALYSIS AND DISCUSSION

This paper studies the grand challenge in India related to the underrepresentation of VI persons in STEM education despite innovations in ATs and a policy level endorsement of the United Nations Convention on the Rights of Persons with Disabilities (CRPD). The ATs which are examined in this paper are targeted at VI students. Our findings indicate that the demands for accessible content and ATs arise from the VI students and their teachers, while the resource providers and designers of AT artifacts form the supply-side of this eco-system. We therefore analyze our findings from the perspectives of both the demand side and the supply side stakeholders using the aforementioned "biopsychosocial" lens. In doing so, we highlight the gaps from the supply side stakeholders in servicing some of the well-articulated needs of VI persons, as well as the probable gaps in articulation of needs by the stakeholders on the demand side. The variation in the needs of the demand side stakeholders based on the socio-economic variations of students and teachers deserves further research and is beyond the scope of this paper.

Demand Side Perspectives

On the Biological needs of VI students

Braille device and Taylor frames are widely used to learn Math and Science. These technologies help child in learning the subject through non-visual means. Most of these technologies are designed purely from a medical standpoint so as to overcome the functional challengers to develop the capacity to learn these subjects.

As the mainstream methods of teaching these subjects are highly dependent on visual capacities for learning and practicing, special efforts have to be taken to assist these children in sharpening other sensory skills such as feeling and listening so as to let them to grasp Math and Science concepts taught later.

Many of the VI students in schools expressed a desire to pursue careers in the STEM field. However, schools specially designed for educating the visually impaired do not provide Math and Science education due to the high levels of perceived difficulty in teaching these subjects which rely on visual means for diagrams and equations. Extra effort is required to teach these subjects, be it in procuring the technology (3-D models, tactile diagrams) and making Braille content accessible or in training the teachers and equipping them with special skills and methods needed to teach VI students. Our findings indicate lack of affordable and easily available technologies, and the lack of vision among stakeholders to enable teachers.

On the Psychological needs of VI students

While students do not have reference material to study Science and Math, those that exist, are not necessarily created to suit their needs. For text books which have been translated to Braille, the content is often not comprehensible by children who are blind by birth. For example, authors do not consider the needs of such students while including terms such as a "V-shaped" or "L-shaped" curve, which is both a psychological and biological disadvantage.

Besides, VI students in special schools are also not aware of the possibilities that ATs can unlock and, therefore, are not forthcoming on their explicit demand for them. In fact, despite relatively better infrastructure at inclusive international schools, VI students preferred to be included further in the learning process. For example, though they are presently not expected to perform lab experiments during exams, they expressed a need to have appropriate ATs to learn the experiments.

We have no evidence to suggest that an average Indian VI student's perspective, which should be the most crucial while designing ATs such as the Taylor Frame for them, has been considered during design. The limitations of design are apparent in the challenges described by students in performing larger calculations on the device, and lack of inspiration and, therefore, the scanty number of students taking Math in higher classes.

Lack of awareness in teachers has a causal relationship with the psychological awareness of the child. Persistent demotivation from teachers and a continuous reminder of the limits of their functional capacities can have long-lasting negative psychological effects on the child and might even lead to a negative introspection.

Students in higher education feel the need to be included in 'regular' institutions and prefer that these institutions are sensitized about their psychological and technological needs both in class and during exams, provide accessible content and learning resources like some of the leading universities abroad. The VI working professionals also prefer that VI students be not treated with sympathy. They would rather be enabled through ATs to fulfill the eventual expectations of their employers.

On the Social needs of VI students

A key reason why Braille books are not available to every child is the sheer volume of a text book equivalent Braille content for every printed book. Braille paper is expensive, heavy and the sizes of the books are not amenable for ready reference or portability. Digital technologies to provide refreshable Braille displays are priced above Rs.30,000 (USD 450), beyond the reach of most VI Indian children attending schools. ATs for education have clearly not considered the socio-economic perspectives of students in developing countries such as India.

While teachers have the power to change existing social stereotypes, most teachers, although enthusiastic, are not aware of apt teaching methods or even the fact that such subjects can be taught with a little help from appropriately designed technology. As a result, they give in to prevailing societal norms and motivate these children to take up careers which don't require a high visual orientation such as telephone operators or music artists. We find that they often compel students to avoid STEM related subjects even if the latter find these subjects interesting.

Supply Side Perspectives

Resource Providers

The focus on assisting VI students in India has largely been on addressing their biological needs, largely by providing mobility training and vocational courses on basic livelihood and independent sustenance. Despite a large number of resource providers supporting VI persons in India over the last two decades, accessible content is still not available to each VI student in schools for the blind. The resource centers address biological challenges by supporting schools with Braille or audio books on demand and providing training on ATs. Yet, most of the providers have chosen to remain oblivious to the needs of children to study Science and Math. The resource centers have rarely advised technology designers on the needs of VI students until very recently, by facilitating field testing newly created technologies such as the refreshable Braille displays or tactile diagrams.

While a couple of VI experts pointed out the lack of focus on Science and Math and the need to disrupt the status quo, there is an overall lack of awareness within the organizations on the psychological impacts of not addressing this challenge. While dance, music and even sports for the visually impaired has been focused upon to address some of the social needs, there has been no attempt to recognize or foster a scientific temperament among them. We came across just one center in our sample, which attempts to address the psychological needs of VI students by providing advocacy and spreading awareness about the capabilities of VI persons in the public sphere.

Resource centers focus on social needs of the visually impaired by providing rehabilitation and livelihood training. Being aware of the ubiquity of digital technologies, all resource centers have acquired computers and provide training to VI persons on computer usage. Funded through CSR initiatives of private companies, resource providers enable VI persons to use the computer to perform some of the desk jobs at corporate organizations. A couple of larger players in this space also provide professional courses on accessibility testing or programming and have begun to facilitate placement of VI persons in the industry. As the intermediaries between the corporates and the VI community, they have been able to highlight the challenges they deemed possible to address in their capacity, often competing with each other to reach the end user for the same set of services.

Technology Designers

Only a handful of the technology labs in the country design AT specifically addressed for the the visually impaired. Moreover, a clear disparity is seen when it comes to inclusivity of the disabled in educational research. ATs are designed to overcome the challenges due to the medical condition of the user, as per the understanding of the designer or the medical practitioner, rarely with inputs from the user. This results in rework and loss of precious time and resources to take care of demand for better ergonomics or appropriate functionality.

Our findings suggest that while the vision of these labs is to make positive changes in the lives of VI students, the techno-centric focus of the engineering team has informed the design of the products, which are also often not affordable by the average VI student attending a special school in India. Some designers were unaware of the magnitude of the challenges faced by VI students in acquiring basic knowledge of Science and Math. Education portals, online learning games and applications to assist students with their studies in Science and Math do not consider accessibility guidelines in terms of content and usability. Very few technology companies have expressed their desire to be inclusive in terms of hiring qualified VI technologists. Moreover, the firms have spent very little effort to understand the needs of the visually impaired at the workplace. As indicated earlier, we also found that one of the labs where technology designers are working in close collaboration with resource providers and VI users, has been able to make a greater positive impact on creation of Science and Math content for VI students.

6.0 CONCLUSION

To address the gaps demonstrated in our analysis of the supply and demand side perspectives using the biopsychosocial framework of addressing disability, we conclude that in addition to Braille books, an accessible and affordable online platform for Science and Math content, especially catering to the needs of VI school students is the need of the hour. It is also essential that print content in Science and Math books be supplemented with durable 3D models and refreshable tactile diagrams with Braille or audio labels. The need for a standardized training curriculum for STEM teachers to be equipped to administer lessons to VI students cannot be overemphasized. Technology enabled interactive learning tools and games assisted by a teacher are found to reinforce and enhance their learning. For VI students to be inspired to pursue STEM education, it is essential to create accessible and affordable laboratory equipment in schools. Finally, our findings also indicate that accessibility needs of VI persons using technology products may be adequately addressed through active participation of these persons in technology design teams and eventually increase the adoption of these products. However, the current under-representation of VI persons trained in STEM disciplines highlights the need to make STEM education accessible for them in the first place.

To implement the recommendations, the AT design process should be made aware of the biopsychosocial dimensions of the challenges faced by the users. First, the technology designers should complement each other's work rather than repetitively create singular artifacts to address a single challenge. Second, technology labs and vendors are required to divert focus from only the medical or biological aspects to also the psychological or social aspects in the design of their artifacts. Third, close interaction between the various stakeholders on the supply side and the demand side is required to address the challenge of lack of STEM education. Therefore, the research shows that there is a need to transcend barriers and bring the stakeholders together into an institutional structure, rather than addressing the challenge individually, thereby creating an AT eco-system to empower VI students.

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