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Educational Computing for the Blind in India:

Design, Development and Learning Impact

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Abstract— **The aim of this paper is to present software engineering methodologies that were employed in developing educational solutions for the visually impaired. Empirical studies and experiments were conducted to measure the impact of the educational tools on the learning and cognitive abilities of the target user group. This study highlights the various technological and design challenges that were faced while developing and deploying these customized learning solutions. Observations and results indicate that there is significant merit in developing and utilizing such applications for the educational empowerment of the blind.**

Keywords-Accessibility, Educational software, visually impaired, Assistive technology

I. Introduction

In the general populace, computer based educational tools play an important role in the learning process of a student [1]. The disabled sections of the society, who find it difficult to access computing devices, find themselves more marginalized due to this [2]. Of the disabled, there are over 1.4 million visually impaired children below the age of 15 [3, 4], rendering the development of educational technologies for the visually impaired a necessity.

Imparting educational content and training to visually impaired students is a challenging task. Existing educational solutions assume visual ability, and hence are designed to be graphical and heavily based on human-computer interaction based on visual feedback from the system. Visually impaired students face tremendous challenges in comprehending those concepts which are usually taught in an illustrative manner [8].

Despite the availability of screen readers and accessibility standards, there are very few educational solutions designed keeping in mind the regional, cultural and educational background of the visually impaired[1,2]. Accessibility issues prevent the effective utilization of the numerous assistive technologies available [5, 6].

Since most of these solutions employ Audio User Interface (AUI), the voice based feedback appeals to the cultural and educational background of the western audience, particularly in terms of accent, voice speed, grammar, logical construct of sentences, application design and use.

Due to unavailability of Information and Communication technology (ICT) based learning tools for the blind, teachers face challenges in pedagogy. Along with that, software related problems and learner differences are among the major problems encountered in the computer operating courses for the visually impaired [7].

This paper is divided into five sections. Section II discusses the various design and learning requirements of educational products that were considered while designing the applications. The various development, deployment and testing issues faced are discussed in section III. The evaluation methods used and the results obtained are elaborated in Section IV. Our general observation and inferences are discussed in Section V.

II. REQUIREMENT ANALYSIS AND DESIGN

The model followed while developing the software consisted of a mixture of evolutionary and incremental models. A prototype with the main features was developed, by keeping in mind the users, their culture and abilities.

The applications evolved in the following 5 phases (Figure 1):

Requirements Identification - It was a detailed procedure starting from identification of cognitive and learning abilities, infrastructure requirements and educational curriculum. The faculty of various blind schools assisted us in this phase. The requirements identified included educational curriculum requirements in subjects such as co-ordinate geometry to know the depth of knowledge and understanding of the subject by the students. Co-ordinate geometry, otherwise taught using tactile methods, turned out to be an excellent basis for our application as it served as a very good educational tool. The data gathered during this phase aided us in gaining knowledge on the students' proficiency with Windows and Linux and in identifying whether the application could serve as an educational tool or as a source of entertainment only.

Requirements Analysis – This phase involved analysis of existing software solutions, tools and research work for developing applications for the visually impaired. We researched on the guidelines to be followed while developing assistive technologies for the blind. Based on our research work, MIT Media Lab's programming environment, Scratch, [11] that used a simplified approach to programming, was found suitable for light weight applications using pre-recorded voices for AUI. The rest of the applications had the AUI designed with speech synthesized from text in order to make the applications flexible and scalable. Java being well documented, open source and easy-to-use, was the preferred choice to develop these applications. A major reason that backed the use of Java was platform independence. Our target audience being spread over a range of educational institutions for the blind, where training in computers was specifically Windows or Linux but not both, it was

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necessary to ensure platform independence of our applications. To enable our applications to be independent of screen readers, we chose to use Text-To-Speech (TTS) converters. A good analysis of existing TTS showed that open source TTS libraries were convenient. It played a vital role in making our applications independent of expensive screen readers which are not easily affordable for most students in the Indian context due to their low economic background.

Software Design - The interactive software we developed comes under the purview of educational single user games. The skills targeted by these applications spanned mathematical, quizzing, memory retention and vocabulary skills [9]. Developing such educational tools required an AUI to help the students interact effectively with the system. The applications were designed to ensure a good learning experience and thorough understanding of concepts with the help of clear and unambiguous hints provided at various stages during the use of the application. Another design aspect that was given importance is the usage of intuitive and simple keystrokes for navigation. For example all applications use "Ctrl+r" to repeat a question. Scalability and customizability of questions was another vital feature. Most importantly, it was required of the application to guide the user with a clear description of the game and unambiguous instructions for using it.

One of the applications developed, "ViMath - Mathematics for the Visually Impaired" helps students understand basic arithmetic operations. The tool ensures effective assimilation of concepts by providing a step-by-step explanation of how the operation is to be carried out to derive the correct answer for the given question. Studies show that, audio interfaced applications help improve memory retention skills [10]. Based on this, we developed "FindTheMatch" - a typical memory game of matching a pair of elements in one set to a specific element in another. The design allows memory games of varying difficulty levels to be played by the user. This scalability aspect of the design is brought in, again with the use of files for storing the data sets. Learning is primarily auditory based for the visually impaired. Sound recognition is very vital in this respect. Considering this, we developed "Sound Bird" - A sound recognition application that helps learn about sounds heard in daily life. This application has proved to be efficient in helping the visually impaired learn more about animals, birds and other objects. With the idea of developing diverse software that would support faculty as a learning aid "Illuminate", quizzing software was developed. The application can also be used by the mentors to teach specific topics as the design allows customizability by maintaining files to store the questions. Visualization in general is highly demanding for the visually challenged. Visualisation of orientation of shapes in space is particularly trying but is vital for understanding of mathematical concepts such as co-ordinate geometry. In retrospect, we developed "Co-ordinate Geometry Aid". The application aims to teach co-ordinate geometry by reading out a set of points and expecting the user to recognize the shape formed by joining those points in order. This application also provides additional features such as graph plotting to assist the partially blind. It also incorporates difficulty levels to suit diverse IQ levels. With a strategy of targeting students spread over a wide range of learning abilities, it was apt to come up with applications based on games involving simple logic and rules. Considering this, "Guess the Number", an excellent method to teach the concept of conditional logic, was developed. Apart from arithmetic, cognitive and quizzing skills, vocabulary was another area targeted by means of a scrambled words application "Unscramble It". This application helps develop speech delivering in terms of diction as well.

The design included display of required information at all stages to enable partially blind students to use the applications effectively. Localization, a unique feature of our applications was also introduced in this stage using translation to regional languages, specifically Kannada and Malyalam. Educational content in each application was written with due consideration to Indian education system and teaching methodologies.

III. DEVELOPMENT AND DEPLOYMENT

Software Development- This involved usage of appropriate tools to provide a Graphical User Interface (GUI) and an AUI for the prototype. The prototypes were developed after referring to IBM Guidelines for Writing Accessible Applications Using 100% Pure Java™ [12]. These prototypes were tested by the faculty and qualitative feedback was collected from them. The design was revised and necessary changes were made to the application before they were ready for user testing. This phase also included addition of features such as options to repeat and skip specific instructions. For example, the initial prototype of "ViMath" did not include an option to skip the explanation to the solution. Initial prototypes of "FindTheMatch" were devoid of levels. These features were included in the subsequent prototypes as they evolved.

Software Deployment – This stage was where the visually challenged students used our applications. Our applications were deployed at RCLSB Mangalore, Ramanamaharshi School for the Blind, Bangalore, Insight Kerala, Akhil Bhartiya Netraheen Sangh, Delhi, and Karnataka Welfare Association for the Blind, Bangalore.

Testing – It was a rigorous phase that contributed significantly to the improvement of quality and usability of the applications. An important part of this was user testing which consisted of collection of feedback from the user to perform quality checks. The feedback was based on the user's comfort with the navigation, clarity of instructions and other information, and requirement of external guidance for using the application. A primary aspect of our observations was the students' proficiency with keyboard strokes and how it affected navigation

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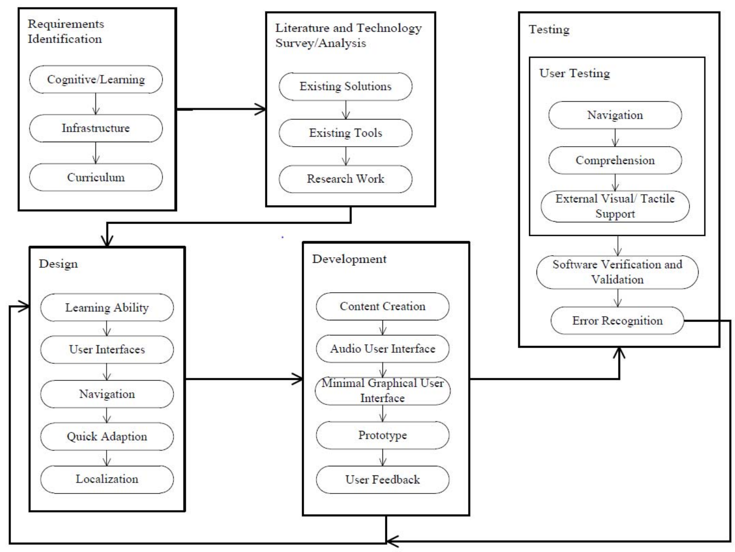

Figure 1. Software Development Model

and use of the application. A good observation made was the need for the shortcut keys to be alongside each other so that the blind do not have to search for the keys each time they use it. Other critical issues such as recovery on software failure and error recovery in situations caused by use of illegal keystrokes were handled during this phase.

IV. RESULTS AND OBSERVATION

The evaluation is based on an empirical analysis and study, which involved a series of trials by the student on the applications. The data collected varied from one application to another. For applications intended to help in learning new concepts, the time taken by the students was measured for each successive trial. The collected data was inspected for changes in average time taken to solve problems of a particular difficulty level. For tools such as "FindTheMatch" and "Guess the Number", the observational parameter was the number of trials taken to arrive at the correct answer. Applications involving concept learning had to be analyzed for the successful grasp of the concept, which was realized by the amount of time taken to solve each problem. The timings recoded were analyzed by means of a learning curve. A learning curve provides a graphical representation to see the effect of any educational software on the learning ability of a subject. In both cognitive psychology and cognitive modeling, learning curves have been shown to provide mathematical accounts for the rate of learning. Analysis of human based data often demonstrates a continuous learning process which is effectively portrayed by a learning curve [13]. The results were normalized and plotted onto a learning curve (Figure 2). The exponential trend line is used to depict the trend as it has been shown to be the best fit in typical learning curves when learning is based on a fixed percentage of what remains to be learnt [14]. The curve, when considered as a Rasch model [15], can be subjected to regression analysis, and a governing equation can be found. For the data collected, the regression equation has been shown in the figure (figure 2). The negative power of the exponent indicates that the curve has negative acceleration, implying that, further practice improves performance but with lesser effect [14].

Another important tool, to analyze the effectiveness of educational software applications, especially the ones based on memory, is analyzing the change in number of trials required to deduce the correct answer, with repeated exposure to the same kind of questions. As the number of repetitions of an exercise increased, the retentive ability of the students also increased, which conforms to the theoretical expectations [15]. The application "FindTheMatch" is based on the ability to quickly commit relations between objects to memory, and to recall them when needed. A trend based on the normalized times of a large number of subjects, will indicate the effectiveness of the tool under consideration [15]. A large group of students, were asked to use the tool and their readings were averaged, and a forgetting curve [16] was plotted (Figure 3). The overall decreasing nature of the curve indicates that the application has been effective in increasing the retentive ability of the student.

A lot of qualitative feedback was also collected from both the visually impaired students and their facilitators. The collection of this data was based on the heuristic model, which was shown to be effective with the visually impaired [16,17]. For feedback from the students, parameters such as clarity of voice, comprehensibility of instructions, self sufficiency of the tool and ease of navigation were considered. The parameters for the educators that were focused on for this feedback were, whether the difficulty level of the questions was compatible with previous knowledge of users, whether the extent and type of subject coverage was complimentary to their curriculum, and whether the keystroke layout of our application was feasible for the level of typing proficiency the students were trained to. Teachers and students acknowledged the effectiveness of the applications. Students shared their experiences with each other and also

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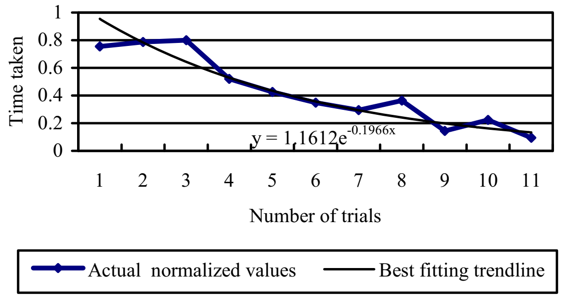

Figure 2. Learning Curve

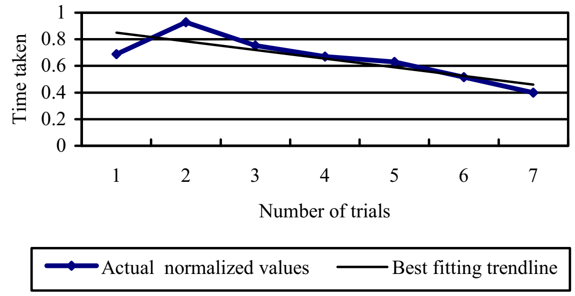

Figure 3. Forgetting Curve

played the games in teams, thus encouraging group learning. We also conducted an experiment where we asked the blind students who were already proficient with the software to teach other blind students of the same or lower age group. We found that students were able to explain the game and guide the new learners with ease. This highlights the empowering aspect of the software solutions, which can give a visually challenged student the independence and enabling power to master a concept without any constant visual or tactile human aid.

V. CONCLUSION

From our empirical studies and analysis, we come to a conclusion, that the software solutions developed for the visually impaired community have had a positive impact on the learning ability of the students. The software development methodology employed, was effective in tackling the various design issues related to developing ICT based technologies that can impart education and at the same time have an empowering effect on the learner.

During the course of the study, we were able to infer that rather than a universal design, a customized design based on the locality, culture, and the prevalent educational curriculum of the target audience is more feasible and able to meet the requirements of the users.

We believe that an extension or modification of our proposed model and associated evaluation techniques will serve as a yardstick or a guide, in the development and deployment of educational assistive technologies on a larger scale. This will not only add value to the society through its empowering nature but also contribute extensively to the study of accessibility aspect of human computer interaction.

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