USABILITY EVALUATION: USER EXPERIENCE EVALUATION FOR DYSCALCULIA STUDENTS USING AUGMENTED REALITY IN MATHEMATICS

Abstract

Augmented technologies have found to be an effective approach for special needs learners in enhancing their learning skills. On the other hand, these applications must be designed in such a way that they are usable and intuitive for individuals with special need specially dyscalculia students. Usability evaluation on user interface is an informal method of usability analysis evaluation which presented within an interface design and required experts to comment on it. Usability evaluation principles applied focused to improve the efficiency and learn ability of the applications The usability evaluation involved summative evaluation which was conducted on the use of the application by fifteen (15) elementary dyscalculia students. Finding of the research indicated that the important for early intervention through embedded in Augmented Reality application was certainly significant to assist dyscalculia students to learn mathematics. The result outcome shows that usability evaluation on user interface has evidence a break in the field of special needs students.

Keywords: Dyscalculia, Augmented Reality, Mathematical Difficulty, Usability evaluation, Visual Based, Cognitive walkthrough, Informal Walkthrough

Author

Kohilah Miundy
Senior Lecturer
Department of Information & Communication Technology
Polytechnic Metro Kuala Lumpur
Malaysia.
kohilah.miundy@gmail.com

I. INTRODUCTION

Diverse technologies were used to evaluate Augmented Reality for Dyscalculia students' application testing vital to ensure the efficiency and learn ability of the working prototype for elementary dyscalculia learners. There is a major difference between Augmented Reality (AR), and traditional interfaces due to their differences in physical environment. AR has a complicated environment in which users mainly move freely as well as moving parts of their physical body to interact with the application. The various strategies used to collect data were employed such as informal and cognitive walkthrough embedding questionnaire and expert evaluation. The diverse techniques used in date collection uncovered various aspects of how learning for dyscalculia learners can take is various form apart from the traditional conventional approach.

In 1981, usability evaluation design by Shackel emphatically sought to replace the application as a user-friendliness phase. Learn ability, throughout, adaptability and attitude are the four (4) components of usability evaluation that are of interest (Shackel 1990). The four (4) characteristics of usefulness, effectiveness (easy of use), learnability, and attitude (likeability) articulated by Shackel (1990) and Booth (1989) are included in Rubin's (1994) definition of usability. In generally usability testing consists of three (3) feature as easy to learn, easy to use and user satisfaction to use an application (Stone, Jarrett & Minocho 2005; Smith, & Mayes 1996). Usability refers to efficacy and efficiency in achieving defined goals and user satisfaction based on international standards.

Usability standard is described as "the extent to which a product may be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified content use" by ISO 9241 (1998). However, usability testing has considerable effects on learning applications for students with dyscalculia. Additionally, a dyscalculia supportive Augmented Reality learning application should experience usability testing to confirm that it meets both its learn ability and efficiency standards (Gresse von Wangenheim et al. 2016).

II. OBJECTIVE

Summative usability evaluation goal is to assess dyscalculia students at the conclusion of a course by comparing them to a standard. The end does not refer to the finish of a whole course or module of study. Summative evaluation may be distributed throughout a lesson after a particular lesson that is taught, and there are advantages to doing so. The technique of summative evaluation employed in AR learning application prototype was aimed to summarise overall learning after the intervention was through informal walkthrough and cognitive walkthrough.

III. METHODOLOGY

The process of usability evaluation which includes summative review focuses on satisfactory way to understand and use the program to accomplish their goals. It is about the degree of user satisfaction with the evolve Augmented application (Nayebi, Desharnais & Abran 2012). Summative evaluation was also adopted to access the goal of the Augmented Reality application in fulfilling the stated intended goal.

Usability testing was done as part of the summative evaluation process using a sizable sample of representative users. Aimed at identifying the advantages and disadvantages as well as contrasting various design options or related applications. The summative evaluation involved assessing the impact of efficiency and learnability of the application. Summative evaluation refers to the assessment for the learning of participants where the focus is on the outcome of a learning application. These contrasts with formative evaluation, which summarises the participants' development at a particular time.

The methodology based on Table 1 can be used to collect information from the target users. The informal walkthrough technique was a fundamental method for gathering data about the application's intended usage, embedded cultural meanings and indicated ideal users use. The informal walkthrough technique indicates that the user allows to explore the use of the application at their own pace and in the order that they see fit without the researcher getting in the way. This method can be used to assess how user-friendly and intuitive the application is. Usability evaluation instrument used during the summative evaluation for the Augmented Reality learning application as working prototype was developed to collect data on usability evaluation of the prototype. Once the elementary dyscalculia learners were comfortable using the AR learning application, information retrieve using a informal walkthrough strategy as shown in Table 1. The cognitive walkthrough technique was used to identify usability issues in an interactive application. It focuses on how easy for a new user to accomplish tasks with the application.

Table 1: Summary of Usability Evaluation Methods for Augmented Reality Application

Type of evaluation	Evaluation Method	Implemented
Summative Evaluation	Informal Walkthrough	Allows participants to explore the system without preparing a thorough test task.
	Cognitive Walkthrough	Primarily focus on ease of use and confidence as first time users.

1. **Usability Test Sampling:** As many as 35 students from an elementary school who were found to have dyscalculia symptoms made up the sample size. In all, fifteen (15) samples were used in the usability test. These students had dyscalculia, according to a screening. through a specially built screening tool (DYScrin), using a random sample technique. These students were identified as dyscalculia students during screening using a specially designed screening tool (DYScrin) using a random sample method. One of the state's national schools in Selangor hosted the study. Purposive sampling, a non-probability sampling technique used in this study, selects respondents based on a set of criteria, such as similarity in academic background, learning style, and attitude to the learning environment. According to Nielsen (2000), a sample size of three (3) to five (5) persons is adequate for usability testing because only three users are needed to identify 80% of all usability issues.

IV. FINDING AND DISCUSSION

Data was gathered by observation, informal walks, and cognitive walks. The efficiency and learn ability of dyscalculia students were the two (2) constructs on which the usability testing was based. Additionally, information was gathered by observation, informal walks, and cognitive walks. The efficiency and learn ability of dyscalculia learners were the two (2) constructs used to guide the usability assessment.

1. **Findings on Learn Ability Construct:** The application utilization of the learn ability construct was branched into two (2) components which are interactive environments in both the real world and augmented reality environment as the instrument used to gather and measure data on the aforementioned instrument that evaluates the learn ability construct. The sections utilized to assess the learn ability qualities are listed in Table 2. The learn ability construct of Augmented Reality application is measured using a rubric that has been modified from Nielsen's (2001) earlier research on learn ability features.

Table 2: Construct on Learn Ability Assessment Rubric

Scale	Explanations
F	Fail: unable to complete the assignment despite assistance
PS	Partial success: able to complete the task after receiving assistance
S	Success: competent to work without assistance

Usability testing based on the learn ability construct is evaluated using the Usability Testing Analysis Model I: Learn ability construct (UTCMI: Learn ability construct) as in Figure 1

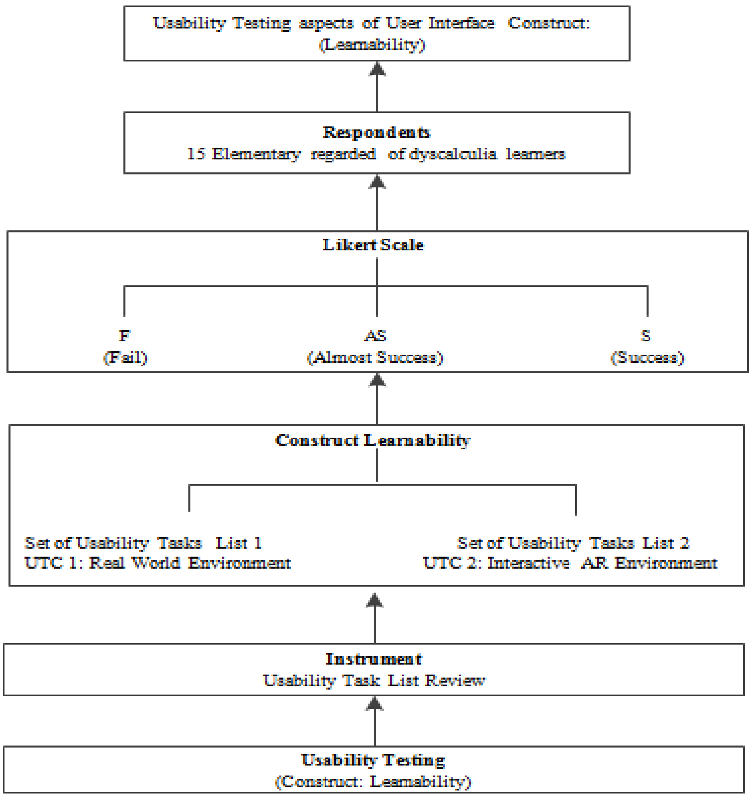

Figure 1: Usability Testing Analysis Model 1: Learn ability Construct (UTAM1: Learn ability)

The following challenge was completed by the dyscalculia students using the provided tool Usability Tasks List 1: Table 3 presents results from the study on task success for the Learn ability Construct (UTC 1). The values in Table 2 are built on the components in Table 3 as their base.

Table 3: **Usability Testing Construct Task for Learn ability constructs**

Learner	Task List																			
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**	**T16**	**T17**	**T18**	**T19**	**T20**
S1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S6	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S7	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S8	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S9	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S10	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S11	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S12	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S13	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S14	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S15	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S16	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S17	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S18	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S19	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S20	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
(%)	100	100	93.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
$\bar{x}$	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
σ	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

Based on a formula developed by Nielsen (2001), Usability testing construct was used to calculate the success rate score in Table 3. The students attempted the tasks a total of 300 times (students x task list). Number of 299 students those attempts were successful and one

(1) Student was partially so. For each partial success 50% of a point was awarded.
The Usability Testing task for learn ability construct success rate is as according:

Success outcome = Success + (Almost Success x 0.5) / attempts perform x 100
= 299 + (1 x 0.5) / 300 x 100
= 99.8%

According to the findings of the Usability Testing Construct Task for Learn ability indicates that the Augmented Reality application for dyscalculia students was very positive scoring for successful outcome which indicates that the students were able to complete the tasks on their own.

Another test was administered towards the dyscalculia students, usability testing construct task for the learning prototype interactive augmented reality environment as in Table 4. Task 2 usability testing success rate is as according:
Success outcome = Success + (Almost Success x 0.5) / attempt perform x 100
= 101 + (4 x 0.5) / 105 x 100
= 98%

The usability testing was designed to determine the success outcome of dyscalculia students in order to give a broad overview of how the application supports them and how much work is still needed to make it more accommodating for these students. The finding of the student informal walkthrough results on the learn ability construct reveals that the construct score in the real world environment is minimal higher than it is in the interactive AR environment usability testing.

This may be as a result of dyscalculia student present newly discovery to the augmented reality learning environment. However, there was no difference in the success outcome attained for usability testing tasks 1 and usability testing tasks 2. Therefore, it can be summarized that the learn ability based on the augmented reality interactive learning environment was highly favourable, at the success outcome which implies the students were able to complete the tasks on their own pace.

2. **Findings on Efficiency Construct:** The efficiency construct was assessed using the UTAM 2: Efficiency construct from the Usability Testing Analysis Model. Efficiency is defined as a way to gauge how long it takes to complete a task. It is often the amount of time needed by participants to finish a job assigned in any given module. There are two ways to calculate efficiency construct which is the overall relative efficiency and time-based efficiency.

   While time-based efficiency referred to the measurement of the amount of time spent by the students to complete the task, overall relative efficiency referred to tests conducted on the students who successfully completed the task in comparison to the total time taken. Table 5 displays the efficiency construct as measured by how long it took the students to finish the exercise. The efficiency construct of the augmented reality prototype application has been measured using the usability metrics rubric for efficiency attributes which has been modified from the earlier study of Nielsen 2001b.

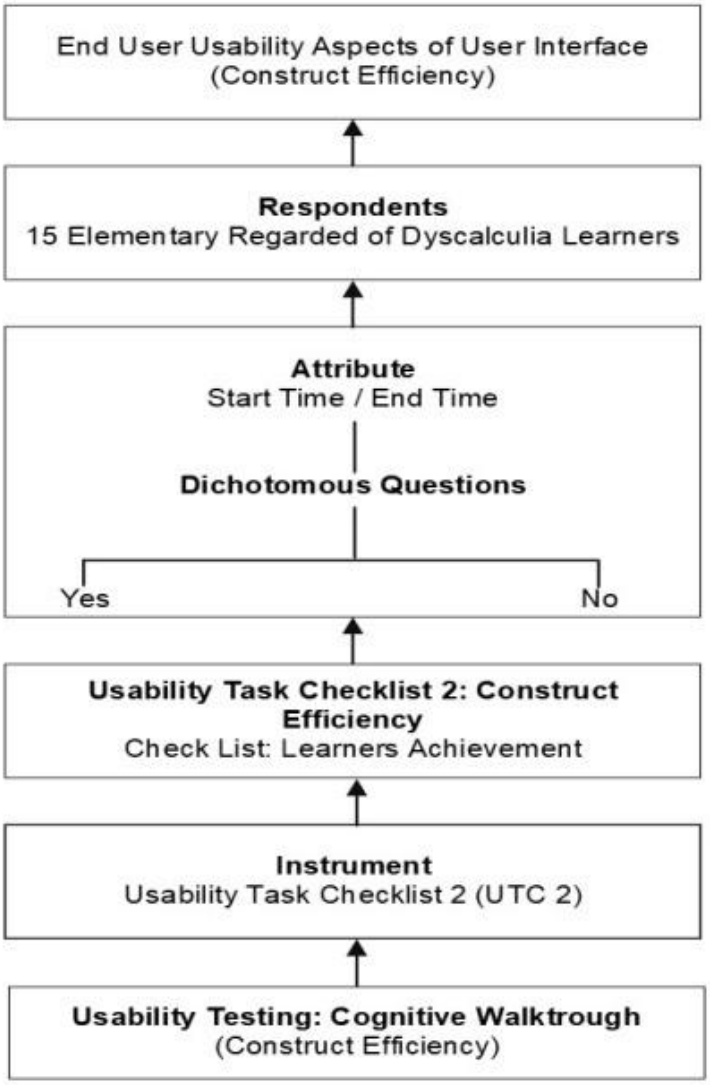

Figure 2: Usability Testing Analysis Model 2: Efficiency Construct (UTAM 2: Efficiency)

Table 4: Usability Testing Construct Task for Learn Ability Constructs

Learner	Task List																			
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**	**T16**	**T17**	**T18**	**T19**	**T20**
S1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3	S	S	A S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S6	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S7	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S8	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

S9	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S10	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S11	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S12	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S13	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S14	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S15	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S16	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S17	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S18	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S19	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S20	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
(%)	100	100	93.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
$\bar{x}$	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
σ	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

Table 5: Efficiency Construct: Time taken to complete Task

Learner	**Time taken to complete the Task (minutes)**	**Time taken to complete the Task (seconds)**
S1	15 minutes	900
S2	10 minutes	600
S3	15 minutes	900
S4	10 minutes	600
S5	10 minutes	600
S6	15 minutes	900
S7	20 minutes	1200
S8	15 minutes	900
S9	15 minutes	900
S10	15 minutes	900
S11	15 minutes	900
S12	15 minutes	900
S13	15 minutes	900
S14	25 minutes	1500
S15	20 minutes	1200

Overall Relative Efficiency is calculated as follows:
Where

$$\text{Overall Relative Efficiency} = \frac{\sum_{j=1}^{R}\sum_{i=1}^{N} n_{ij} t_{ij}}{\sum_{j=1}^{R}\sum_{i=1}^{N} t_{ij}} \times 100\%$$

Where

N: number of tasks (N=1)
R: number of users (N=15)
nij result for the task (i) by the user (j) If the task is completed successfully, then
nij=1 otherwise nij=0
tij time spent the user 'j' to complete the task 'i'. If the students are unable to properly accomplish the task, time will be counted down from that point until the students give up. The efficiency construct measure based on the overall Relative efficiency is displayed in Table 6. Following is how the overall efficiency was determined:

=(1*900+1*600+1*900+1*600+1*600+1*900+1*1200+1*900+1*900+1*900+1*900+1*900+1*900+1*1500+1*1200) x 100%
(900+600+900+600+600+900+1200+900+900+900+900+900+900+1500+1200)
= 100%

This is how the Time Based Efficiency is determined:

$$\text{Time Based Efficiency} = \frac{\sum_{j=1}^{R}\sum_{i=1}^{N} \frac{n_{ij}}{t_{ij}}}{NR}$$

Time based Efficiency =
=
(1*900+1*600+1*900+1*600+1*600+1*900+1*1200+1*900+1*900+1*900+1*900+1*900+1*900+1*1500+1*1200) (1*15)
= 920 (goals/seconds) / 15.33 (goals/minutes)

Table 6: Overall Relative Efficiency to Complete Task Efficiency Construct

Learner	Time taken to complete the Task (minutes)	Time taken to complete the Task (seconds)	Time based Efficiency	Overall Relative Efficiency
S1	15 minutes	900	Time<=920s	100%
S2	10 minutes	600	Time<=920s	100%
S3	15 minutes	900	Time<=920s	100%
S4	10 minutes	600	Time<=920s	100%

S5	10 minutes	600	Time<=920s	100%
S6	15 minutes	900	Time<=920s	100%
S7	20 minutes	1200	Time>920s	100%
S8	15 minutes	900	Time<=920s	100%
S9	15 minutes	900	Time<=920s	100%
S10	15 minutes	900	Time<=920s	100%
S11	15 minutes	900	Time<=920s	100%
S12	15 minutes	900	Time<=920s	100%
S13	15 minutes	900	Time<=920s	100%
S14	25 minutes	1500	Time>920s	100%
S15	20 minutes	1200	Time>920s	100%

Based on the results of the cognitive walkthrough study was determined that Time Based Efficiency measures 15.3 seconds of the time needed to complete the activity by the dyscalculic learner. In terms of the total time taken to complete the exercises, the overall relative efficiency of the fifteen (15) dyscalculia students demonstrated that 100% of them finished the tasks effectively. The assignment was attempted by three (3) dyscalculia learners (L7, L14, and L15) as can be shown, however they took longer overall to complete it than the other dyscalculia learners.

When using the tangible method, children were more engaged and had more fun. The severely disabled youngsters enjoyed using their interactive physical system. It is supported as based of Fan et al. (2017) discovered that the majority of students enjoyed utilising the physical application and wished to do it once more. Additionally, the current study showed that all students used the application and the physical objects without any trouble. Through the informal and cognitive walkthrough, none of them encountered any challenges that led to a successful outcome. Children can readily comprehend how to utilise the AR application, according to Antle et al. (2011). They had no trouble using the AR application during the learning phase. Additionally, claimed that users with learning difficulties picked up on the application rapidly. According to these, it was discovered that the kids said the AR tangible technology was simple to use.

V. CONCLUSION

For the current analysis to find the theoretical gaps that are relevant, prior literature was essential. The study covered topics such as the identification and early detection of dyscalculia students, the approach field of Augmented Reality (AR) in education, the advantages of Augmented Reality technology for learning tangible user interface (TUI), application development principles, usability inspection and usability testing. It also covered the approach of behaviourist theory and cognitivist theory underpinning the use of Augmented Reality (AR) assistive learning technology for dyscalculia students. To uncover components suited for teaching and learning the fundamentals of mathematics for dyscalculia learners utilising AR technology, the theoretical gap between cognitivist and cognitive learning theories was examined. In order to design and develop an AR learning application that can truly meet the needs of dyscalculia learners taking into account their learning difficulties, important components such as an integrated design and development LD application model that incorporated with the Iterative-Evolution model and the Human-Computer Interaction (HCI) development model.

The other aspects that need to take into consideration as the suitable for dyscalculia learners; the pedagogical approach in relation to visual materials and visualisation due to the preferred approached of dyscalculia learners in learning mathematics particularly the abstractive aspects of mathematics, where there is need for them to visualise. Therefore, the more attributes of dyscalculia learners are known, the more accurate would be the design of the learning application for them. A cognitive tour is a technique for testing usability that is geared towards novice users and involves the examiner completing a number of task scenarios. Learn ability and efficiency are amidst the usability testing components.

REFERENCES

[1] Ariffin, K, Halim, N. A., & Darus, N. A. (2020). Discovering Students' Strategies in Learning English Online. Asian Journal of University Education (AJUE), 17(1), 261-268.
[2] Antle, A. N. 2007. The CTI Framework: Informing the Design of Tangible Systems for Children 15–17.
[3] B. Shackel. 1990. Human factors and usability. In Preece (pnyt.) & Keller (pnyt.). Human Computer Interaction: Selected Readings., hlm.27–41. London: London: Prentice Hall.
[4] Booth, P. 1989. An introduction to human-computer interaction. London: Lawrence Erlbaum Associates.
[5] Fatih Nayebi; Jean-Marc Desharnais; Alain Abran (2012). The State of The Art of Mobile Application Usability Evaluation.
[6] Gresse von Wangenheim, C., Witt, T. A., Borgatto, A. F., Nunes, J. V., Lacerda, T. C. Krone,
[7] C. & Souza, L. de O. 2016. A Usability Score for Mobile Phone Applications Based on Heuristics. International Journal of Mobile Human Computer Interaction, 8(1), 23–58.
[8] Stone, D., Jarrett, C. & Minocho, M. 2005. User Interface Design and Evaluation. Amsterdam: Elsevier.
[9] Smith, C. & Mayes, T. 1996. Telematics Applications for Education and Training: Usability Guide. Commission of the European Communities.
[10] Rubin, J. 1994. How to plan, design, and conduct effective tests. Handbook of usability testing:,. New York: John Wiley & Sons.
[11] ISO 9241. 1998. Software Ergonomics Requirements for Office Work with Visual display
[12] Terminal (VDT). Geneva Switzerland.
[13] Nielsen, J. 2000. Why you only need to test with 5 users.
[14] Nielsen, J. 2001a. Ten Usability Heuristic.
[15] Nielsen, J. 2001b. Success Rate: The Simplest Usability Metric. Jakob Nielsen's.