SCREENING TEST ON DYSCALCULIA LEARNERS TO DEVELOP A SUITABLE AUGMENTED REALITY (AR) ASSISTIVE LEARNING APPLICATION

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ABSTRACT

Dyscalculia refers to persistent difficulty in learning Mathematics without being aware of the condition. Such a condition is not easily detected and most of them would be left undetected, apart from being labelled as lazy or slow learners. Early delay places them behind in acquiring other fundamental areas of Mathematics. As such, this study identified learners suffering from dyscalculia (also known as acalculia) through screening tests for early intervention. The methodology used in this study was based on two screening tests (ST1 and ST2) conducted on learners to identify 'student areas' or their specific type of dyscalculia using the Dyscalculia Screening Test Instrument (DSTI) and verification of the specific types made by selected expert teachers, respectively. An early identification study on suitable assistive learning technology for these learners was performed. Prior studies reported that suitable assistive technological tools can improve the learning process of those with learning disability (LD). The findings displayed the effectiveness of the screening tests (ST1 and ST2) in detecting learners with dyscalculia, particularly in areas related to memory, abstraction, sequencing processing, motor, and visual perception. The results derived from plausible assistive digital technology revealed that visual-based fusion technology, such as Augmented Reality (AR), exposed the dyscalculia learners to experiential learning approach that made learning Mathematics meaningful.

Keywords: Visual-based Fusion Technologies, Assistive Learning Aid, Dyscalculia Screening Test Instrument (DSTI), Augmented Reality (AR)

1.0 INTRODUCTION

Screening tests carried out on dyscalculia learners for early intervention is crucial in schools. This is to ascertain that learners can be supported by the right kind of teaching and learning aids generally, and suitable digital assistive technological aid specifically. Dyscalculia refers to the difficulties faced by learners in comprehending numerical concepts and basic arithmetic. Dyscalculia is one's inability to acquire suitable competency in Mathematics and the inability to form Mathematical relationships successfully [1]. Dyscalculia derives from a Greek term 'dys' that means 'badly' and a Latin word that means 'to count'. Putting these two words together reflects 'badly count' or 'inability to count.' Some authors in the field have termed dyscalculia as acalculia, while some others have distinguished acalculia from dyscalculia. Acalculia is understood as the inability to calculate by the entire system of the learner, whereas dyscalculia is the inability of part of the system of the learner to calculate, hence resulting in the impairment of the entire system. Therefore, dyscalculia in a learner is due to a deficit in the intra-parietal sulcus (IPS) part of the brain [1]. There are types of learners based on their disabilities in the field of Mathematics such as Developmental Dyscalculia, Disabilities in Mathematical concepts, Difficulties in Specific Arithmetic operations, Disabilities in Learning Arithmetic and Acalculia.

One with difficulty to conduct Mathematical operations is labelled by others as having disability in Mathematics [33], [14] Disability in Mathematics usually occur due to various factors, such as lack of motivation, inappropriate teaching and learning strategies and approaches, unconducive classroom environment, as well as unsuitable teaching and learning tools [14]. If the listed factors are not the causes of a learner's disability in Mathematics, one may be experiencing a learning disability (LD) in Mathematics termed as dyscalculia. [47] had categorised six levels of dyscalculia based on varying terms, whereby a dyscalculia learner can be categorised by one, a few or all of the varied types of dyscalculia. This was agreed upon by many other researchers as well [38], [75] as presented in Table 1.

Table 1: Definition of the Different Types of Dyscalculia

Type of Dyscalculia	Definition of the different types of Dyscalculia
Verbal Dyscalculia, Aphasia acalculia	An individual who cannot understand numbers
Lexical Dyscalculia, Alexic Acalculia	An individual who does not possess literacy in Mathematics symbols
Graphical Dyscalculia, Agraphic Acalculia	An individual who cannot write Mathematics symbols
Operational Dyscalculia, Frontal Acalculia	An individual who cannot conduct operations and calculations in Mathematics
Ideognostic Dyscalculia, Anarithmetia	An individual who is unable to understand Mathematical concepts or do mental arithmetic
Practognostic Dyscalculia, Spatial acalculia	An individual who cannot make enumeration, manipulation, comparison or relation between objects and numbers

2.0 RELATED WORKS ON ASSISTIVE DIGITAL TECHNOLOGIES

Assistive digital technologies have been introduced to assist learners struggling with dyscalculia by helping them indemnify their deficient skills and abilities through use of various media, including voice, visual, virtual, and augmented, mainly because assistive learning helps dyscalculia learners to be self-reliant in their learning [12], [49]. Worldwide education experts have agreed that the integration of digital learning technology into the education curriculum of dyscalculia learners is imperative to enable democratisation and inclusivity of education for all [82]. Hence, digital learning technologies have been accepted as assistive learning tool to support learning amongst learners with dyscalculia disabilities.

Digital environment teaching approach, namely Computer Assisted Instruction (CAI), may embed suitable visual fusion technologies (e.g., Augmented Reality (AR) and gamification) to engage, motivate, and encourage dyscalculia learners with specific Mathematics disabilities [69]. Apart from CAI, many other emerging computer-based learning approaches may be employed for dyscalculia learners, such as Six Sifteo cubes [40], Adaptive e-learning [11], Apple Application IPhone Voice memo and Graper [61], Calculator Application [19], MathemAntics [20], and Calculating Aid Tools: KitKanit [21]. The listed approaches and technologies have significant strengths and preferences, as they all promote better learning performance and motivation for dyscalculia learners. Despite the availability of numerous digital fusion technologies in light of education purpose; in reality, teachers seem to face a range of obstacles. A study reported that more than 80% of the interviewed Malaysian teachers complained regarding lack of accessibility to the Internet and technical support to aid the teachers in case of computer breakdown (see Table 3).

As for web-based digital learning applications, many have been proposed for dyscalculia learners, for instance, Dots2Digit and Dots2Track [1], Number Race and Graphogame Math [26], Calcularis [24], and Number Sense [1]. These applications have significantly contributed to dyscalculia learners in acquiring Mathematical skills. Nevertheless, a study conducted across selected Malaysian schools revealed contradicting outcomes, as 60% of the teachers claimed that they faced barriers when using such applications due to limited technical and infrastructure support provided by the schools.

There are also emerging mobile digital learning applications that may be applied by teachers to teach dyscalculia learners, namely MathBoard [27], Long Division (Nagavalli & Juliet, 2015), Multiplication Genius, Flashcards to Go, Math Drills, and Multiplication [29], Go Play Ball and Go Road Trip [30], Go Math [31], and Calculic Kids [32]. These applications have been proven to assist dyscalculia learners in Mathematics in a more effective manner due to their user-oriented design that meets the needs of such learners. [32] proposed a mobile application prototype known as Calculic Kids that focused on number counting, object counting, addition, and subtraction using gaming strategies. It was developed to support dyscalculia learners learn Mathematics in schools across Malaysia. The study reported positive improvement noted in dyscalculia learners as they obtained correct answers during post-test, when compared to pre-test that employed the prescribed mobile fusion technology application. Besides, 80% of the

teachers felt that mobile devices, such as smartphones and tablets, have both short and long-term impacts on learning.

Other studies also displayed the effectiveness of virtual environment applications on dyscalculia learners, such as Hanoi Towers puzzle [33], Tom's Rescue [34], ICT-based dynamic assessment [35], [36]), and My vWallet [37], wherein positive results were obtained in light of both behavioural and cognitive theoretical assumptions. In the Malaysian context, another study found that 70% of the teachers felt that virtual environment technologies should be made more readily available and at an economical price that schools and parents can afford.

Only a handful of studies seemed to assess Artificial Intelligence (AI)-based technology or Intelligent Tutoring System (ITS) [38] and its related applications, such as Active Math [39], which is adaptive to the learners' individual achievement based on self-paced learning approach. This approach appears to be effective as learners can complete their Mathematical exercises more accurately and rapidly. This finding was echoed in a study conducted in Malaysia, whereby 20% of the sample teachers agreed that AI could assist individual dyscalculia learners more explicitly and accurately.

Gamification has been reckoned as a technology that is suitable in assisting dyscalculia learners. For example, an application known as disMAT [40] successfully improved the achievement of dyscalculia learners in Mathematics. Based on a study conducted in Malaysia, 60% of the teachers claimed that dyscalculia learners found gaming enjoyable. They opined that gaming can stimulate interest and excitement in learning Mathematics amongst dyscalculia learners.

Hence, the literature presents a range of assistive digital learning technologies that can assist dyscalculia learners overcome their Mathematics disability. Such technologies were developed based on both conventional multimedia technology and cutting-edge revolutionised fusion technologies, such as virtual reality (VR) and AR. These fusion technologies, if embedded into multi-dimensional digital environment, serve as future assistive learning aids for learners diagnosed with dyscalculia.

Learning Mathematics can be an unapproachable task for dyscalculia learners without suitable learning aids. [52] found that dyscalculia learners learnt better through instructive amusements and fun learning tools, as dyscalculia learners are attracted to virtual environment, visual stimuli, and flexible learning.

2.1 Augmented Reality (AR)

The AR technology was first used in the aviation industry for training purposes. After that, large manufacturing and engineering companies began adopting the AR technology to visualise and train skills that were dangerous and expensive to train otherwise. The existence of AR technology allowed new opportunities to innovate novel assistive learning aids that can integrate virtual and real world objects in a multi-dimension digital environment for both training and learning purposes [41], [42]. The AR technology psychometric tools have been applied as a VR rehabilitation approach for dyslexic and dyscalculia learners to learn abstractive concepts by seeing and manipulating virtual objects composited with the real world. Dyslexic and dyscalculia learners can manipulate AR objects by using either Tangible User Interaction (TUI) based on detection cards or magnetic pen; or Natural User Interaction (NUI) using finger or eye detection approach. These technologies have displayed a significant educational learning potential in this 21st century learning environment and many more future learning environments to come.

2.2 Advantages of the AR Technology

The advantages of the AR technology are vast. One of the main advantages of the AR technology is that it integrates the AR world with the real world based on the learner's experience. This means; the learners can attain a greater sense of realism present in the visual virtual environment that they are in. The AR learning aids pose as suitable interaction tools for constructivist discovery-based learning approach among dyscalculia learners. It allows errorless-based learning, where learners can make mistakes and still continue without fearing negative consequences. The other advantage of AR technology is the seamlessness that exists between the real and virtual environments that allow both TUI and NUI metaphors for object handling and manipulation. Gaze trackers using the AR technology, used in experiments to test its use with dyscalculia learners [41], are trends that will be seen more in the near future.

Teachers can help learners enhance their understanding of Mathematics by using learning aids embedded with AR technology [43]. These AR-based learning aids offer an experience for dyscalculia learners that goes beyond the formal classroom limits [42]. Most studies reported that AR-based learning aids assist dyscalculia learners to comprehend Mathematical concepts better and motivate them to learn. This is because; AR technology provides realistic content and allows learners to interact with it through user interface manipulation, which makes understanding of Mathematical concepts more concrete and meaningful. Dyscalculia learners are more engaged with the lessons as they use more than a stimulus and are open to more flexible learning paths [44].

2.3 Challenges of AR Technology based Learning Aids

The AR-based learning aids have been reported to possess some drawbacks. Any AR application meant for learning includes a vast amount of graphic and textual information that demand high-end computers and devices. Thus, the hardware used (e.g., desktop or hand-held devices) must have high-end capability to perform well. Since some high-end hand-held devices are not supported by certain hardware [45], it turns into a challenge for teachers when using AR in schools. The technical challenge that seeks the availability of accurate markers and tracking system tend to discourage teachers from using the AR technology as learning aids for dyscalculia learners. In order to ensure that the AR technology is suitable for dyscalculia learners, both hardware and software obstacles linked with AR technology for education purpose need to be addressed. Suitable software package for specific AR systems is crucial to ascertain that useful information is filtered, retained, discarded, and displayed in the best possible way [46].

2.4 AR Technology for LD Learners

The use of AR technology has been extensive to assist learners with LD. The ability to integrate virtual realm into and the real world to bring about a new learning environment has made learning more engaging and meaningful to LD learners, including those suffering from dyslexia, dyscalculia, and dysgraphia. The AR has been embedded in numerous applications for autistic learners, such as Sixth Sense for Autism, OxSight for visually-impaired learners, AR-based TextBook for LD learners, and AR-deaf for deaf learners. Since AR technology allows LD learners to visualise objects as in the real world and manipulate them via interaction, this technology is suitable for dyscalculia learners, as Mathematics is also a subject that requires visualisation and manipulation.

2.5 AR Technology and Dyslexia

Dyslexia is an LD related to literacy skills without affecting one's general intelligence [47]. Related studies on dyslexic learners revealed that AR learning aids substantially benefited the learners. In a study, the first phase was conducted by giving the students words to memorise within 90 seconds. The control group underwent the process without exposure to AR, whilst the experimental group was exposed to AR. The second phase tested them on writing out the words and letters. The study outcomes revealed that through the use of AR, the dyslexic learners were able to learn more easily and effectively [48]. In Hong Kong, KanHan Technologies Limited (KanHan) developed the first AR Learning Chinese characters application that comprised of five stories for dyslexic learners. Four stages were embedded in each story, whereby the learners must match the corresponding strokes of Chinese characters to move to the next level with the assistance of marker cards to access AR objects. This application successfully motivated the dyslexic learners to learn. In Malaysia, an AR application called AR-Baca was developed to help Down Syndrome learners acquire literacy skills [49]. Similarly, this AR book successfully engaged and motivated the learners to read in Malay. Both studies unravelled the effectiveness of AR technology as assistive learning aid for dyslexic learners [49], [50]. Dyscalculia is closely related to dyslexia, whereby the latter refers to difficulty of reading skills, whereas the former refers to difficulty of skills pertaining to understanding of symbols such as numeric in Mathematics. Both studies indicated that AR can be used by dyscalculia learners to slowly gain better attention in their learning process.

2.6 Comparative Analysis on Use of AR and Dyscalculia Learners

To date, no study has assessed the use of AR amongst dyscalculia learners. Most studies on AR usage, both locally and globally, focused on other types of LD learners, such as cognitive disabled learners (Autism and Trisomic), Dysgraphia, Attention Deficit Hyperactivity Disorder (ADHD), Developmental Disorder, Deaf, Down Syndrome, and Dyslexia. Table 2 presents the comparative analyses regarding the use of assistive technologies, such as AR, for various types of LD learners.

Table 2: Comparative Analyses on Use of AR for Different Types of LD Learners

Author/s	Learning Disorder / Field	Purpose of AR Use	AR apparatus Used	Hardware used				
				Smartphone and Tablets	Smart Glass and Headsets	AR Kiosk System	AR installation	Table top
[51]	Cognitive Disabled (autism and trisomic)	To introduce 2D and 3D plant entities in a simple and intuitive way for children via ARVe (AR applied to Vegetal field)	AR marker	No	No	No	Yes	No
[52]	Dysgraphia	To develop students' interest in writing and to assist in writing activity by providing help in spellings	AR Smart Glass over Smartphone	Yes	Yes	No	No	No
[53]	Learning Disabilities (Developmental delay, ADHD, Mild Mental Retardation)	To motivate learning Mathematics and to increase assimilation of knowledge	AR marker using table top design	No	No	No	No	Yes
[54]	Autistic Spectrum Disorder (Autism)	To engage students in science by connecting science vocabulary terms	AR Mobile Application	Yes	No	No	No	No
[55]	Learning, physical & developmental disabilities; communication, emotional & behavioural disorders; and deafness	To engage interest, as well as to increase motivation and memory retention in learning	AR Mobile	Yes	No	No	No	No
[56]	Down Syndrome	To explore utility in communication and learning	AR Mobile	Yes	No	No	No	No
[57]	Attention Deficit Hyperactivity Disorder (ADHD)	Focused on the effects on word recognition in learning Chinese literacy ability	AR Mobile Application	Yes	No	No	No	No
[58]	Dyslexia	To stimulate children's interest to learning Chinese language/characters and to strengthen their proficiency	AR 3D marker cards	No	No	No	Yes	No
[50]	Dyslexia	To improve school book, and to offer visual & auditory aid in exercises and reading activities	AR Mobile Application	Yes	No	No	No	No

Based on the analyses listed above, this present study assured that the attributes embedded into the AR prototype developed for dyscalculia learners were not only based on AR apparatus and hardware; but also incorporated the aspects of Human Computer Interface (HCI), namely immersive, thematic, guided exploration, and learning by mistakes, so as to meet the needs of dyscalculia learners.

3.0 METHODOLOGY

This study identified dyscalculia learners to ascertain user experience and requirements in order to successfully develop an effective assistive digital technology using AR. The methodology incorporated Screening Test 1 (ST1) and Screening Test 2 (ST2). The objective of ST1 is to identify the 'student areas' that distinguishes them into six types of dyscalculia: verbal dyscalculia, lexical dyscalculia, graphical dyscalculia, operational dyscalculia, ideognostic dyscalculia, and practognostic dyscalculia. The Dyscalculia Screening Test Instrument (DSTI), which had been administered to the students, was guided by the researcher. The screening test identified difficulties faced by the learners based on five components: visual perception and processing ability, sequential processing disability, abstraction disability, memory disability, and motor disability. Next, the objective of ST2 is to verify the type of Dyscalculia based on teachers' perception of the learners.

3.1 Screening Test 1(ST1)

The objective of ST1 is to identify the 'student areas' that distinguishes them into several types of dyscalculia by using the DSTI. The student areas were represented by five disability dimensions with their respective components. Table 3 presents these dimensions and their respective components.

Table 3: The Dyscalculia Screening Test Instrument (DSTI) used during ST1: Student areas based on dimension and components

No.	DSTI Dimension	DSTI Components
1.	Disability of dyscalculia learners in visual perception and processing	• Transpositions and omissions made when writing or copying numbers • Sense of time and direction • Reversals and isolations made while copying numbers
2.	Disability of dyscalculia learners in sequential processing	• Recalling number sequences • Reproducing sequential order on demand • Applying rules and formula in this dimension
3.	Disability of Dyscalculia learners in abstraction	• Application of Mathematical process to solve problem • Ability to recall details but not the main idea, as the ability emphasised is abstraction
4.	Disability of dyscalculia learners in memory retention	• Inconsistent auditory memory • Inconsistent visual memory • Inability to recall and recognise words
5.	Disability of dyscalculia learners in motor skills	• Difficulty in drawing • Difficulty in writing • Difficulties in expression using motor skills

The screening test was conducted on 50 Year Four primary school children (10 years old) from a government school situated in Selangor, which comprised of 34 boys and 16 girls. The students were selected based on their poor results in Mathematics scored during Mid-Term Examination 2017. [59] and Wilson and Dehaene (2007) found that a child with Mathematics disability can be identified from the age of eight years old. Specially developed instruments or tools have been used by experts to identify dyscalculia learners, such as the Butterworth Screener [60] available from GL Assessment, DysCalculiUM [61], and The Screening Test [62]. Since these screeners lacked reliability and validity, this study employed the DSTI prescribed by [63] with some amendments to suit the Malaysian dyscalculia learners and environment. The DSTI is composed of two parts; the demographic aspect of learners, and the 'students areas' with 20 specific items. The items were used to screen the difficulties faced by individual learners based on five disability dimensions, namely visual perception and processing disability, sequential processing disability, abstraction disability, memory disability, and motor disability. Table 4 lists the item numbers based on the components.

Table 4: Items in Dyscalculia Screening Test Instrument (DSTI) based on components

No.	Component	Item numbers	Total
1.	Visual perception and processing disability	1,5,13,18	4
2.	Sequential processing disability	8,12	2
3.	Abstraction disability	3,4,6,14,16	5
4.	Memory disability	2,7,10,15,17,19	6
5.	Motor disability	9,11,20	3

Table 5 lists the six types of Dyscalculia in DSTI; practognostic dyscalculia, verbal dyscalculia, lexical dyscalculia, graphical dyscalculia, operational dyscalculia, and ideognostical dyscalculia.

Table 5: Items in Dyscalculia Screening Test Instrument (DSTI) based on classification

No.	Type of Dyscalculia	Item numbers	Total
1.	Practognostic	8,11,14,15	4
2.	Verbal	2,4,5,14,16,17	6
3.	Lexical	7,10,13,19	4
4.	Graphical	1,7,9,18,20	5
5.	Operational	6,8,16,17	4
6.	Ideognostical	3,6,8,12,13	5

Table 6 shows the scores obtained by 56 Year Four students for their Mathematics performance during the Mid-Term Examination in 2017. A total of 46.7% of the students obtained grade E or failed in the subject. This signified that a screening must be performed amongst the students to detect the presence of dyscalculia learners amidst this group of low performance Mathematics students.

Table 6: Mathematics results scored in mid-term examination (2017)

No.	Grade	Number of Mathematics learners	Number of Mathematics learners in %
1.	A	4	7.1
2.	B	7	12.5
3.	C	8	14.3
4.	D	11	19.6
5.	E	26	46.4

The scale used in DSTI is suitable for the Malaysian school setting, easy to use, and inclusive. This tool serves as a guide for education professionals to identify learners suffering from dyscalculia. The Purposive Sampling approach was applied among the low achievers to select the study sample. Table 7 presents the items used to screen the learners.

Table 7: Identifying Dyscalculia learners based on student areas disability

No.	Statement
1	Sometimes when I see and write a number, I write it in the wrong place and I leave out some numbers.
2	I cannot remember even the most used phone numbers.
3	I do not always understand Mathematics rules and formula.
4	I am always confused in cash exchange. I always do not know how much money I have to give at shops.
5	I am always confused by the 24-hour clock.
6	I cannot always do minus operation when it involves large numbers.
7	Sometimes when I see + or – symbol, I do not know how to say it. If someone tells me it is divide, I cannot visualise its symbol.
8	One day, I can understand a Mathematical concept but the next day, I do not know anything about it.
9	I cannot write the number told by others in numbers.
10	I easily forget the name of shapes such as □ and Δ.
11	Even though I know the answer for a Mathematics calculation, I cannot explain how the results are obtained.
12	I get confused about the largest number between large numbers. For example, between 10000 and 9999.
13	It is very hard to understand time and direction.
14	I always do not know Mathematics if it involves distance. For example, how long will it take to cross 19 kilometres, if it takes 5 minutes for a person to cross 22 kilometres?
15	I cannot focus on all the steps when the Mathematics teacher teaches a calculation.
16	Sometimes I cannot solve a problem related to fractions.
17	I was able to complete all Mathematics exercises, but I failed in tests and quizzes.
18	I sometimes write 9 as P, 7 as L, 6 as 9, and 3 as E.
19	It is hard for me to memorise my multiplication tables.
20	I do not know how to draw geometric shapes, such as rectangles and triangles.

3.2 Screening Test 2 (ST)

The objective of ST2 is to verify the evaluation from the teachers and to gather their perceptions of the types of dyscalculia learners in their respective classrooms in the school. Fifteen teachers who were responsible to teach Mathematics for Years Four, Five, and Six had been selected from a government school situated in Selangor. The methodology applied in this part of the study had been based on a series of video clip presentations to enable the teachers to observe the behaviour of the learners in the classroom, so as to verify their dyscalculia types, along with an instrument for this verification purpose. The instrument was built based on prior knowledge and literature review. The questionnaire was divided into three main sections: demography, 18 questions on verification and perception of dyscalculia learners, as well as two open-ended questions.

4.0 RESULTS AND DISCUSSION

This section presents the results of both ST1 and ST2. Table 8 tabulates the outcomes of ST1 that looked into the difficulty dimension. The results of ST1 indicated the following difficulties: memory was M=1.54, SD=1.313; abstraction was M=1.24, SD=1.188; sequencing processing was M=0.52, SD=0.735; motor was M=0.52, SD=0.677; while visual perception and processing was M=0.38, SD=0.602. The findings retrieved from ST1 showed that learners with dyscalculia were confronted with difficulties mostly pertaining to numbers when it involved memorisation factor. This calls for a study to assess the working memory, so as to increase the ability of memorising among the learners. Not many studies have examined this particular difficulty dimension amidst learners, especially within the context of Malaysia, hence making it challenging for teachers to understand the problems faced by dyscalculia learners. The screening tests conducted on the selected learners offer several significant inputs to better handle dyscalculia learners.

Table 8: Screening Test 1 (ST1) Results on difficulty dimension

No.	Difficulty Dimension	Mean	Std. Deviation
1	Memory	1.54	1.313
2	Abstraction	1.24	1.188
3	Visual Perception and Processing	0.52	0.735
4	Motor	0.52	0.677
5	Sequencing Processing	0.38	0.602

As for the type of dyscalculia, Table 9 shows that practognostic dyscalculia obtained M=1.32 and SD=1.316, which reflects difficulties in manipulating concrete materials or enumerating numbers. Next, M=1.18 and SD=1.555 were obtained for operational dyscalculia, signifying those who experience difficulties in applying basic arithmetic operations and rules of Mathematics. Difficulties faced in Mathematics literacy on symbols and numeric categorised as lexical dyscalculia resulted in M=0.80 and SD=0.833. The scores for graphical dyscalculia, who experienced difficulties in writing Mathematics symbols, were M=0.80 and SD=0.833. Those with verbal dyscalculia scored M=0.74 and SD=0.922, as they faced difficulties in using Mathematics concepts orally and explaining Mathematical relationships. The results of ST1 indicated that M=0.60 and SD=0.857 of the learners had Ideognostical dyscalculia with difficulties in understanding Mathematical ideas and correlations.

Table 9: Screening Test 1 (ST1) Results on type of dyscalculia

No.	Type of Dyscalculia	Mean	Std. Deviation
1	Practognostic	1.32	1.316
2	Operational	1.18	1.555
3	Graphical	0.80	0.833
4	Lexical	0.80	0.833
5	Verbal	0.74	0.922
6	Ideognostical	0.60	0.857

After the screening tests were conducted to identify the types of dyscalculia learners, it had been essential to verify the outcomes with experienced learning psychologists and special education Mathematics teachers. Hence, ST2 was conducted. Table 10 tabulates the ST2 results based on the questionnaire prepared for the selected teachers to gather their perceptions, as well as to verify both the types of dyscalculia and the dyscalculia learners.

Table 10: Screening Test 2 (ST2) Results on Teachers' verification on Dyscalculia Learners

Item No.	Question	Yes (%)	No (%)
1	Are you aware about Dyscalculia?	12 (80)	3 (20)
3	Was dyscalculia discussed during your teaching training program?	2 (13.3)	13 (86.7)
4	Are you able to identify dyscalculia learners in your classroom?	6 (40)	9 (60)
5	Are dyscalculia learners related to dyslexia?	5 (33.3)	10 (66.7)
6	Dyscalculia learners may be able to solve Mathematical problems, such as 3+2=5. However, they are unable to solve the same exercise when presented in words. For example, Ali has three pens and Samy has two, how many do they have all together?	10 (66.7)	5 (33.3)
7	Dyscalculia learners have difficulty comparing objects using concepts, such as 'bigger or smaller' and 'more or less'.	10 (66.7)	5 (33.3)
8	Do dyscalculia learners get distracted only during Mathematics classes? Do they sometimes appear to be frustrated and anxious? Do they complain about the teaching materials used?	9 (60)	11 (40)
9	Dyscalculia learners face difficulty with measures involving weight, distance, and time.	12 (80)	3 (20)
10	Dyscalculia learners face difficulty with sequencing elements in dates, as well as cardinal and ordinal numbers.	12 (80)	3 (20)
11	Dyscalculia learners use their fingers to count and persist in using their fingers longer compared to their peers.	12 (80)	3 (20)
12	Dyscalculia learners show difficulty with numbers at an early age and they write certain digits in a reversed manner. For example, number 12 as 21 and vice versa.	10 (66.7)	5 (33.3)
13	Dyscalculia learners undergo numeracy development slower when compared to their peers.	12 (80)	3 (20)
14	Dyscalculia learners have difficulty telling time by reading the clock.	11 (73.3)	4 (26.7)
15	Dyscalculia learners have difficulty telling left from right and vice versa.	8 (53.3)	7 (46.7)
16	Dyscalculia learners have the tendency to interchange similar digits. For example, 6 and 9.	9 (60)	11 (40)
17	Dyscalculia learners may have negative attitude towards Mathematics homework as they do not like doing number work.	7 (46.7)	8 (53.3)
18	Do they complete their homework, when they are given Mathematics tasks to do at home?	4 (26.7)	11 (73.3)
19	Throughout your teaching career, have you confronted different types of dyscalculia learners?	11 (73.3)	4 (26.7)
20	The DSTI screening results on dyscalculia learners are similar to those screened by us; they display similar student areas difficulty.	14 (95)	1 (5)

The ST2, which had been based on the video clips of learner behaviour in the classroom, indicated positive results as they match the results retrieve from ST1. The ST2, which was conducted on experienced teachers with learning psychology and special education backgrounds, was able to verify and match the findings obtained from ST1 using the DSTI. This was further verified in item 20 of the questionnaire administered during ST2, wherein the results were retrieved after viewing a series of video clips pertaining to the behaviour displayed by dyscalculia learners.

In order to better understand the perceptions of teachers regarding dyscalculia learners in Malaysia in light of ST2, some items of the questionnaire are discussed in the following:

For instance, Item 2 of ST2 (Give your definition of Dyscalculia) showed that most teachers (58.3%) defined dyscalculia as a problem faced by learners related to difficulty in understanding arithmetic or numeracy, while only a few (23%) stated that these learners have difficulty understanding numerical functions, calculation, and the concept of numbers. Based on the answers provided by the teachers, one can infer that most teachers can broadly define dyscalculia learners and there is a need to highlight specificity when defining dyscalculia learners based on their dyscalculia types, so that suitable intervention may be applied to the learners.

As for the following question, "based on questions 6 to 18, can this student be classified as a Dyscalculia learner?", the findings showed that most teachers (80%) answered "maybe", while 13.3% answered "yes", and a minority (6.6%) answered "no". The findings revealed that merely using a screening test, such as ST1, may not be helpful in labelling the learners. Hence, teachers also need time to work with the learners to actually verify and classify them as dyscalculia learners.

In Item 21 (In your opinion, which topic in the primary Mathematics curriculum is difficult for learners?), most teachers (66.7%) opined fraction as the most difficult topic, followed by multiplication (20.0%), and division (13.3%). Thus, one can infer that the difficulties faced by dyscalculia learners may differ from one learner to another and there is no 'one fix for all' remedy. Teachers will have to know the dyscalculia type of learners to ascertain the topics that specific dyscalculia type of learners will face difficulty. Generally, the ST2 conducted on teachers with special education background and experience, was able to verify students who were identified as dyscalculia from ST1 using the DSTI.

From both the screening tests (ST1 & ST2), it is clear that dyscalculia is a disorder that is as common as other learning disorders amongst Malaysian learners. Early detection of dyscalculia learners is crucial, mainly because early intervention is bound to help these learners overcome their problems way earlier through adoption of suitable assistive learning tools. The study results have several educational implications. One important implication is for the Ministry of Education to look into the various early intervention strategies to detect students with different types of dyscalculia to enable suitable intervention to be conducted on these students. This ascertains that learners can better understand the fundamental concepts of Mathematics at an early stage of their school experience, rather than later stage of their learning experience when the concepts learnt are more intricate.

The study findings showed that all the different dimensional disabilities need to be screened as early as possible. This is because; each individual dyscalculia learner with different dyscalculia type may have different perceptions and may require a range of strategies of learning with varied assistive digital learning materials specially prepared for them as they have to be personalised to meet their unique needs. A well-designed digital learning material that is suitable for dyscalculia learners would help dyscalculia learners to strengthen their spatial short-term memory skills in real life.

5.0 IDENTIFYING ASSISTIVE TECHNOLOGY FOR DYSCALCULIA LEARNERS

The initial identification of possible assistive technology that can help dyscalculia learners screened through ST1 and ST2 is imperative so that appropriate technologies can be selected, customised, and adjusted to suit the specific needs of the type of dyscalculia learner. Table 11 shows the results of the interview conducted to identify early and appropriate remedial intervention [64] assistive learning technologies, such as AR, to help dyscalculia leaners overcome their disabilities. An early intervention on dyscalculia learners by adopting appropriate assistive learning aids using the AR technology may minimise the effect it would have on dyscalculia learners later in life [65].

Table 11: Identifying Assistive Learning Aids for Dyscalculia Learners

Item no.	Comments on interview with teachers	Percentage (%)
1.	Teachers are ignorant of the levels and types of dyscalculia. They need help to develop different types of learning aids for the different types of dyscalculia learners.	85
2.	Teachers lamented on the constant lack of internet access and technical support in schools. Therefore, they feel that assistive learning aids in schools must be backed by good infrastructure and technical support.	80
3.	Dyscalculia learners need to see numerical concepts in concrete form and not in abstractive form. The AR would be useful to teach these learners.	80
4.	Mobile devices are an excellent choice of medium for learning. Any AR assistive learning aid that can be integrated with mobile devices can be effective for learning. Integrating AR would also be effective in teaching dyscalculia learners to understand numbers and numerical concepts in a more concrete manner.	80
5.	Mobile technology using AR assistive learning aids should focus on short and long-term impacts on learning for dyscalculia learners.	20
6.	Virtual learning environment using AR technology is costly for most schools.	70
7.	The use of AR technology as an assistive learning aid is positive as dyscalculia learners can be seen to bring their i-pads and smart phones to school in search for education and entertainment elements in the internet.	20
8.	Gaming technology is ineffective in helping teachers to improve dyscalculia learners' understanding of Mathematics.	40
9.	Gaming learning aids that used AR technology with 3D objects can be very effective and fun for dyscalculia learners to understand Mathematics concepts as they can understand better through use of concrete objects.	80
10.	Teachers have not used AR technology but they know it is costly. They also know that AR is difficult to integrate with most other learning systems.	85

Note 30 Teachers were the samples interviewed during this study*

6.0 CONCLUSION

One can conclude that Dyscalculia is a numeracy disability in learners that can be screened to determine the type of dyscalculia and to identify suitable assistive learning technologies, for early intervention in order to help them overcome their disability. Based on the literature review and the study findings, it is safe to conclude that assistive digital learning aids, such as AR applications, have the potential to make learning more meaningful through use of digital objects and diagrams, which make concepts look more concrete, as well as make learning fun and entertaining. The first part of this study involved two tests (ST1 and ST2); the former was conducted using the DSTI, while the latter was based on a questionnaire administered to the teachers for verification and to gather perception of the teachers on the students who were tested. Both the tests were compared to see if they matched. The students who were selected using both tests seemed to match. The selected students were chosen as 'users' to participate in the digital assistive learning application that will be developed. The specifications shall be based on their specific dyscalculia disabilities. The study also looked into the type of digital assistive learning application. The literature review and the interviews conducted with teachers revealed that AR-based assistive learning aids via mobile devices have the potential to support dyscalculia learners in learning Mathematics. This is possible by placing focus on increasing the retention of short and long-term memory among dyscalculia learners with the help of visual support.

7.0 FUTURE WORK

Very few studies have applied screening instruments to identify and select specific types of learners suffering from dyscalculia, in order to develop suitable assistive learning aids. Our future work shall look into improving the Dyscalculia Screening Test Instrument suitable for Malaysia (DSTIM), to be incorporated as part of the software development process for LD learners, specifically for Dyscalculia. Our future work embeds software engineering process into the AR visual-based assistive learning aid to be used by specific types of dyscalculia learners.

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