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Evaluation Of Visual Based Augmented Reality (AR) Learning Application (V-ARA-Dculia) For Dyscalculia Learners

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***Abstract*— The rapid growth in technology have affected processes in various domains such as business, healthcare, agriculture and education. Computer related applications used in these domains are available so easily, that it is impossible to imagine a situation without them. Technologies that were available but hardly commonly used a few decades ago such as Virtual Reality (VR) and Augmented Reality (AR) have now become technologies that are fast gaining interests in most fields including service related1 fields such as healthcare and education. The basic idea of AR is to superimpose sense enhancements over a real-world environment. It is a perfect solution for learners with learning difficulties as it combines the advantages of multi senses of the learners, helps them to understand learning better when the integration of both virtuality and reality is embedded in their learning applications. AR is mostly effectively used when computer generated visual enhancements are integrated into real life applications. Thus, this paper highlights the evaluation of the visual-based AR learning application to investigate its plausible assistive functions that can help dyscalculia learners learn Mathematics in a more meaningful way. Findings of the study showed that the students who had difficulties on memory, abstraction, sequencing processing, motor and visual perception, found the visual-based Augmented Reality (AR) technology embedded in an application, a positive assistive learning application that can help dyscalculia learners learn mathematics more effectively.**

***Keywords*— Dyscalculia, Mathematical Difficulty, Visual based learning application, Augmented Reality (AR), Usability engineering.**

I. INTRODUCTION

Numerical processing is a state of high level cognitive process which has to be further explored by neuroscience because of the multifaceted nature associated with it. It is difficult to characterise a specific mathematical learning disability such as dyscalculia. For difficulties present in dyscalculia, efforts are being made to identify and define what dyscalculia really is. The pioneer researcher on dyscalculia was Kosc, who initiated his work based on a neuropsychological definition of development dyscalculia (DD) (Kosc 1974). His perception was that dyscalculia is "a difficulty in mathematical performance resulting from the impairments to those parts of the brain that are involved in mathematical processing without a concurrent impairment in general mental function" (Kosc 1974). This definition is yet to be utilised fully by researchers in cognitive neuroscience when characterising dyscalculia. Dyscalculia is generally defined by most researchers as a specific learning disorder that is characterised by persistent impairment in processing numerical information and learning arithmetic facts (American Psychiatric Association 2013). According to Cowan and Powell (2014), a mathematical learning disability is acknowledged to be the same construct as a mathematics disorder (American Psychiatric Association 2013). Further, Kucian, & Aster (2015) defined dyscalculia as a "specific learning disability affecting the development of arithmetical skills" and "a heterogeneous disorder resulting from individual deficits in numerical or arithmetical functioning at behavioural, cognitive or neuropsychological and neuronal levels." Consequently, almost all researchers in the field emphasised that the individual who suffers from dyscalculia are generally underachievers based on standardised tests undertaken according to their age, education and intelligence. They would also experience disruptions to their academic achievements as well as day to day living. Standardised tests generally test a range of skills, which may include spatial and verbal activities, before integrating the total test into one global score of 'mathematics achievement' (Landerl et al. 2004). In this study, a screening test was conducted to identify learners with symptoms of dyscalculia, in order that national primary schools can use to detect these learners for early intervention (this aspect will not be discussed in this paper as it is published in a previous paper).

II. Augmented Reality (AR) Application For Learning

This paper highlights the evaluation process that was undertaken to determine the plausible use of the visual-based Augmented Reality (AR) learning application for dyscalculia learners. AR technology enriches the real world with virtual representations to enhance visual perception (Sahin, & Uluyol 2016). Several benefits of the use of AR in education have been identified, including improved motivation and attention, smooth integration, accessibility, and creativity (Diegmann et al. 2015). AR is a relatively low cost innovation that can efficiently be utilised in educational settings. A promising AR can enhance learning and teaching and are evident in various past works (Abas 2018; Billinghurst, & Dunser 2012; Diegmann et al. 2015; Dunleavy, Dede & Mitchell 2009; M.Garrett, Jackson & Wilson 2015; Periasamy 2013; Nor Hasbiah Ubaidullah 2007) AR interfaces have a potential for human senses than present learning paradigms. By complementing human associative information processing, and aiding information integration through sensory elaboration by utilising visual-spatial, verbal, proprioceptive, and tactile memory while the learner is performing the knowledge acquisition tasks, AR is creating increasing amounts of elaboration on the subject material (Yilmaz 2016). In other words, the increased number of memory channels over present forms of instruction allows for a greater chance of the information to be encoded properly and retained in long-term memory. The appropriate encoding of information enormously affects whether the information will be effectively and efficiently retrieved when it is needed in the real environment (Safar et al. 2017).

In addition to incorporating multiple memory channels, AR learning is aided by two other distinct advantages. These advantages stem from using the real world environment as the learning environment. Past literature has shown that retrieval and recall of learned information is most effective when the similarities between the learning environment and the task environment are maximised (Thornton et al. 2012). AR environment, by overlaying the annotations and graphics on the real world, optimises similarity effectiveness by using identical environment for acquiring knowledge and applying that knowledge, thus, promoting retention of learned information and successful retrieval of learned information during real world tasks.

The second advantage is that AR incorporates visual-spatial ability that are commonly known as spatial cognition. Spatial cognition is associated with the representations of spatial information, such as location in memory. The use of this type of information has been found to be an extremely powerful form of elaboration for setting up associations in memory, not to mention that spatial information is automatically processed when visual scenes are encoded into long-term memory (Majoros et al. 2002). Therefore, when knowledge acquisition takes place in an AR system, most, if not all the information will be encoded with an associated spatial cue obtained due to AR's use of the real-world as the learning environment. These spatial cues are highly effective mnemonic devices (Thornton et al. 2012). This has been evident by previous past research that has shown knowledge of the spatial location, or cuing of spatial location dramatically improves recall of the semantic content (Sommerauer, & Müller 2014)

Recent technological advances in mobile computing have also made it possible to develop mobile AR systems rapidly. In an educational setting, AR can be used as a cognitive tool that places the learner within a real-world physical and social context while still facilitating participatory and metacognitive learning (Dunleavy et al. 2009; Sungkur, Panchoo & Bhoyroo 2016). AR in education supports interactive learning, simplicity, contextual information acquisition, efficiency and effectiveness, interpretation skills, as well as creativity (Sungkur et al. 2016). AR has the abilities to give users the kind of experiences they crave such as exciting, useful, usable and meaningful. An appropriate instructive condition for helping or advancing learning exercises outside the classroom can be given utilising through portable innovations of AR (Hussain et al. 2016). This idea has been seminared in education in the future (Hussain et al. 2016; Nor Zuhaidah Mohamed Zain et al. 2013).

AR has an inspiring potential to deliver experiential and location-based learning to Learning Disabilities (LD) learners, including dyscalculia learners by supplementing existing worlds rather than creating new ones. In keeping up abreast with the fourth industrial revolution (4IR) and Industry 4.0, AR is applied in all sectors, manufacturing, health, education and also applied in diverse learning disabilities. AR has a great possibility to enhance the living of those with learning disabilities (LD). As a result, intuitive tooltion capabilities of bringing the displaying context connected to digital learning has been introduced to engage dyscalculia learners in learning more readily. Currently, there a few promising evidence based studies on AR intervention for learners with symptoms of dyscalculia (Antonioli et al. 2014; Walker et al. 2015).

III. Methodology

The methodology used on the evaluation of the visual-based Augmented Reality (AR) application (V-ARA-Dculia) focused on the topic of Fraction, involved two types of evaluation: (i) Formative evaluation and (ii) Summative evaluation. Formative evaluation involved heuristics evaluation through expert testing which involved the testing of user interface, instructional materials, and the AR interaction of the application/prototype. Formative evaluation also involved the iterative evaluation of the application during the design and development phase that took place three (3) times iteratively, before the final evaluation of the application took place at the summative evaluation. The summative evaluation involved usability testing by the end-user or the dyscalculia learners themselves.

The validity of the content related to the topic Fraction, and modules as well as the sub-modules suitable for dyscalculia learners were verified by five (5) experts in the field of Special Education and Mathematics. The experts were teachers with special needs education expertise and teachers teaching mathematics in elementary schools. The experts evaluated the content, modules and sub-modules, and reported on the working prototype application. The working prototype application was revised and then enhanced based on their reviews and also the needs requirement of one dyscalculia learner that was selected to help in the iterative evaluation as an active participant in the design and development process of the learning application. The experts conducted a heuristics evaluation and validated the prototype application based on an instrument provided (V-ARA-Dculia:HE). This process involved the use of two instruments (i) Questionnaire on Formative Evaluation by expert (V-ARA-Dculia: HE1) and Formative Evaluation Problem Report (V-ARA-Dculia: HE 2). An interview session was conducted with the experts to verify and further enhance the findings of the heuristics evaluation based on the questionnaire. Upon completion of the validity exercise by the experts the modules and sub-modules were implemented and integrated into the system, ready to be used by the dyscalculia learners. The validity of the learning application V-ARA-Dculia was conducted at the summative evaluation based on a usability testing which involved five (5) constructs: learnability, effectiveness, efficiency, ease of use and confidence of dyscalculia learners when using V-ARA-Dculia.

3.1. Sampling

The sample size of the usability testing was 15 learners identified to have symptoms of the dyscalculia from the national primary school, selected based on purposive sampling to undergo the usability testing. These were learners identified as learners with symptoms of dyscalculia screened through the screening instrument (DYScrin), which consists of aspects on Mathematics Learning Ability and Mathematics Learning Performance. The number selected is suitable due to the fact that Nielsen (2006) states, for usability testing, a sample of three (3) to five (5) people is sufficient to carry out usability tests as 80% of the total usability problems can be detected with just three users to test. According to Nielsen (2006) too, the usability test does not require large samples because the number of users to test more than three people does not affect the discovery of the usability error of an application. Even according to Barnum et al. (2003) and Nielsen (2000; 2006), increasing the number of samples not only increases the cost but extends the testing time of an application. However, Johnson and Schleyer (2003), recommend that five (5) to six (6) learners would be better for usability evaluation. Although from Burton's (2006), Neilsen's and Halimah's experience (2009), usability test results can have better results of about 95% - 98% of problems detected with more than twelve (12) to fifteen (15) users . Thus, based on previous studies, a total of fifteen (15) learners were thought sufficient as samples to test the usability of the visual-based Augmented Reality (AR) learning application for dyscalculia learners.

3.2. Design of Heuristics Evaluation

The heuristics evaluation was an informal approach to discover usability issues by gathering feedback from experts about the user interface, related to layout, user interaction, and work process. The user experience and information experience are connected, checking one aspect of the application that lead to identifying issues in the other. The heuristics evaluation was based on the working prototype application, which made this an effective and low-cost method for gathering feedback throughout the development cycle of the AR learning application for dyscalculia learners. The experts recruited for heuristics evaluation were not necessarily usability experts but they have some level of expertise with the subject matter or technology required to use the application.

The design heuristics was concerned with the user interface design, learner-centred design, learner preferences and abilities. The design heuristics was a crucial aspect to as undertake dyscalculia learners do not want to struggle with the application just because they are not interested in the user interface. It should also take into consideration the mental and physical ability of the learners. Therefore, the user interface should be very natural and intuitive for dyscalculia learners based on their abilities and characteristics.

IV. Findings

4.1. Formative Evaluation: Heuristics Evaluation (HE 1)

Heuristics Evaluation during the formative evaluation was conducted with five (5) experts to gain their insights and perceptions regarding the content of the modules developed. The evaluation involved three (3) variety of instruments: heuristics evaluation using questionnaires; heuristics evaluation problem report and interview session. The heuristics evaluation on interface design is as indicated in table 1

TABLE I
FORMATIVE EVALUATION: HEURISTICS EVALUATION ON INTERFACE DESIGN

Scale	Explanation	(%)
0	I do not agree that there is an interface problem at all	99.23
1	Cosmetic problem only exist need not be fixed	0.77
2	Minor interface problem: fixing this should be given low priority.	0
3	Major interface problem: important to fix, so should be given high priority.	0
4	Interface design catastrophe: imperative to fix this before product can be released.	0

Based on Table 1, majority of the experts (99.23%) agreed that the application do not have any interface problem .

TABLE II
FORMATIVE EVALUATION: HEURISTICS EVALUATION ON LEARNING MATERIALS

Scale	Explanation	(%)
5	Strongly Agree	80
4	Agree	20
3	Neutral	0
2	Disagree	0
1	Strongly Disagree	0

Table 2 shows findings on sub-items of instructional materials designed based on: effectiveness with the scale of strongly agree and agree. Results show that the experts strongly agree (80%) and agree (20%) on effectiveness of the learning materials on the topic, Fraction embedded in the prototype application V-ARA-Dculia.

Heuristics evaluation on Interactive Design in Augmented Reality (AR) majority of the experts strongly agreed (72%) and agree (28%) on the effectiveness of the interactive design in AR. This indicates that there was no serious problem with the interactive design in AR for the visual-based AR the prototype application for dyscalculia learners as indicated in Table 3.

TABLE III
HEURISTICS EVALUATION BASED ON INTERACTIVE DESIGN IN AR

Scale	Explanation	(%)
5	Strongly Agree	72
4	Agree	28
3	Neutral	0
2	Disagree	0
1	Strongly Disagree	0

4.2. Formative Evaluation: Heuristics Evaluation Problem Report (HE: 2)

The experts were required to evaluate the working prototype through the expert experience measured on the attributes of user interface design, instructional material design and interactive design in AR environment. Their findings were reported in the Heuristics Evaluation Problem Report (HE: 2). The feedback from the experts are as shown in Table 4

TABLE IV
HEURISTICS EVALUATION PROBLEM REPORT ON USER INTERFACE DESIGN, INSTRUCTIONAL MATERIAL DESIGN AND INTERACTIVE AR

Expert	Type of Problem	Proposed Improvement
Expert 1	AR learning interface navigation problem.	Have a home button navigation button and reset button to improve navigation of application for ease of dyscalculia learners
Expert 2	Different shapes applied in examples such as square, circle, triangle and triangle to explain the construct of Fraction.	Use uniform shape in tutoring and quiz session as examples for better understanding and allow dyscalculia learners to imagine.
Expert 3	Material content tend to be to wordy. San Serif font not appropriate and unfamiliar with elementary school learners especially dyscalculia learners. As an example, the alphabet a and g.	Use simple text approach. Suitable to use Comic Sans.
Expert 4	AR marker is over-decorated. May confuse the dyscalculia learners.	AR marker should be simple and use soft colours suitable for dyscalculia learners.
Expert 5	Q-Minda questions in range for average dyscalculia learners.	Q-Minda should be kept simple for difficulties learners especially dyscalculia learners.

4.3. Formative Evaluation: in-depth interviews

In-depth interviews were conducted to enhance and support the findings conducted earlier based on the heuristics questionnaires. The interviews were conducted with five (5) experts to gain their insight and perceptions on the learning modules and sub-modules of the visual based Augmented Reality (AR) learning prototype application, V-ARA-Dculia. A summary of their comments were grouped into six (6) dimensions. Each dimension were discussed in detail with the experts. The findings are as shown in Fig. 1.

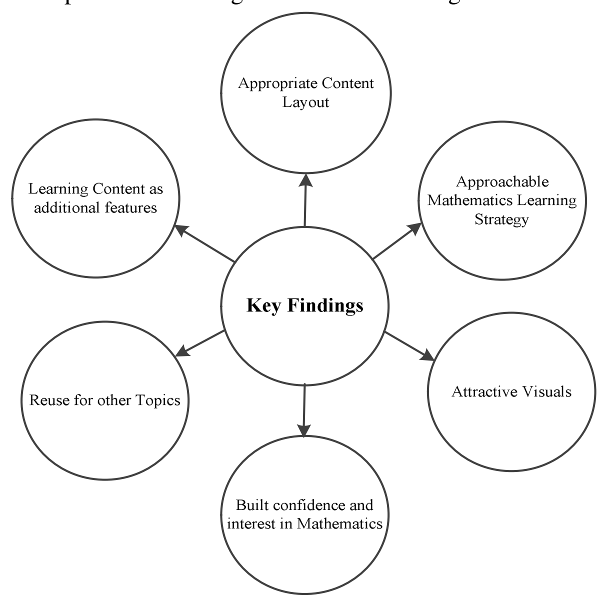

Fig. 1. Key Findings of In-depth Interviews

A. Approachable mathematics learning strategy

Based the in-depth interview, it was found that the learning strategy used was suitable for dyscalculia learners. Majority of the experts agree that the learning strategy used in the modules developed were capable in helping dyscalculia learners learn mathematics. However, there were experts who felt that more approachable strategy could be used to engage dyscalculia learners in learning mathematics. Some of the comments that were related are as follows:

" I think the current application is. Very very suitable and it is very approachable to our students".

Source: [Expert 1]

"The current develop application is appropriate enough because it considers the elements and features that are suitable for primary school students in learning mathematics"

Source:[Expert 3]

"should introduce more interactive strategy. More AR is good because interactive".

Source: [Expert 4]

" use more visual strategy and less text to explain the problem…"

Source: [Expert 5]

These findings support past research that emphases in the use of visuals to help dyscalculia learners learn mathematics. However, the visuals should not allow confusion when used to represent numbers. The findings also support the benefits of Augmented Reality (AR) technology. The use of AR technology in learning mathematics have shown to make dyscalculia learners more active and engaged in their learning.

B. Appropriate content layout

The seemed entity in the key finding of the in-depth interview conducted was appropriate content layout. Experts in the study agree that the content layout was suitable in helping dyscalculia learners learn mathematics. Among the extract quoted from the experts are as follows:

"The current develop application is appropriate enough because it considers the content elements and features that are layout suitable for primary school students in learning mathematics."

Source : [Expert 3]

"Yeah.the...arrange.. the..application the arrangements...are appropriate. And it's... err. It's really suitable...for the students and dyscalculia learners"

Source: [Expert 2]

"Yes, I agree. The arrangement and the delivery of the application content are very appropriate for the learning of dyscalculia learners."

Source: [Expert 1]

Hence these finding, support past study with regards to the interview which found that appropriate content layout was important in the process of learning mathematics for learners with disabilities including dyscalculia learners. Past studies also highlighted the ability of AR to ensure a well arranged content layout so that interaction with AR markers can be conducted with ease. This is also one of the reasons why the content elements layout of V-ARA-Dculia was found to be effective and engaging for dyscalculia learners.

C. Attractive visuals

The third dimension in the key findings of the in depth interview conducted was attractive visuals used in V-ARA-Dculia. Findings of the interview highlighted that attractive visuals were important in the learning modules, as it helped dyscalculia learners to gain attention and understanding of the mathematics concepts to be learned. An expert, (Expert 1) emphasised on the attractiveness of the modules in terms of colour distribution and interesting photos, pictures and graphics used which were related to everyday life. This was supported by Expert 4 and Expert 5 in the interviews conducted. The extracts of their comments are as follows:

"Yes it's very very likely visually attractive it's suitable colors and image"

Source: [Expert 4]

"Attractive..because of it errr It's tally to the real environment"

Source: [Expert 5]

This is in line with previous works that find dyscalculia learners face difficulty when working with tasks that require understanding of mathematical concepts and relationships such as identifying which sequence of numbers is larger or smaller and faces difficulty in recalling mathematical ideas after learning it. Hence, it is believed that attractive visuals that show 'small' and by objects will able to not only attract their interest in learning mathematics but at the same time capable of helping them to learn the fundamental concepts in mathematics.

The ability of AR to incorporates visual-spatial concepts commonly known as spatial cognition is a great help to learners. Spatial cognition is associated with the representations of spatial information, such as location in memory. The use of this type of information (shows learners a case in a virtual room) has been found to be an extremely powerful form of elaboration for setting up associations in memory, not to mention that spatial information is automatically processed when visual scenes are encoded into long-term memory. Therefore, it can help dyscalculia learners learn mathematical concepts more effectively.

D. Build confidence and interest in mathematics

The fourth dimension in the key findings of the in depth interview was build confidence and interest in mathematics amongst the dyscalculia learners. The experts felt that the modules embedded in the visual-based AR learning application was able to build confidence and interest in mathematics amongst the dyscalculia learner. Extract from the experts that support this dimension are as follows:

" Yes, this learning approach can increase interest and give confidence to dyscalculia learners to learn mathematics"

Source: [Expert 1]

"The modules started off with something simple. And it progresses into..errr a sort of high …higher level. Which means that the dyscalculia learners will find that is not too tough. Then they probably would like to try some more….then this will motivate them to do so…" Source

Source : [Expert 5]

" the use of 3D objects used with the AR markers…err…are really interesting and the 'hands-on' that it allows learners help gain their confidence and interest in mathematics learning… I like it."

Source: [Expert 4]

E. Reuse for other topics

The fifth dimension in the key findings of the in depth interview was reuse of the modules for other possible topics. Findings of the interview conducted found that experts were agreeable that the modules developed for the visual-based AR learning application for dyscalculia learners for the topic Fraction, is suitable and can be used for other topics.

"Yes, I strongly agree that this approach could likely assist in other sub-topics of basic mathematics such as addition, cessation, multiplication and division because it consists of strong interactivity between the student and application. This also helps them learn mathematics in a different approach by learning through everyday life themes that are related to their lives and handling 'real-life' objects through AR"

Source: [Expert 3]

"suitable to teach sub-topics, other topics….Maybe division, subtraction errr many more topics."

Source: [Expert 1]

"appropriate…for example to teach percentage…"

Source: [Expert 2]

Currently, there are promising evidence-based AR intervention for learners with learning disabilities including dyscalculia learners. Thus, the present study offers new research interest to explore on the ability of AR-based modules to assist dyscalculia learners learn mathematics more effectively.

F. Learning content as additional features

The sixth entity in the key findings of the in-depth interview was on learning content as additional features to the modules. Based on the findings, the experts were of the opinion that the modules could be improved by adding learning content as additional features. Majority of the experts suggest diversifying the topics of the study by adding additional contents as additional features in modules with only one expert satisfied with existing modules. Interview extracts have as follow:

"Yeah definitely. It's not only fraction. But also other topics."

Source: [Expert 1]

"Alright..errmm..Probably after doing this we should...errr the class should start with manipulative. Something like cutting up the shapes properly and labeling the shapes like what they have seen in the.. application. Then to have to do it...errr err With the real material. Cut it off label it. As what they saw."

Source: [Expert 4]

"Actually. I'm very happy with this application…… going through it 'hands-on' myself….I feel all of it is very appropriate. And I'm really very glad. To have this application for my students. I know it will build their confidence and their interest in learning mathematics or any other topics for that matter."

Source: [Expert 2]

The current scenario in schools see teachers segregating learners with learning disorders from the mainstream by labelling them as 'slow' or assigning them to a less challenging classroom. However, these learners should be taught using assistive learning tools to suit their learning difficulties to ensure they can succeed in school and beyond. Hence, the findings indicate a new opportunity to explore in AR capabilities to help children with learning disabilities (LD), including dyscalculia learners.

4.4. Summative Evaluation: Usability testing

Summative evaluation or usability testing is widely applied in educational setting. The objective of summative usability testing is to evaluate the usefulness of the visual-based Augmented Reality (AR) learning prototype application developed for dyscalculia learners. The usability testing was conducted based on five (5) constructs: learnability efficiency, effectiveness, ease of use and confidence of dyscalculia learners when using the application. The technique of summative evaluation employed was the'informal walkthrough' for the learnability construct, 'cognitive walkthrough' for the efficiency construct, pre-test and post-test for the construct on effectiveness and a set of questionnaire for the ease of use and confidence constructs.

A. Usability Testing: learnability construct

Informal walkthrough is a technique implemented without providing any tasks in advance. The dyscalculia learners explored the learning application prototype at their own pace. This technique was applied to find out how intuitive and easy it was to navigate the learning application prototype by the dyscalculia learners. The informal walkthrough started by asking the learners to convey in action the navigation of the learning application prototype. The dyscalculia learners demonstrated how they used some of the buttons in the learning application to do the navigation. A checklist of learnability functionality was also prepared. The learnability construct was divided into two (2) parts of application usage that involves: interactive environment in the real world environment and interactive AR environment. Use Tasks Checklist (UTC 1) was developed to evaluate learnability construct used to collect and measure data on the said construct. Table 5 shows the sections used to evaluate the learnability attributes. The rubric for learnability attributes have been adapted from the previous study of Nielsen (2001) and used to measure the learnability construct of V-ARA-Dculia.

Table V
Rubric for Construct On Learnability

Scale	Explanations
F	Fail: cannot perform the task even though it is assist
PS	Partial success: able to perform the task after being assist
S	Success: able to perform tasks without assist

Table 6 shows task success data from the study generated after the dyscalculia learners had completed the given task based on the set instrument Usability Tasks List 1: Learnability construct (UTC 1).

TABLE VI
USABILITY TASK 1: LEARNABILITY CONSTRUCT

Learner	Task List																			
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
L1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L2	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L3	S	S	AS	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L4	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

L5	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L6	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L7	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L8	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L9	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L10	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L11	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L12	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L13	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L14	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
L15	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
Mean	2.00	2.00	1.93	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Standard Deviation	.000	.000	.258	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

The success rate score in Table 6, implemented using UTC 1 is based on the formula created by Nielsen (2001b). In total, there were 300 (learners x task list) attempts performed by the learners. Of those attempts, 299 were successful and one (1) was partially successful. For each partial success given half a point (50%) was given. The success rate of Task 1 (UTC 1) as follows:

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

Based on the results of the Usability Task I (UTC I), the learnability based on real-world environment of the Visual-based Augmented Reality (AR) learning application of dyscalculia learners (V-ARA-Dculia) was very positive, at the rate of 'Success', which means, the learners were able to perform the tasks without assistance. The dyscalculia learners also went through another test: Task 2 (UTC 2) on the interactive AR environment of the learning application prototype as shown in Table 7.

TABLE VII
USABILITY TASK 2: LEARNABILITY CONSTRUCT

Learner	**Task List**						
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**
L1	S	S	S	S	S	S	S
L2	S	S	S	S	S	S	S
L3	S	S	S	S	S	S	S
L4	S	S	AS	S	S	S	S
L5	S	S	S	S	S	S	S
L6	S	S	S	S	S	S	S
L7	S	S	S	S	S	S	S
L8	S	S	S	S	S	S	S
L9	S	S	S	S	S	S	S
L10	S	S	S	S	S	S	S
L11	S	S	AS	S	S	S	S
L12	S	S	AS	S	S	S	S
L13	S	S	AS	S	S	S	S
L14	S	S	S	S	S	S	S
L15	S	S	S	S	S	S	S

The success rate of Task 2 (UTC 2) as follows:

Success rate = (Success + (Almost Success x 0.5) / attempt perform x 100
= 101 + (4 x 0.5) / 105 x 100
= 98%

The test was conducted to get the success rates of dyscalculia learners to provide a general picture of how the application supports them and how much improvement is needed to make the application more suitable for dyscalculia learners. The learners findings on the learnability construct conducted based on an informal walkthrough observation concluded that the score for the construct in real world environment based on the task (UTC1) was slightly higher compared to that based on the interactive AR environment (UTC 2). This could be due to the new exposure on AR learning environment by the dyscalculia learners. However, the success rate obtained in task UTC 1 and UTC 2 was not much difference. Therefore, it can be concluded that the learnability based on the AR interactive learning environment of the V-ARA-Dculia was very positive, at the rate of 'success', which means the learners were able to perform the tasks without assistance.

B. Usability Testing: Efficiency construct

Cognitive walkthrough was a technique used in the observation AR approach to collect information on the efficiency experience of dyscalculia learners using the prototype application. The idea of the cognitive walkthrough is to focus on how efficient it is for new learners especially dyscalculia learners to accomplish the tasks developed in the application prototype rather than having to read a manual or follow a set of instructions. The focus on the cognitive walkthrough for the evaluation of the AR learning application prototype was to understand the efficiency of the application for new learners such as dyscalculia learners. A checklist with 20 items was used to verify the efficiency of the AR learning application based on the usability task.

Efficiency construct was used to measure the time taken to finish a task by dyscalculia learners. It is usually based on the time taken by the participants to complete a task set in any on the modules performed. Efficiency can be measured using two methods: Overall Relative Efficiency and Time based Efficiency. Efficiency construct was conducted on the dyscalculia learners through the cognitive walkthrough. The Overall Relative Efficiency referred to test conducted on end-users (dyscalculia learner) who successfully completed the task in relation to the total time taken, whilst Time based Efficiency referred to the measurement of the time spent by the end-users (dyscalculia learners) to complete the task or speed of work. Table 8 shows the efficiency construct measured based on time take to complete the task by dyscalculia learners. The usability metrics rubric for efficiency attributes have been adapted from the previous study of (Nielsen 2001b) and used to measure the efficiency construct of V-ARA-Dculia. Table 9 shows the efficiency construct measure based on the overall relative efficiency.

TABLE VII
EFFICIENCY CONSTRUCT: TIME TAKEN TO COMPLETE TASK

Learner	Time taken to complete the Task (minutes)	Time taken to complete the Task (seconds)
L1	15 minutes	900
L2	10 minutes	600
L3	15 minutes	900
L4	10 minutes	600
L5	10 minutes	600
L6	15 minutes	900
L7	20 minutes	1200
L8	15 minutes	900
L9	15 minutes	900
L10	15 minutes	900
L11	15 minutes	900
L12	15 minutes	900
L13	15 minutes	900
L14	25 minutes	1500
L15	20 minutes	1200

Overall Relative Efficiency is calculated as follows:

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

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 user does not complete the task successfully, then the time will be measured until the moment the user gave up from the task.

The Overall Effiency calculated as follows:

$$= \frac{(1*900+1*600+1*900+1*600+1*600+1*900+1*1200+1*900+1*900+1*900+1*900+1*900+1*900+1*1500+1*1200)}{(900+600+900+600+600+900+1200+900+900+900+900+900+900+1500+1200)} \text{ x } 100\%$$

= 100%

The Time Based Efficiency is calculated as follows:

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

Time based Efficiency =

$$= \frac{(1*900+1*600+1*900+1*600+1*600+1*900+1*1200+1*900+1*900+1*900+1*900+1*900+1*900+1*1500+1*1200)}{(1*15)}$$

= 920 (goals/seconds) / 15.33 (goals/minutes)

TABLE IX
EFFICIENCY CONSTRUCT: OVERALL RELATIVE EFFICIENCY TO COMPLETE TASK

Learner	Time taken to complete the Task (minutes)	Time taken to complete the Task (seconds)	Time based Efficiency	Overall Relative Efficency
L1	15 minutes	900	Time<=920s	100%
L2	10 minutes	600	Time<=920s	100%
L3	15 minutes	900	Time<=920s	100%
L4	10 minutes	600	Time<=920s	100%
L5	10 minutes	600	Time<=920s	100%
L6	15 minutes	900	Time<=920s	100%
L7	20 minutes	1200	Time>920s	100%
L8	15 minutes	900	Time<=920s	100%
L9	15 minutes	900	Time<=920s	100%
L10	15 minutes	900	Time<=920s	100%
L11	15 minutes	900	Time<=920s	100%
L12	15 minutes	900	Time<=920s	100%
L13	15 minutes	900	Time<=920s	100%
L14	25 minutes	1500	Time>920s	100%
L15	20 minutes	1200	Time>920s	100%

Findings on the efficiency construct based on the 'cognitive walkthrough observation' concluded that Time Based Efficiency measures 15.3 seconds of the time spent by the dyscalculia learner to complete the task. The Overall Relative Efficiency of the fifteen (15) dyscalculia learners showed 100% successfully completed the task in relation to the total time until the moment they completed the tasks performed. However, as can be observed, three (3) dyscalculia learners (L7, L14, L15) attempted to complete the task with a longer total time taken compared to the other dyscalculia learners.

C. Usability Testing : Effectiveness construct (Pre-test and post-test)

Effectiveness construct was measured based on the completion of a task. It also measured the number of mistakes made by dyscalculia learners when trying to complete the task. The effectiveness construct was measured using the set of questions based on the pre-test and post-test set of questions. Table 10 shows results of the pre-test and post-test conducted.

TABLE X
EFFECTIVENESS Construct: Pre-test And Post-test

Learners	Pretest		Posttest		Achievement
	Correct Answer	(%)	Correct Answer	(%)	(%)
L1	0	0	3	50	50
L2	2	33.3	4	66.7	33.4
L3	1	16.7	4	66.7	50
L4	0	0	4	66.7	66.7
L5	2	33.3	5	66.7	33.4
L6	1	16.7	5	66.7	50
L7	1	16.7	4	66.7	50
L8	1	16.7	2	33.3	16.6
L9	0	0	3	50	50
L10	0	0	3	50	50
L11	0	0	3	50	50
L12	1	16.7	4	66.7	50
L13	0	0	3	50	50
L14	2	33.3	4	66.7	33.4
L15	2	33.3	4	66.7	33.4

Table 11 and 12 show that all fifteen (15) dyscalculia learners, had their scores on post-test greater than their pre-test, indicating major improvement on post-test scores compared to the scores acquired during their pre-test. There were no tied ranks.

TABLE XI
USABILITY TEST ON EFFECTIVENESS: PRE-TEST AND POST-TEST RANKS

		N	Mean Rank	Sum Of Ranks
POSTTEST - PRETEST	Negative Ranks	0^a	0	0
	Positive Ranks	15^b	8	120
	Ties	0^c		
	Total	15		
A. POSTTEST < PRETEST				
B. POSTTEST > PRETEST				
C. POSTTEST = PRETEST				

TABLE XII
TEST STATISTICS

	POST TEST – PRE TEST
Z	-3.497^b
Asymp. Sig. (2-tailed)	0
a. Wilcoxon Signed Ranks Test	
b. Based on negative ranks.	

A Wilcoxon test conducted, indicated that the median post-test ranks (Mdn = 4.0) was statistically significantly higher than the median pre-test ranks (Mdn = 1.0), Z= -3.497, $p < 0.05$. Therefore, it can be concluded that the Visual-based Augmented Reality (AR) Learning Application for dyscalculia learners (V-ARA-Dculia), was positively effective in helping dyscalculia learners learn mathematics. This result is supported by comparing the median value of the boxplot graph as shown in Figure 2. It can be seen clearly that the median ordinal score (4.0) for post-test was higher than the median ordinal score (1.0) for pre-test.

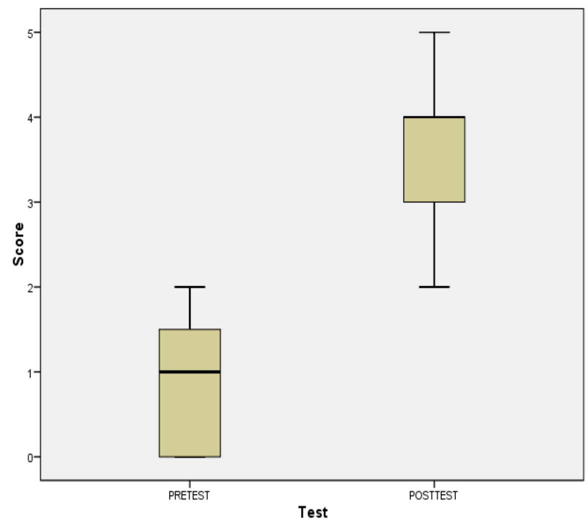

Fig 2. Boxplot on Pre test and Post-test

D. Usability Test : Ease of use and Confidence constructs

The ease of use and confidence constructs were measured based on a questionnaire verified by five (5) experts with significant experience in the related fields. A five (5) point scale ranging from 1 as strongly disagree to 5 as strongly agree was used as the measurement. After the dyscalculia learners had completed answering questionnaire the scale offers a formula which transfers the subjective impressions of learners into objective data information for analysis. The range estimate score was from 0 to 100. The higher the score the more useful and easy is the application to be used by the users.

The usability questionnaire consisted of 23 scale items. The first 16 items were related to perceived overall ease of use of V-ARA-Dculia. The remainder seven (7) items were to assess learners confidence on the learning application prototype. Table 13 shows the rubrics for the Ease of use and Confidence constructs ,and Table 14 shows items in Ease of use construct.

TABLE XIII
RUBRICS: EASE OF USE AND CONFIDENCE CONSTRUCTS

Scale	Explanations
5	Strongly Agree
4	Agree
3	Neutral
2	Disagree
1	Strongly Disagree

TABLE XIV.
ITEMS: EASE OF USE CONSTRUCT

Items	Scale					Mean	Standard Deviation
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**		
Question 1	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 2	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 3	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 4	0	0	0	4	11		
	0%	0%	0%	26.70%	73.30%	4.73	0.458
Question 5	0	0	0	2	13		
	0%	0%	0%	13.30%	86.70%	4.87	0.352
Question 6	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 7	0	0	0	5	10		
	0%	0%	0%	33.30%	66.70%	4.67	0.488
Question 8	0	0	0	5	10		
	0%	0%	0%	33.30%	66.70%	4.67	0.488
Question 9	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 10	0	0	0	4	11		
	0%	0%	0%	26.70%	73.30%	4.73	0.458
Question 11	0	0	0	6	11		
	0%	0%	0%	40%	60%	4.6	0.507
Question 12	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 13	0	0	0	4	11		
	0%	0%	0%	26.70%	73.30%	4.73	0.458
Question 14	0	0	0	4	11		
	0%	0%	0%	26.70%	73.30%	4.73	0.458
Question 15	0	0	0	1	14		
	0%	0%	0%	6.70%	93.30%	4.93	0.253
Question 16	0	0	0	2	13		
	0%	0%	0%	13.30%	86.70%	4.87	0.352

Analysing ease of use questions as shown in Table 14, the highest mean score was for: *I felt the operation of this application is simple and uncomplicated* (Question 15) indicated 4.93. Similar responses were indicated for *The step to use the application is easy to remember* (Question 5) and *I felt that using the application was comfortable for my arms and hands* (Question 16) both indicated mean score of 4.87.

The highest mean scores in the confidence sub-area as shown in Table 15 indicated that: *After the introductory information, I felt confident that I knew what I suppose to learn from this lesson* (Question 20) and *AR learning make me feel confident* (Question 22) respectively with mean score of 4.93. *After working on this lesson for a while, I was confident that u would be able to do Fraction* (Question 21) and *I felt very confident using the application* (Question 23) had similar responses by the dyscalculia learners which generated mean score of 4.87.

TABLE V
ITEMS: CONFIDENCE CONSTRUCT

Items	Scale					Mean	Standard Deviation
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Question 17	0	0	0	5	10		
	0%	0%	0%	33.30%	66.70%	4.8	0.414
Question 18	0	0	0	6	11		
	0%	0%	0%	40%	60%	4.6	0.507
Question 19	0	0	0	3	12		
	0%	0%	0%	20%	80%	4.8	0.414
Question 20	0	0	0	1	14		
	0%	0%	0%	6.70%	93.30%	4.93	0.253
Question 21	0	0	0	2	13		
	0%	0%	0%	13.30%	86.70%	4.87	0.352
Question 22	0	0	0	1	14		
	0%	0%	0%	6.70%	93.30%	4.93	0.253
Question 23	0	0	0	2	13		
	0%	0%	0%	13.30%	86.70%	4.87	0.352

V. DISCUSSION & CONCLUSIONS

This paper had highlighted the study on the evaluation of a visual-based Augmented Reality (A-R) learning application for dyscalculia learners (V-ARA-Dculia). The evaluation was based on the formative evaluation and the summative evaluation. The former, was conducted based on heuristics evaluation through questionnaire and in-depth interview sessions; whist the summative evaluation was conducted based on usability testing which relied on five (5) constructs: learnability, efficiency, effectiveness, ease of use and confidence.The formative evaluation conducted on a case of one (1) dyscalculia learners and the heuristics evaluation by five (5) experts was purposely intended to conduct a sound development software or application process which was iterative and allowed for improvements to be done within an ongoing process of development. This approach was found to be effective as the one dyscalculia learner was an active participant in the design and developement process of the application development life cycle, and feedbacks by the experts too gave opportunities to iteratively improve the application until it was found to be satisfactory to the dyscalculia learner at the formative evaluation stage. The usability testing on the other hand, focused on how well end-users can learn to use the application to achieve their goals. It refers to how satisfied users are with the application that has been developed specially for them This is inline also with the findings of Nayebi et al. (2012).

Dyscalculia learners need elements that will enable them to enjoy while learning and understand mathematical concepts put forward for them to learn. Dyscalculia learners have difficulties in various cognitive processes, thus they need assistive learning applications that can help enhance their cognitive processes. The integration of virtual and real world environment in AR can help dyscalculia learners enhance their cognitive process by retaining attention and processes in their long-term memory so that they can not only understand better, by looking at ‘real objects in the virtual environment as something concrete but also help them retain whatever mathematical concepts learned much longer. Many researchers have found that AR technology as assistive learning application has shown positive results in helping learners with learning disabilities (LD) including dyscalculia learners learn mathematics more meaningfully.

Moreover, the interactive element in AR allows dyscalculia learners to interact with the learning materials and be active in their learning process rather than just watch without interacting with them as with conventional learning materials (Te’eni, Carey & Zhang 2007). Learning based on independent learning approach using this novel approach of visual-based AR application for dyscalculia learners is able to help dyscalculia learners learn mathematics with minimal help. In this way, they can start learning according to their own pace. This is important as an effort to encourage dyscalculia learners be engaged in their learning, as their preferred learning approach is visual, the use of visual-based AR is most apt for them to use.

The investigation was done to evaluate the visual-based AR learning application. The findings of the evaluation conducted was found to be positively inclined as both the formative and summative evaluation showed both the experts (teachers teaching mathematics and special education experts) as well as dyscalculia learners found the application to be interface friendly, cosmetically adequate, technically and content adequate suitable for the dyscalculia learners. The learners on the other hand, found the application to be fun, intuitive, interactive and game like when they had to use the AR markers. The fact that they were able to manipulate the objects with the markers made learning active and enjoyable. The visual based AR application was able to enrich the dyscalculia learners’ learning process. This is inline with findings of Sahin & Uluyol (2016) which found that AR technology application "enriches the real world with virtual representations" that is able to enhance visual perception of learners.

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