Heuristic Evaluation on Affective 4-Dimensional Augmented Reality Mathematics for Children with Low Vision

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***Abstract*—Low-vision children need engaging technology to explore learning materials regardless of visual impairment, which usually restricts their access to innovative learning tools. Understanding and learning fractions in Mathematics could be challenging for them as it requires conceptualization and visualization of the divisional concept. Having considered their ability to visualize the learning content, this study introduced a mobile 4-Dimensional Augmented Reality with the inclusion of affective attributes, which are feeling, thought, emotion, and action, known as Affective 4-Dimensional Augmented Reality Mathematics for Low Vision (ARM4LV). Before the apps are introduced to the targeted users, this study conducts a heuristic evaluation to extract comments and suggestions from the perspective of experts and validate the prototype. The heuristic evaluation is based on Nielsen and Molich's 10 Heuristics with nine principles and engaged with six experts. They were involved in two phases of evaluation sessions. Results revealed that all experts strongly agreed that the prototype is usable and applicable to low vision needs with the overall mean score being 4.7. However, it still requires some improvement and enhancement in terms of user control expectations which will be further explored in the future.**

***Index Terms*—Augmented reality, affective design, assistive technology, user-centered design approach, heuristic evaluation, visual impairement.**

I. Introduction

Augmented Reality (AR) is a method to engage with an actual world environment in which computer-generated perceptual information is used to augment the objects in the actual world, typically throughout different sensory modalities such as visual, aural, haptic, somatosensory, and olfactory [1]. AR is a system or application that integrates actual and virtual worlds, allows for real-time interaction, and allows for accurate 3-dimension registration of virtual and actual objects [2]. The AR sensory data can be either constructive or deductive which means the AR sensory data is either additive to the natural environment or masking the natural environment [3]. This experience is so completely integrated with the actual world that it is recognized as a fully immersive part of the actual environment [3]. The key value of AR is the technique whereby digital elements mix into a user's view of the actual world, not only as a display of data but as the integration of immersive sensations that are seen as natural features of an environment [4]. One of the first practical AR systems that provided users with realistic mixed-reality experiences was the Virtual Fixtures system. It was developed by US Air Force's Armstrong Laboratory in 1992 [4]. The first commercial AR experiences appeared in the entertainment and gaming industries [1]. As a result, AR applications have spread across a variety of economic sectors, including education, communications, medical, and entertainment. AR is a technology that is used to improve natural environments or circumstances by providing perceptually enhanced experiences [5]. The surrounding information of the actual environment becomes interactive and digitally modified with the use of advanced AR technologies [6]. This includes augmenting computer vision, embedding AR cameras into smartphone applications, and object authentication. The actual world is augmented with data on the environment and its objects. In addition to accumulating and sharing tacit knowledge, AR offers a lot of possibilities. Augmentation techniques are often used in real-time with ambient factors in semantic contexts. For example, in a live video stream of a sporting event, immersive perceptual information is occasionally integrated with extra information such as scores. This utilizes the advantages of both AR and heads-up display (HUD) technology. Meanwhile, in education, the learning content can be accessible by scanning an image marker with a mobile device by using markerless AR technologies [7]. In line with the advancement of AR technology, this study has come out with the AR application of Mathematics content which emphasized interaction and affective design concepts [8].

A. Interaction Design in Augmented Reality

In AR technology, interaction design focuses on the user's engagement to maximize the user experience and satisfaction. The goal of interaction design is to avoid distracting or confusing users [9]. Therefore, designers should provide comprehensible accessibility system controls because user engagement relies on the user's input. A prominent strategy for improving the usability of AR applications is by recognizing the commonly used spots in the device's touch display and designing the application that matches those areas of control [10]. It is also crucial to coordinate the mapping of the user interaction design and the flow of information displayed, which minimize the cognitive load and enhances the application's learning curve [11]. Therefore, developers should use AR technology that complements the system's operation and function in creating interaction design. For example, Snapchat's usage of fascinating AR effects and the functionality of its unique sharing platform allow users to enhance their in-app social connection. Also, designers can utilize a reticle or raycast from the device on

Manuscript received August 19, 2022; revised November 3, 2022; accepted November 7, 2022.

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doi: 10.18178/ijiet.2023.13.2.1809

which the users must focus. Furthermore, AR creators could find it useful to produce digital elements that are able to capture or interact with the device's direction and the context of identified objects. AR technology enables the integration of 3D space which means that inside a single AR application, a user may be able to access various copies of 2-Dimension interfaces. In the context of this study, a 2-Dimension interface has been designed in the proposed AR application. However, since the proposed AR application of this study caters to low-vision children as the target users, it is critical for this study to explore the visual design in AR that is able to engage the target users.

B. Visual Design in Augmented Reality

Generally, visual design is application's appearance that attracts the user's attention. Developers can utilize visual cues to notify the user interface element that is designed to engage with and interact with to enhance the graphic interface elements and user interaction. Although interacting in an AR application can be challenging and irritating, the use of visual cue design is vital to make the interactions appear more realistic [12]. The 2-dimensional control environment does not adapt well to 3-dimensional space, making users apprehensive to discover their surroundings in specific AR applications that use a 2-dimension device as an interactive surface [13]. Therefore, designers could utilize visual clues to support and encourage users to explore their environment to address this problem [14]. In reflection of this study, the visual design of the proposed AR application has utilized the concept of visual cues through the audio which has been expressed via the character.

C. The Proposed AR Application

This study developed an AR Application called Affective 4-Dimensional Augmented Reality Mathematics (ARM4LV) specifically designed according to the needs of low-vision children. The ARM4LV is a mobile-based AR application that is specific to Mathematics content. The interaction design of ARM4LV is integrated with the affective design concept are feeling, thought, emotion, and action. This is to ensure that ARM4LV able to fulfill the requirement of low vision children particularly in their learning activities. This means all the multimedia elements and AR features included in ARM4LV is meaningful to low vision children compared to others AR Application which focus more on general users. The details explanation of 4-Dimensional elements of ARM4LV has been discussed in detail in [8]. Fig. 1a and Fig. 1b are screenshots of the sample of the ARM4LV interface. Therefore, the main objective of this paper is to validate the ARM4LV through a heuristic evaluation technique before proceeding with user experience testing.

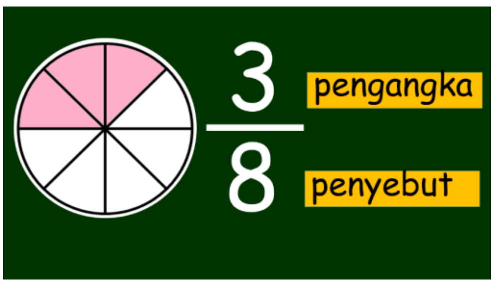

Fig. 1 a. Sample of ARM4LV (interface 6).

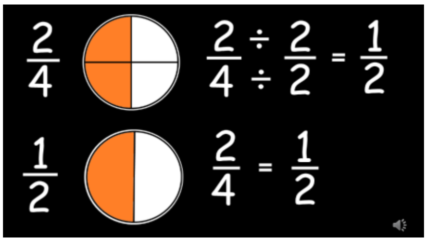

Fig. 1b. Sample of ARM4LV (interface 11)

II. Methodology

This study applied the heuristic evaluation method to validate the ARM4LV. Fig. 2 demonstrates the procedure involved to carry out the heuristic evaluation adapted from [15].

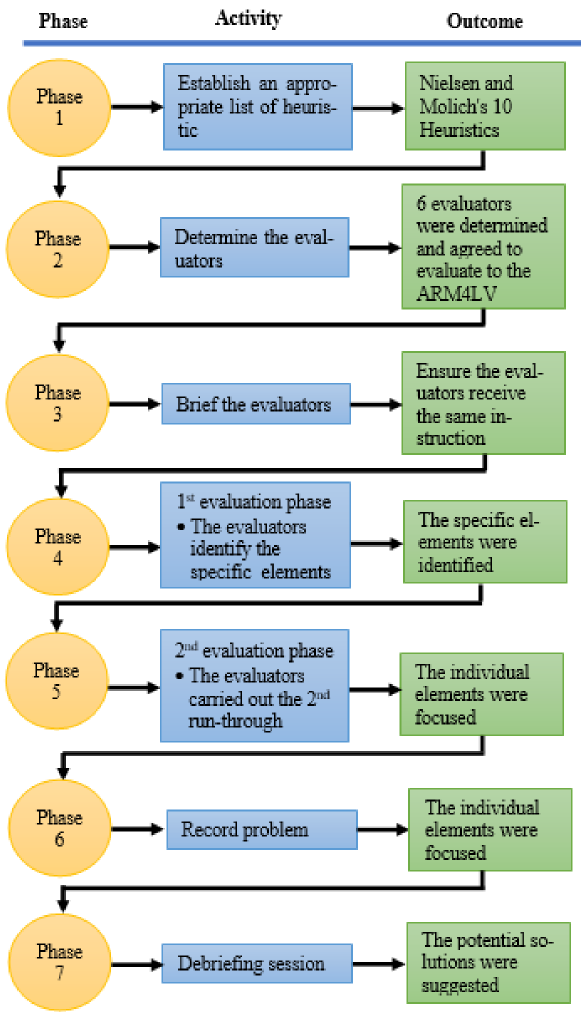

Fig. 2. The procedure of heuristic evaluation.

Phase 1: Establish an appropriate list of heuristic

This study chooses to refer to Nielsen and Molich's 10 heuristics as a guideline to construct the heuristic evaluation questionnaires to evaluate the ARM4LV.

Phase 2: Determine the evaluators

There are six experts from different higher learning institutions have been selected to evaluate and validate the ARM4LV. They have been identified based on their qualification. Generally, all of them are experts in Human-Computer Interaction (HCI) and have more than 15 years of working experience in HCI, particularly in the Multimedia field.

Phase 3: Brief the evaluators

This study uses communication media including email and WhatsApp to brief the evaluators. This is to ensure that all the evaluators receive the same instructions and focus on the standard tasks. However, some evaluators may specify which elements they will cover based on their experience and expertise. Also, the video demonstration of ARM4LV, documented instruction, and a set of heuristic evaluation questionnaires have been shared with the identified evaluators through Google Drive.

Phase 4: 1st evaluation phase

For the 1st phase of evaluation, this study allows the evaluators to freely use the ARM4LV to get a sense of the instruction and the scope of the prototype. The evaluators also started identifying the specific elements based on the heuristic evaluation questionnaires.

Phase 5: 2nd evaluation phase

In the 2nd evaluation phase, the second run-through was carried out while utilizing the heuristics used for the elements discovered in the first phase. The individual elements of ARM4LV have been evaluated to ensure that all the elements are appropriate to the overall design.

Phase 6: Record the problem

All the problems related to ARM4LV that the evaluators found during the evaluation process have been recorded in the provided form.

Phase 7: Debriefing session

The debriefing session has been conducted to ensure the evaluators organize their findings and make a comprehensive list of problems. The evaluators were then encouraged to suggest potential solutions to ARM4LV.

III. Result and Discussion

This section highlights the result gathered through heuristic evaluation that has been carried out to validate the ARM4LV.

A. *Heuristic Evaluation on ARM4LV*

Heuristic evaluation is a software usability inspection method that supports the detection of usability issues in the user interface (UI) design. It entails evaluating the interface and determining if it adheres to specified usability principles. These evaluation techniques are increasingly typically practiced and applied in the new media industry, where user interfaces are frequently designed in a short amount of time on a budget that may limit the amount of money available for other methods of interface testing. This study implements the heuristic evaluation to evaluate and validate the usability of the prototype. The demonstration of ARM4LV has been shared with the identified experts through Google Drive together with the instructions and a set of heuristic evaluation questionnaires (Table I). The usability of the prototype has been evaluated based on the heuristic criteria. They are 1) visibility of the system status, 2) match between the system and the real world, 3) user control and freedom, 4) consistency and standard 5) recognition rather than recall, 6) flexibility and efficiency of use, 7) affective and minimalist design, 8) visual representation, and 9) help and documentation. 30 questionnaires have been asked pertinent to the heuristic principles. The scale to evaluate the heuristic principles applied in ARM4LV is from 1 to 5 which indicates 1 is for strongly not agreeing, 2 is for not agreeing, 3 is for not sure, 4 is for agreeing, and 5 is for strongly agreeing. The results are presented and explained based on each of the heuristic elements.

TABLE I: Heuristic Evaluation Questionnaire

Visibility of System Status						
1	There is the appropriate response when the user scans the AR marker (e.g.: welcoming remarks by the character).	1	2	3	4	5
2	After scanning the AR marker, the animation scene contains instructions, and visualization of related Math content indicates which content is being scanned.	1	2	3	4	5
Match Between System and the Real World						
3	The voices in the *Augmented Reality (AR) Math App* are clear and the words used are suitable for low-vision children.	1	2	3	4	5
4	The use of the AR marker and flashcard is intuitive and easily recognizable	1	2	3	4	5
User Control and Freedom						
5	It is easy to change the AR marker after each scene is completed.	1	2	3	4	5
6	The AR app can be terminated at anytime	1	2	3	4	5
Consistency and Standard						
7	The size of the AR marker is consistent	1	2	3	4	5
8	The size of the Flashcard is consistent	1	2	3	4	5
9	Standard fonts type and sizes are used throughout the application	1	2	3	4	5
10	Standard character is used throughout the application	1	2	3	4	5
Recognition rather than Recall						
11	The text areas have "breathing space" around them	1	2	3	4	5
12	Each of the objects has "breathing space" around them	1	2	3	4	5
Flexibility and Efficiency of use						
13	It is easy to scan the AR marker to all screens in AR Math App	1	2	3	4	5
14	Based on the Math Flashcard, the user can choose the preferable AR marker to play the related animation	1	2	3	4	5
15	Based on the Math Flashcard, it is easy to scan the AR Marker and view the corresponding animation	1	2	3	4	5
Affective and minimalist design						
16	The structure of the AR Math App is simple, it only contains the necessary information to support low-vision children in learning Mathematics	1	2	3	4	5
17	The content of the AR Math App is clear without unnecessary complications	1	2	3	4	5
18	There are no instances of extraneous information	1	2	3	4	5
19	There are no instances of misplaced information	1	2	3	4	5
20	The design of the graphics in the AR Math App provides affective interaction for the low-vision children	1	2	3	4	5
21	The design of the animations in the AR Math App provides affective interaction for the low-vision children	1	2	3	4	5

22	The type of font in the AR Math App provides affective interaction for the low-vision children	1	2	3	4	5
23	The voice intonation of the character provides affective interaction with the low-vision children	1	2	3	4	5
24	The design of the character provides affective interaction with the low-vision children	1	2	3	4	5
25	The color choices provide affective interaction to the low vision children	1	2	3	4	5
26	The user interface provides affective interaction design for the low vision children	1	2	3	4	5
Visual Representation						
27	The use of animations supports the low vision children in learning Mathematics	1	2	3	4	5
28	The use of sounds supports low-vision children affectively in learning Mathematics	1	2	3	4	5
29	The use of graphics supports the low vision children in learning Mathematics	1	2	3	4	5
Help and Documentation						
30	The AR Math App has user guides screens that describe how to use the learning app	1	2	3	4	5

B. *Visibility of the System Status*

Visibility of the system status means the system should always keep users informed of what is going on by providing appropriate feedback promptly. In this study, the criteria that have been asked pertinent to the visibility of the system status are in terms of appropriate response when the user scans the AR marker and whether the provided content is related to the AR marker. The response from the experts indicates that all of them strongly agree with the visibility of the system status provided in ARM4LV except for expert 4 who state as agrees (Fig. 3). Overall, with a mean score of 4.8, the visibility of the system status provided in ARM4LV is acceptable and works satisfactorily.

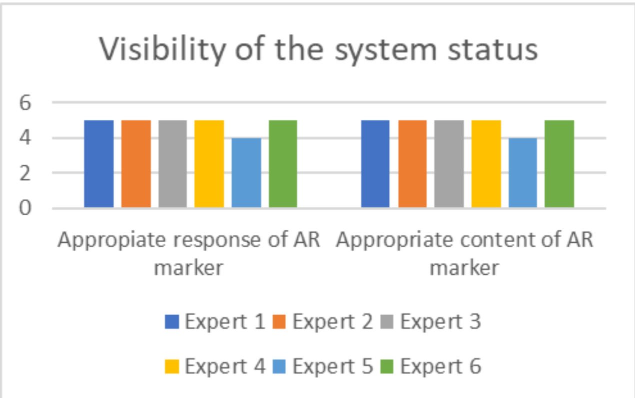

Fig. 3. Visibility of the system status.

C. *Match between System and Real World*

Instead of system-oriented terms, the system should speak the users' language, using words, phrases, and concepts that are familiar to the user. It must adhere to real-world conventions by arranging information in a natural and logical order. The heuristic criteria that have been asked pertinent to match between the system and the real world is the use of clear voice and words appropriate to low vision children and the use of AR marker and flashcard that are intuitive and easily recognizable. As a result, most of the experts agree with the voice and words provided in ARM4LV, and most of the experts strongly agree with the intuitive and recognizable AR marker and flashcards, with a mean score of 4.5. (Fig. 4).

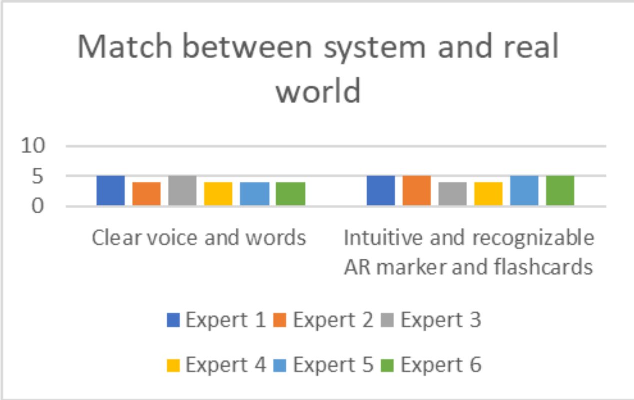

Fig. 4. Match between system and real world.

D. *User Control and Freedom*

User control and freedom mean users frequently select system functions by the unfortunate incident, necessitating the use of a marked emergency exit to leave the undesirable state without having to go through an extended dialogue with the supported undo and redo functions. Regardless of user control and freedom, the heuristic elements that have been asked in the context of this study are whether it is easy to change the AR marker after each scene is completed and whether the ARM4LV can be terminated at any time. The results, with a mean score of 4.4, indicate that most of the users strongly agree and agree with the features provided in ARM4LV related to user control and, freedom except for expert one not sure that the apps can be terminated at any time (Fig. 5).

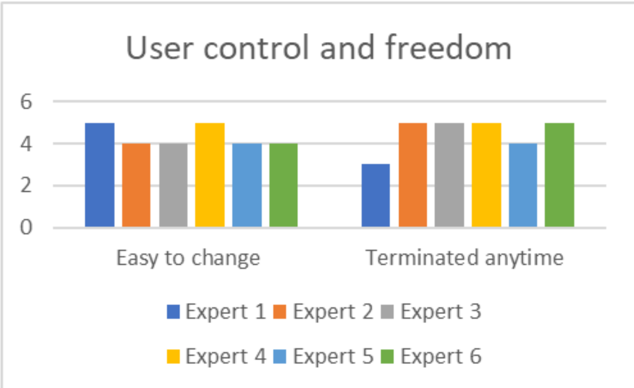

Fig. 5. User control and freedom.

E. *Consistency and Standard*

In terms of consistency and standard, it means users should not have to assume whether numerous different words, situations, or actions that appear in the application mean the same thing. This is because the developer has to provide it by following the established platform and industry conventions. The heuristics criteria that have been asked are in terms of the consistency and standard of the size of the AR marker, size of the flashcard, size, and type of font, and the character used in the ARM4LV. Overall, most of the experts strongly agree with the consistency and standard of markers, flashcards, font type, font size, and characters provided in ARM4LV. Only two experts agree with the standard font type and size. The overall mean score for consistency and stand is 4.9 (Fig. 6).

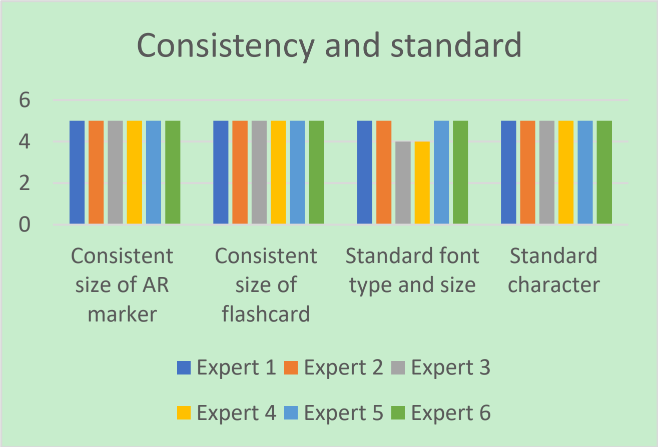

Fig. 6. Consistency and standard.

F. Recognition rather than Recall

Recognition rather than recall means the objects, actions, and options should be visible. The user should not have to recall information from one section of the dialogue to the next. The system instructions should be visible or easily accessible. In ARM4LV, the heuristics criteria considered is the breathing space of texts and objects around them. The results indicate that all the experts strongly agree with the breathing space provided in the ARM4LV between texts and objects (Fig. 7). These are important criteria as the texts and objects designed for low vision children must adhere to their specific requirements demonstrating the experts's acceptance with a means score of 5.

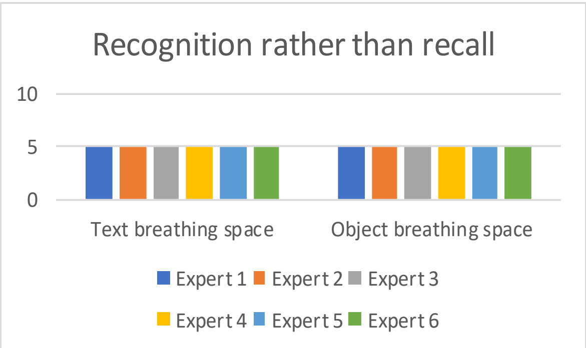

Fig. 7. Recognition rather than recall.

G. Flexibility and Efficiency of Use

Flexibility and efficiency of use mean providing a flexible process that can be carried out in different ways so that users can pick whichever method works for them. It also speeds up the interaction process for the expert user so that the design can cater to both inexperienced and experienced users. In ARM4LV three heuristic criteria are taken into account. They are easy to scan the AR marker to all screens in ARM4LV; users can choose the preferred AR marker to play the related animation, easy to scan the AR marker through the flashcard and view the corresponding animation. The results indicate that most experts strongly agree and agree with the flexibility and efficiency of use provided in ARM4LV, except for only one expert response was not sure (Fig. 8). The mean score for this criteria gained recognition by the experts in which the mean score of 4.5.

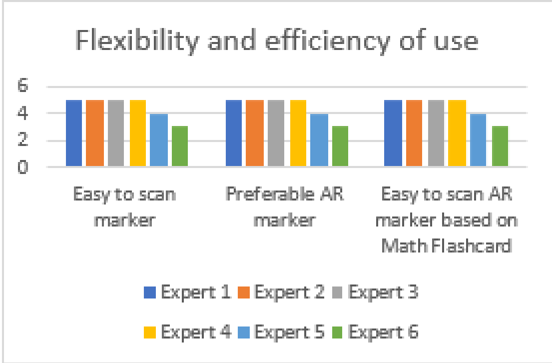

Fig. 8. Flexibility and efficiency of use.

H. Affective and Minimalist Design

The affective and minimalist design means interfaces should not include information that is irrelevant or is only used infrequently. This is because every additional unit of information in an interface competes with the relevant units of information. This will reduce their relative visibility. In the context of this study, each design should cater to the affective design principles. In ARM4LV the criteria of affective and minimalist design that must be included are the structure of ARM4LV must be simple, it only must contains the necessary information to support the low vision children in learning Mathematics, the content of the ARM4LV must be explicit without unnecessary complications, there are no instances of extraneous information, there are no instances of misplaced information, the design of the graphics in ARM4LV must provide affective interaction to the low vision children, the design of the animations in ARM4LV must provide affective interaction to the low vision children, the type of font in ARM4LV must provide affective interaction to the low vision children the voice intonation of the character must provide affective interaction to the low vision children, the design of the character must provide affective interaction to the low visionchildren , the color choices must provide affective interaction to the low visionchildren, the user interface must provide affective interaction design to the low vision children. The results with a mean score of 4.8, indicate that all of the experts strongly agree and agree with the heuristic criteria of affective and minimalist design provided in ARM4LV (Fig. 9).

I. Visual Representation

In terms of visual representation, the heuristic applied in the ARM4LV are animation, sounds, and graphics. It is to ensure that all the elements support the needs of low vision children in learning Mathematics. The results indicate that overall, the expert strongly agrees and agrees that the provided animations, sounds, and graphics in ARM4LV support the needs of low vision children in learning Mathematics (Fig. 10). The mean score for visual representation is 4.7.

Fig. 9. Affective and minimalist design.

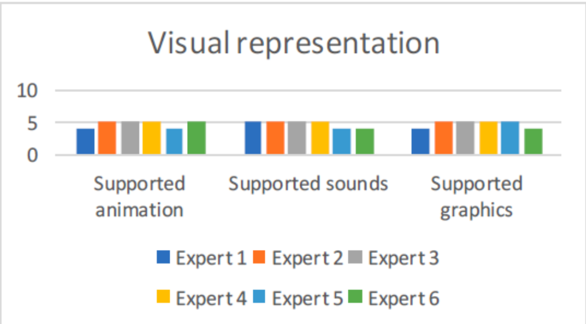

Fig. 10. Visual representation.

J. *Help and Documentation*

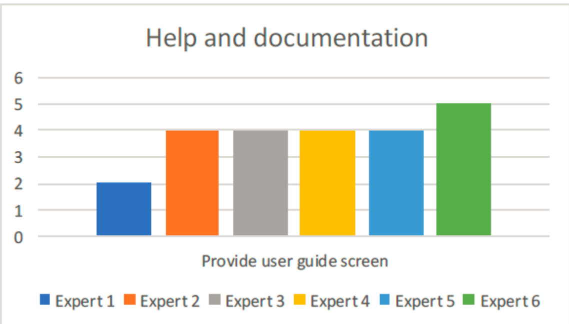

Fig. 11. Help and documentation.

In terms of help and documentation, it is preferable if the system does not require any further explanation. However, documentation may be required to assist users in understanding how to accomplish their tasks. In the context of this study, the ARM4LV should have user guide screens that describe how to use the learning apps. Most of the experts strongly agree and agree that ARM4LV provides user guide screens that describe how to use the learning apps but one of the experts did not agree that ARM4LV provides user guide screens that describe how to use the learning apps (Fig. 11). This study agrees with expert 2 because ARM4LV did not provide the help and documentation functionality, as it is clearly shown the agreement of the experts with the mean score of only 3.8. This study will improve it in the next future research. As this prototype is specifically focused on low vision children, therefore, it is necessary to include the user manual or assistance for them. Apart from that, this study should investigate the usable user assistance, so it will ease the user to explore the apps.

IV. Conclusion and Future Work of the Study

In conclusion, the main aim of this paper has been achieved which is to validate the developed ARM4LV through heuristic evaluation. There are nine usability principles of ARM4LV have been tested which are visibility of the system status, the match between the system and the real world, user control and freedom, consistency and standard, recognition rather than recall, flexibility and efficiency of use, affective and minimalist design, visual representation, and help and documentation. The result of the heuristic evaluation revealed that all experts agreed that the prototype is usable and applicable to the targeted user. However, the ARM4LV is still requiring some improvement and enhancement in terms of user control expectations and the Mathematics content itself particularly the exercise part. Therefore, the user control expectations and the Mathematics learning content will be upgraded in the future so that more affective and interactive design principles could be integrated to evoke a more positive learning experience among low-vision children as well as the enhancement in terms of user guide or user manual assistance.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nurulnadwan Aziz writes the paper. Siti Zulaiha Ahmad conducts the heuristic evaluation. Sariya Binsaleh identify the expert. Wan Rahzihan Zulnasyreeq develops the application. All authors had approved the final version of the paper.

Acknowledgment

We are grateful to the Universiti Teknologi MARA for funding this study through the grant RCF-RACER 2021 (600-TNCPI 5/3/DDN (11) (021/2021). We also owe a debt of thanks to all of the study's participants, experts, teachers, and students.

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