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Words Worth Learning - Augmented Literacy Content for ADHD Students

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***Abstract*—3-9% school-aged children in Ireland are estimated to be affected by ADHD (Attention Deficit Hyperactivity Disorder), according to HSE (Health Service Executive). Typical comorbid conditions include: anxiety disorder, oppositional defiant disorder, conduct disorder, depression, sleep problems, epilepsy, learning difficulties, etc. As such, unless early intervention properly takes place, performance of children with ADHD at school tends to be compromised (e.g. leaving school early and substance abuse etc.). The current work presents a preliminary investigation of creating 3D Learning Objects (3DLO) using Augmented Reality (AR), following the IEEE Learning Objects standards, to enhance an established online literacy programme, *WordsWorthLearning* (WWL). The methodology and experimentation of creating AR 3DLO is proposed, followed by a pilot evaluation, aiming to provide a foundation of a system that can support interactive educational content, service, assessment, and feedback for children with ADHD and their parents and teachers.**

***Index Terms*—Augmented Reality (AR), 3D Learning Objects, Attention Deficit Hyperactivity Disorder (ADHD), Assistive Technology**

I. Introduction

Augmented Reality (AR) has been extensively applied in educational systems in recent years, thanks to its capability to overlay virtual graphics, whether it is 2D or 3D, onto the real-world objects with enhanced real-time interaction. When integrated and combined with the rapidly-growing smartphone technology, AR appears to have a vast potential for application to provide better educational environments for students with difficulties, such as ADHD, and people around them.

This work presents a pilot project which aims to deliver an AR solution for *WordsWorthLearning* (WWL), an established online literacy programme designed to resolve and reduce reading and spelling problems. In particular, the present study focuses on our preliminary implementation and experimentation of 3D Learning Objects (3DLOs) using AR technology, providing a basis for the development of a system using AR 3DLOs to enhance the pre-existing WWL content and learning experience, aided with the use of AR. This study is aimed at laying a foundation for a system deployed within school settings, especially for the community of ADHD students and their parents and teachers, in order to achieve more effective formal and informal educational environments.

The final outcome of this presented work is to create a smartphone (*Android*) application that accompanies the WWL content in order to enhance the learning experience of the user aided with the use of augmented reality. Of all the levels required to complete the original WWL programme, the current study specifically focuses on the vowel chart, a primary chart introduced at the start of Level 1, which constantly appears throughout the programme, containing vowel sounds with respective image representations. These image representations were converted into 3D models and animated using a 3D-modeling software, *Blender*. Corresponding AR markers, which give real-time visual cues for the camera, were created for each 3D mode using an AR development kit, *Vuforia* utilized in the *Unity* game engine. A database for 3D objects and AR markers was generated to create a final application.

This article will firstly provide a review on the WWL content, underpinning the effectiveness of the programme in resolving and reducing literacy problems. The subsequent sections describe specifications of our AR 3DLOs, as well as details of our implementation, including with different functionalities and techniques of 3D modeling and AR marker creation, as well as how to integrate these components together, using relevant software. Lastly, the evaluation of our application based on user feedback will be presented, followed by concluding remarks in the context of potential benefits of using the AR technology in education for children with ADHD.

This work is a part of a European Commission-funded pilot project.

II. *WordsWorthLearning* Content

WordsWorthLearning [1], WWL, is an established online literacy programme that is proven to resolve reading and spelling problems like dyslexia, along with additional literacy-related improvements in comprehension, vocabulary and memory. The programme offers over a hundred video tutorials along with interactive exercises, consisting of seven hierarchical, progressive levels, each of which students are required to complete in order. It utilizes the "Flipped Classroom" model, where students have access to learning content from home, allowing them to learn at their own pace - students can watch the videos as many times as they want, pause, or rewind. Teachers thus can better discuss their lessons with students in class and give more tailored clarification for each student, as well as announce upcoming lessons more effectively so that students can have a head start on the topic that will be covered and gain necessary knowledge in advance.

WWL originated from the work of Rita Treacy for children with "Specific Learning Difficulties" (SLDs) in 1991. Originally paper-based, only available on a client-consultant basis, it was executed privately through speech and language therapy. Over the years, the programme was completed by thousands of students with literacy problems including reading and spelling. Upon completing the programme, the reading and spelling ability of the students significantly improved. The programme was later digitally transformed to replicate the private service, launched in 2011. This allowed even more teachers and parents to sign up with ease and avail of the programme in school or at home.

The first level of the programme starts from the essential speech sounds: "Level 1: Sounds Good - Level 1 is about learning to hear and identify speech sounds (phonemes) with the use of specially designed vowel and consonant charts. These charts are core in the learning process as they are main foundation of the programme. It teaches how to read and write speech sounds and how they are properly pronounced. Sound and symbol association is key in this level."

Characteristically, WWL encourages the students to say the sound (phoneme), and not the name of the alphabet. Of particular importance in this literacy programme is the vowel chart, which consists of 19 vowel sounds (Fig. 1). To the right of the vowel sounds are depicted their corresponding words and pictures to assist the students to identify the target sound of the vowel (e.g., an image of a bee corresponding to the vowel sound "ee", or an image of an apple corresponding to the vowel sound "a (ah)"). The vowel sounds are categorized into four groups (spread, round, resting, and moving) according to the shape of the lips.

III. Augmented Reality Objects

We modeled 3D Learning Objects (3DLO) based on the original 2D graphics on the vowels in the aforementioned chart and their corresponding sound files, to implement as an AR-powered application. Creative freedom was given in terms of the style and the animation of 3D models, so as to allow more interactivity for the users through AR.

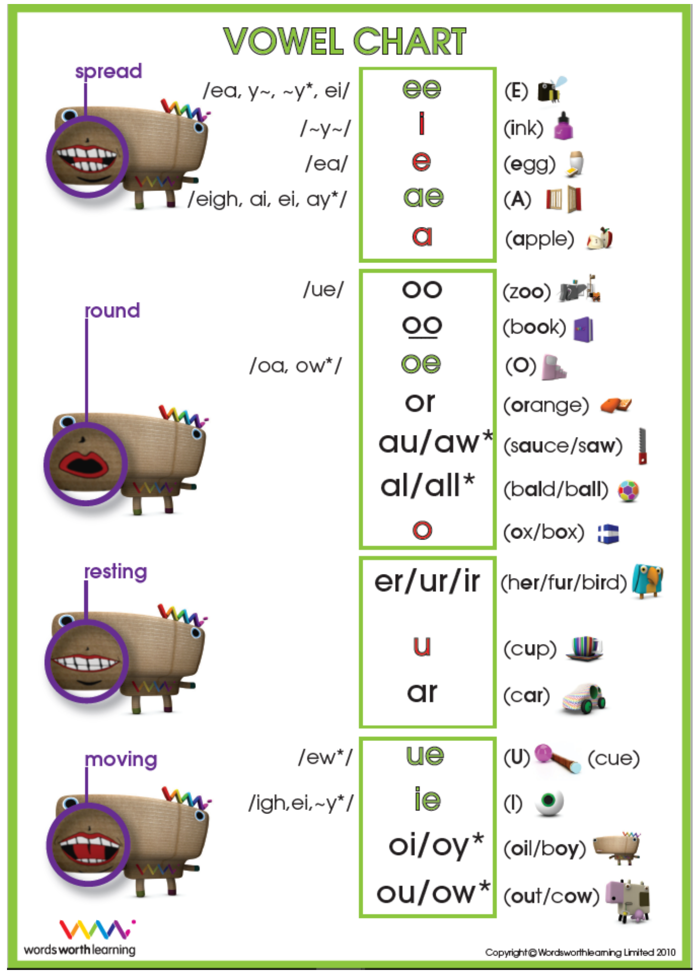

Fig. 1. The vowel chart used in the WWL literacy programme.

The IEEE Learning Objects standards [2] were followed for the entirety of this process. Other general principles for creating learning objects were adopted from [3], [4], [5], [6], and [7]. Also, with [8] being a guideline, a list of basic components in the context of our AR 3DLOs was set out as follows:

- 3D Content: shape and visual characteristics of the object representing each vowel sound
- Learning Objective: the essential vowel sounds and correct pronunciations
- Requirements: smartphones supporting AR technology
- Competences: abilities to correctly listen and pronounce the essential vowels
- Tasks: correctly listening and pronouncing the vowel sound represented by each object
- Evaluation: through analyzing application users' feedback based on a standard heuristics for AR application

For AR in the scope of this project, the **marker-based** tracking mode was chosen (as opposed to the *marker-less* tracking mode), considering the fact that most AR applications implement the marker-based AR as an simpler implementation for AR cameras to detect things that are hard-coded. AR cameras can use pre-defined markers for image recognition to calculate the relative pose of 3D models real time [9]. Moreover, the marker-based AR can take advantage of the fact that the WWL Level 1 recommends the student print out the vowel chart: Having a physical marker, the student can pick it up, rotate, and move it around, adding to the interactivity aspect.

IV. Implementation

For creating 3D models and animation, **Blender** [10], an open-source software, was used. For AR implementation, **Vuforia** [11], an AR software development kit, was used, which offers a database where makers (or, **image targets** in Vuforia) can be stored, fully supported in the **Unity** game engine [12]. A pseudo-UML diagram is shown in Fig. 2.

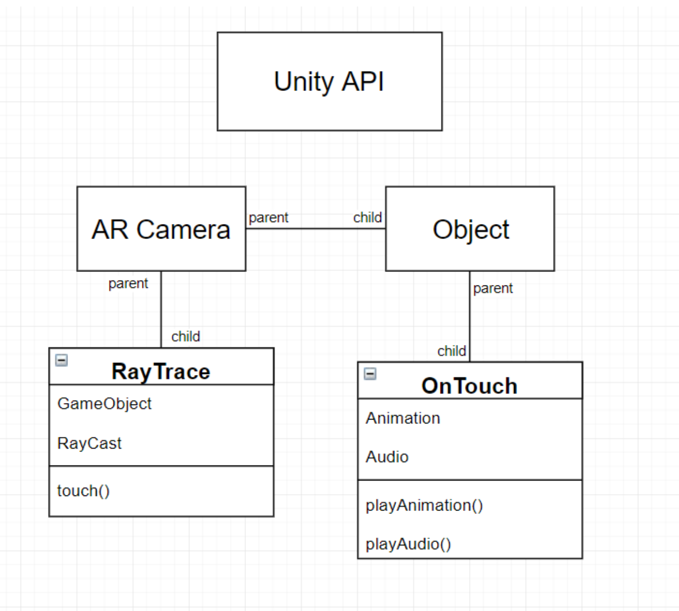

Fig. 2. A pseudo-UML diagram of the proposed application.

The Unity API deals with **GameObjects** and **Components**. It provides C# codes used to register **touch input** from the user, enabling to play associated animation and audio. Everything in a Unity scene is called a GameObject. Components can be attached to GameObjects to change how they look or behave. The **AR Camera** and **Objects** are GameObjects. Every 3D model (an Object) must be a child of the AR Camera. **RayTrace** is a C# script (a Component) that is attached to the AR Camera, which detects touch input from the camera. **OnTouch** is also a C# script attached to every Object. Each Object also has an Animation and Audio Component attached to it.

A. 3D Modeling

3D modeling is the process of creating a polygonal mesh. Primitive shapes like cubes, spheres, cylinder and cones are used as a starting point to create the rough shape of a model. A model consists of vertices, edges (each consists of two vertices), and faces (edges and vertices form a face), which define a shape of an object. These can then be pushed, pulled, moved, rotated, scaled, or extruded along the x-, y-, or z- axis to shape models. The Blender Edit Mode allows to make models more detailed. Careful placement of vertices/edges/faces is required to maintain models' good topology, so that no random deformations or artifacts will be produced. Topology, in effect, means the wireframe structure of a model, affecting the ease of the subsequent animation phase.

The modeling process generally followed these basic steps:

- Add a primitive mesh to be used as a starting point for the model. For example, a cube is the fundamental shape of the given elephant model (Fig. 3).
- Move the vertices/edges/faces in the shape of the model. The cube is scaled along the different axes to encapsulate the general size of the body of the elephant. Loop cuts are placed on the model, "slicing" the mesh, so that faces can be removed to form the legs.
- Continue to position the vertices/edges/faces to refine the body shape and make it more rounded.
- Extrude parts. The trunk and ears are extruded from a selection of faces. Extrusion duplicates the selected faces to create new geometry that is still connected to the original mesh.

Blender built-in modifiers can be applied to objects. The most common modifier is the **Subdivision Surface** modifier, which divides the mesh into more polygons to smoothen the shape of the object. This was particularly helpful in making shapes more rounded without the need to add more vertices. In addition to the Subdivision Surface, smooth shading can be applied to gain extra smoothness of the surface. The notable advantage of using modifiers is that they are non-destructive - they can be easily removed without affecting the original model in the same manner as filters. It is also possible to apply the modifier to replace the previous mesh with the modified mesh. The mirror modifier was useful for creating symmetrical meshes.

Text was modeled in *Futura*, a font type that offers generous letter spacing that makes it easier for children to read, sufficiently similar to the style of letters used in school (Fig. 4).

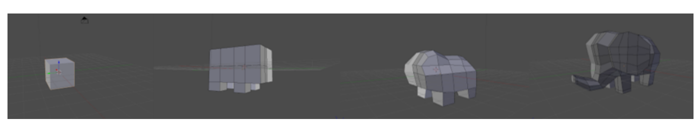

Fig. 3. An example step-by-step 3D model creation.

B. Texturing

Texturing is the mapping of 2D images onto a 3D model, which creates the "skin" of an object. A simple way to texture a model is to select faces of the model and assign a material with a color.

For more complex models like the boy model (Fig. 5), **UV Mapping** needed to be applied, which means the "wrapping"of a 2D image texture onto a 3D model. The model is marked

Fig. 4. A font type used, *Futura*.

using seams which tells signify where to "cut" the mesh into pieces as shown on the left. These pieces can then be colored before mapping back to the 3D model.

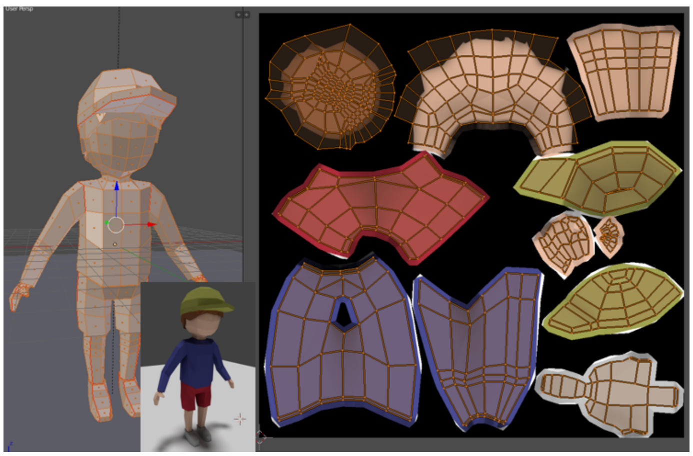

Fig. 5. An example complex texturing.

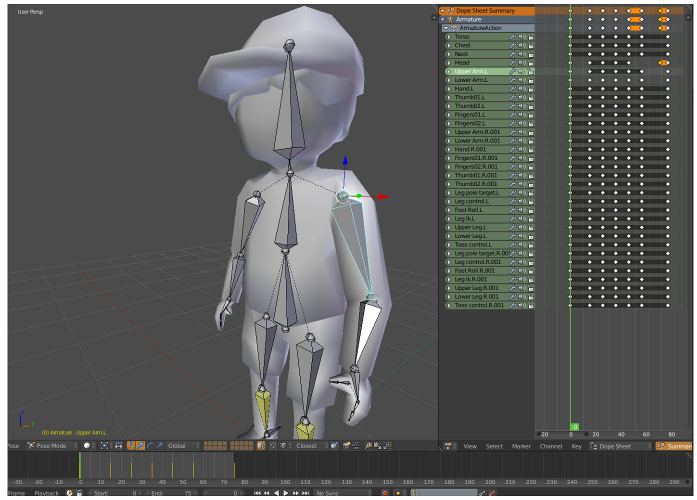

Fig. 6. An example animation creation using armatures.

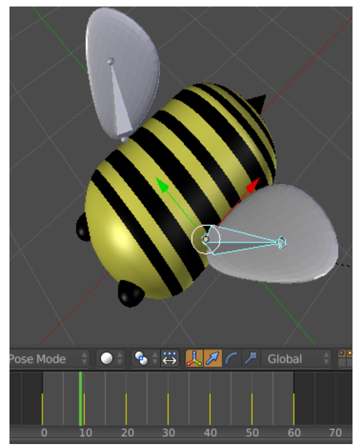

Fig. 7. An example animation creation using keyframes.

C. Animation

Each 3D model created was uniquely animated. In Blender, an animation process is displayed in the Timeline using **keyframes**. A keyframe is simply a mark on the Timeline that allows for interpolated animation. To illustrate, if a keyframe is added on frame 0 and the horizontal position of the model is at 30, and if another keyframe is added on frame 10 and the horizontal position is now set to 60, then Blender will automatically animate in between these keyframes. In other words, Blender can create frames filling between the two keyframes from position A to position B.

Armatures can also be used to move the mesh, which are the "bones" of an object. They were used for rigging, which means to control an object like a puppet. Fig. 6 shows that the armatures for the boy model reminiscent of a skeletal frame, while different armatures can control the main parts of the body (regardless of what the armature is parented to). Another instance of the use of armatures in the project was to control the wings of the bee model, for which keyframes are used to animate the wings flapping up and down, shown in Fig. 7.

D. Marker Creation

Each 3D model created was rendered back again as a 2D image inside Blender to print on a marker (see Fig. 8 for marker examples). The black and white border with small black squares around the image was used to optimize the accuracy and speed of marker detection by the AR camera. "Differences in luminance (brightness) are more easily detected than differences in chrominance (colour) using machine vision techniques. This is due to the poor automatic white balance of the cameras", according to [9]. While using purely black and white markers would be optimal, the design of our final markers is a compromise between aesthetic and accuracy. The markers were stored in the Vuforia database. Note that the WWL logo is not part of the marker, but something subsequently added for branding purposes.

Once markers are uploaded in the Vuforia database, target points are generated, to be used by the AR camera uses for image recognition. Each marker has unique placements of small black squares; naturally, to avoid object overlap or confusion, no two markers should be the same. The database becomes available for download as a Unity package file to be imported so that a licensed AR camera can access the markers.

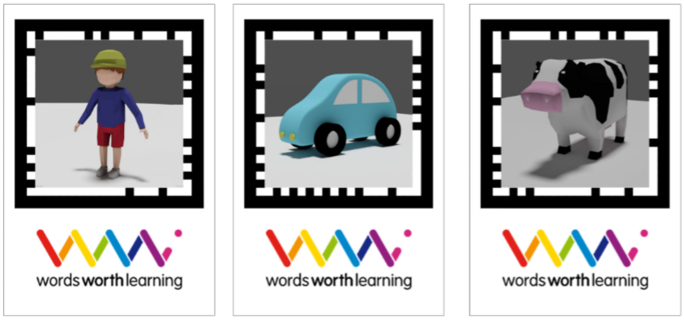

Fig. 8. AR marker examples.

E. Integration

For our implementation of an AR application, the default camera in a Unity scene needed to be replaced by an AR Camera. **Image Targets** was added into the scene. Markers were assigned in the respective configurations according to the database. Each Image Target has to be a child of the AR Camera.

The models (i.e., 3D objects and 3D text created, together with sound effects and vowel sounds) were imported in an assets folder. The 3D objects and 3D text have to be children of their corresponding Image Target, due to the fact that Unity works in a hierarchical fashion, which implies that an Image Target will only display its allocated children.

Each 3D object has an **Animation**, an **Audio Source**, an **OnTouch** C# Script, and a **Box Collider** attached to it. The Animation component contained the animation created in Blender. The Audio Source component contained a sound effect for that particular object (using royalty free material). OnTouch is a simple script that plays the animation and sound if the box collider is hit. A RayTrace C# script attached to the AR Camera was used to achieve a trigger to play animation and sound effects. RayTrace can be linked to a "laser beam" emitting from where the user touches the screen. A Box Collider, an invisible box surrounding the object, can be used for trigger detection - if the"beam" hits the Box Collider, the OnTouch script is executed which in turn plays the animation and sound of the object. The same configuration was also used for the 3D text.

Multiple target recognition was made possible possible by configuring Vuforia's maximum number of tracking objects/images. The image below shows that multi-marker recognition works.

After all AR 3DLOs were implemented, an Android app was exported from Unity by building the project scene and generating an **.apk** file. "Vuforia Augmented Reality" must be enabled in the Android settings (in the "XR Settings") for AR functionality. (The minimum Android version that supports this app is Android 4.1 "Jellybean". This is the lowest version that Unity allows for - any device that is below this version cannot properly run or install the app.) The final .apk file was uploaded in Google Drive to generate a download link (when installing an .apk file outside of the Google Play Store, which is the default app store for Android, the device usually asks the user to enable "Unknown sources" under the security settings to allow the installation of app outside of the Google Play Store.)

Fig. 9 and Fig. 10 show some screenshots of the AR application at work.

Fig. 9. The Android app implemented, showing one AR object.

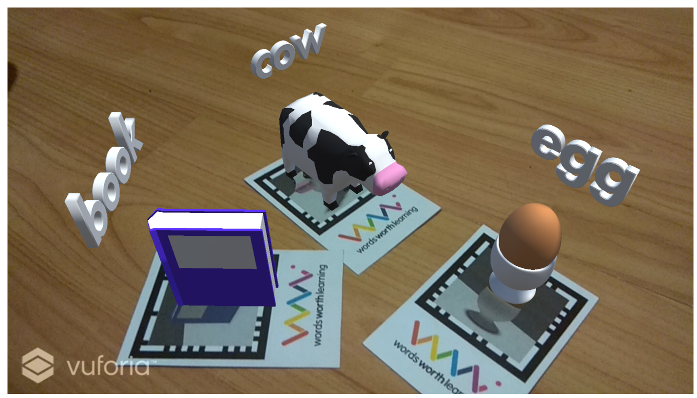

Fig. 10. The Android app implemented, showing multiple AR objects.

V. Evaluation

Feedback on the application with the aforementioned AR 3DLOs was collected and analyzed, following Nielsen's model as a guideline (Fig. 11), and Nielsen's heuristics as a standard for evaluation of AR applications (both described in [13]). Our review according to four particular key points adopted from the heuristics is as follows:

- "Show the system status to the user and give feedback within reasonable time" - The context of the application was explained at the start of the evaluation feedback: that the app was supposed to be used as an extension to accompany the vowel chart from WWL (the actual chart was shown in the feedback form for the users as a visual aid); and that it was aimed at 3rd/4th/5th class children.
- "Match with the real world by speaking the users language with familiar words, phrases and concepts and present information in a natural way" - To reiterate, the content is from WWL, used to teach students with reading

and spelling problems. The concepts are in the English language and the words used are specifically chosen for the vowel chart to maximize the learning experience.

- "Prevent errors" - Once the user has given feedback, any errors were investigated and improved upon to stop the similar errors from occurring in the future.
- "Be aesthetic and minimalist by design" - Since creative freedom was given for the design of the learning objects, the user feedback can have varying opinions due to aesthetic preference.

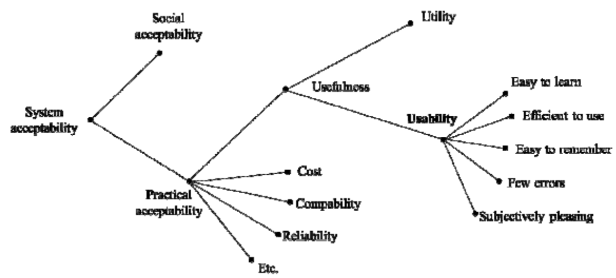

Fig. 11. Nielsen's model of attributes of system acceptability (adopted from [13]).

A. Feedback Responses

The application was evaluated based on the final outcome (i.e. how the AR application performed from a general user's perspective). A total of 25 people, including experts from WWL, participated in the evaluation. (Note that considering the scope of the current study focusing on a preliminary implementation, feedback from students with ADHD was not pursued on an ethical ground.) The overall user experience was positive in terms of the ease of use and the overall visuals, although the marker accuracy was comparatively unsatisfactory (Fig. 12).

On the next question regarding how the user felt about the design of the models, the results were overwhelmingly positive. The aesthetic was considered suitable for children. In this sense, the application was successful in fulfilling the key points about aesthetics in the aforementioned heuristics. Potential appeal to children will require future study.

As it turned out, the users generally believed that the integration of AR with the WWL content would enhance the learning experience of children because of the interactivity aspect and that they would highly recommend the application (Fig. 13, Fig. 14, Fig. 15, and Fig. 16). The visuals and the interactivity were the top qualities users liked about the application, which reinforces the key point about aesthetics in the heuristics. The users who interacted with the application were quite amused when testing it out, suggesting that AR grabbed their attention.

The most common problem experienced during the evaluation was an accuracy-related one, where some objects would overlap with each other or some markers would show completely different objects (see Fig. 17 for example).

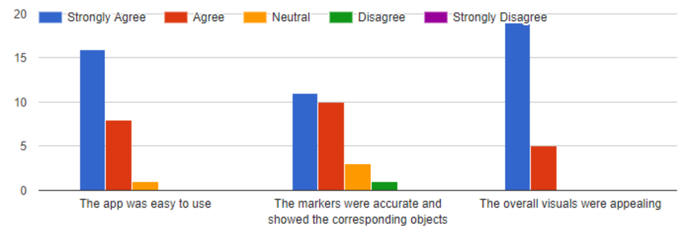

Fig. 12. A feedback overview.

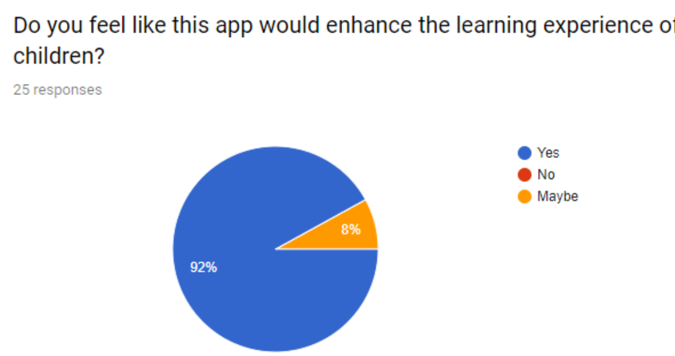

Fig. 13. Feedback about whether the users thought the application would enhance learning experience.

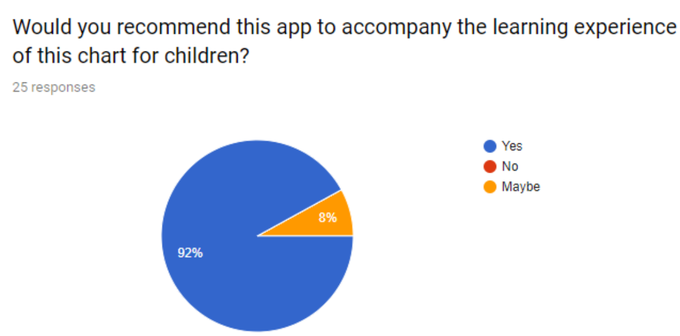

Fig. 14. Feedback about whether the users would recommend the application.

B. Improvement Reflecting Feedback

The problem that occurred might have most likely been due to the lighting conditions in the settings where the users tested the application and/or the actual marker accuracy. The main cause for this problem was the fact that the previous marker design had too little target points for the AR camera to detect. It was for this reason that the marker design was updated to include the black and white border with squares, allowing more target points to be assigned to markers (Fig. 18). Using the black and white border also helped the camera in recognizing markers in poorer lighting conditions. Fig. 18 shows the improvement compared to the previous marker style

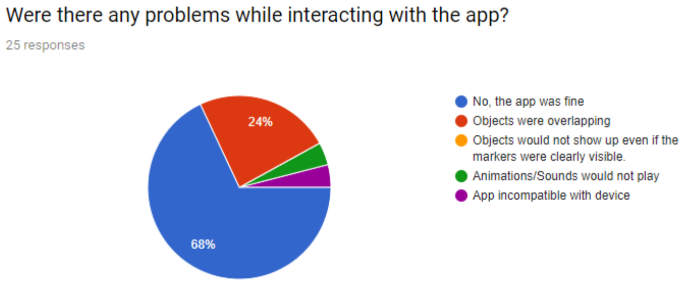

Fig. 15. Feedback about the interactivity of the application.

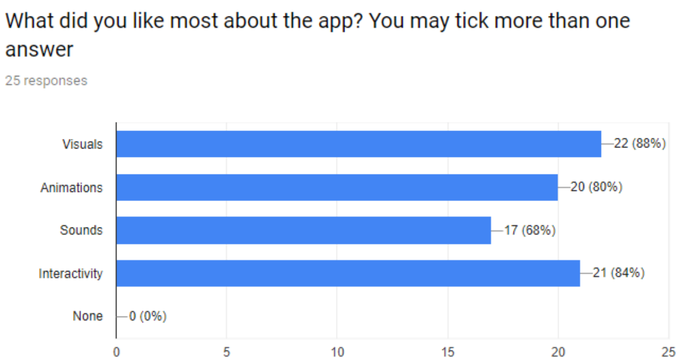

Fig. 16. Feedback about what aspects the used liked about the application.

Fig. 17. An example of the common problem experienced by the users.

(Fig. 19) in terms of the number of target points. The new marker design improved the overall accuracy of the markers as it added more target points, resulting in all the models appearing properly on their corresponding markers.

Another issue experienced was that the animation/sound effects would not play, which was fixed by increasing the Box Collider sizes in Unity so that touch inputs could be detected more easily.

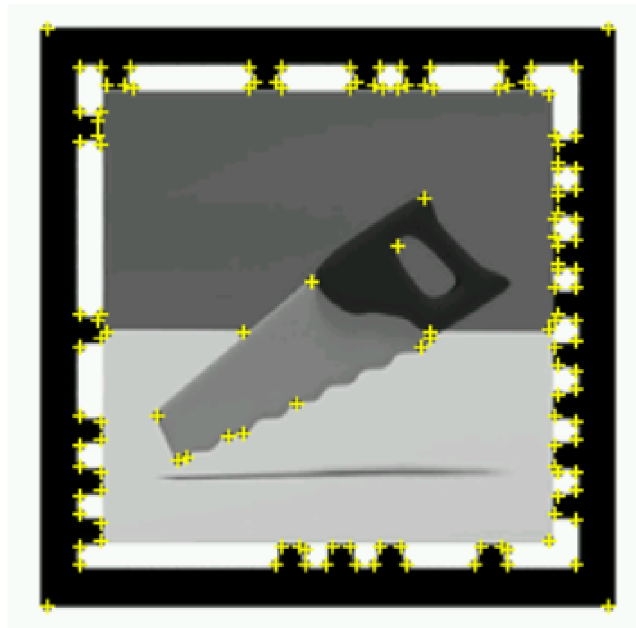

Fig. 18. An improved AR marker example.

VI. Conclusion

The main objective of the current pilot project was to provide a foundation for creating an AR application with 3DLOs to enhance the learning of a student with ADHD. Through the implementation and the evaluation, the potential of the use of AR in an educational system was explored.

Importantly, it was highlighted that AR has potential to bring more interactivity, possibly allowing users to become more engaged in the content, if properly presented, according to different needs of users. Applied in educational settings, students will be more engaged in the learning material, which might be irrespective of whether having any difficulties in learning or studying such as ADHD. AR-powered educational systems will be able to help students visualize concepts that cannot be easily described through two dimensional ways, especially things that are abstract, invisible or unobservable by using virtual objects. Thus, AR will potentially enhance students' understanding of difficult concepts through enhanced visualization.

A. Future Work

Implementing AR for the consonant chart, the other foundational chart in WWL, will be the next step of applying the aforementioned AR 3DLO creation techniques and procedures.

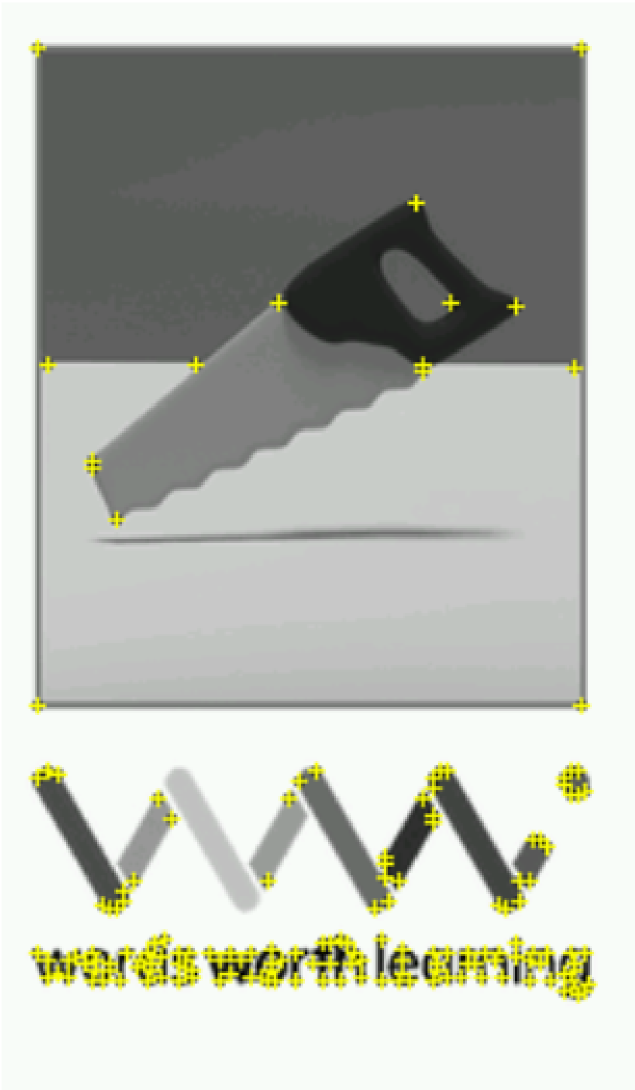

Fig. 19. A previous AR marker example.

More specifically, the consonant chart contains all the consonants in the alphabet except for q, x and y as they do not contain sounds of their own. Sounds are made through different tongue, lip and teeth positions. For most of the sounds the air and voice sounds come out of the mouth but there are three nasal sounds where both the air and voice sounds come out of the nose (m, n and ng). Consonants that have the same tongue, lip and teeth position are contained in the same line (p and b). The sounds on the left column are the voiceless sounds where there is no vibration in your voice when you make the sound. The sounds on the right column are voice sounds where the user will feel a vibration when making the sounds. For this reason, the 3D modeling and animation of lips with a tongue, teeth, and nose will be more complicated and laborious. Similarly, the content for the remaining levels up to Level 7 in WWL will be another future line of research.

Once all the WWL content has been equipped with AR 3DLOs, final evaluation should be pursued from students with ADHD for a better implementation of such an educational system with an AR solution.

B. Final Remarks

Using AR, traditional learning scenarios can be enhanced and complemented by allowing the learners to have a multi-sensory experience, such as by presenting lessons in a 3D format. Furthermore, tablets are becoming widely used in more schools to aid learning. With such readily available devices, it would be easy to integrate AR in the learning environment. It is as simple as downloading an application onto the device. The use of AR in education has a vast potential to allow the students to stay focused on learning and the teachers to support them more effectively.

More in general, such immersive technology with AR-enhanced content can potentially be applied to learning for children with different conditions other than ADHD and for people in different age groups, as well as learning of advanced subjects and in different settings outside school or home. Comprehensive and in-depth research into various parameters and aspects to do with the technology responsible for providing best learning experience in a range of scenarios is recommended, such as embeddedness and modality of AR objects, effects (and side-effects) of introducing gamification, to name a few.

Acknowledgment

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