ARETE – DELIVERABLE (D3.3)

WP3 – D3.3 Interactive collaborative ARETE Mobile app for Pilot 1

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The final version of the deliverable will be published as soon as approved by EC.

Table of Contents

Executive Summary

This deliverable reflects the work conducted for Task T3.3 involving the development of the **ARETE Augmented Reality mobile app for Pilot 1** and also presents **further research** on the area of **applied AR for advancing literacy skills**.

WWL, is an SME with 30+ years clinical/educational experience and 10 years technical experience with our online literacy programme (including Web-AR), working with teachers, parents and children. We started research for the ARETE Project by considering the following factors for the cohort involved: age, educational limitations, access to technology in school and at home. It is important to note that our ARETE Pilot 1 cohort are schoolchildren between the ages 9 to 12 years old and as such, they are subject to restrictions for children of this age, *that precludes using AR/VR wearable technology in school*. Unfortunately, for this cohort, this significantly restricts the use of state-of-the-art AR technology that may be commercially available or available in research labs. According to information gleaned from our Systematic Literature Review, however, we can produce state-of-the-art for both **content and technology for literacy improvement** with the app.

Additionally, WP3 has taken the initiative to **further explore areas of advancement** beyond the state of the art with applications on *vowel training* and utilising *eye gazing functionality for reading speed assessments* (lead by UCD).

Over the last few years mobile device technology (tablets & smartphones) has advanced with significant improvements in using AR software and tracking systems. This has heralded a mass adoption of AR apps across many sectors e.g., Healthcare, Air & Space, Marketing and in particular EdTech which is growing, particularly in tertiary and secondary education. ARETE Pilot-1 focuses on the primary school sector, to provide the following:

A. Meaningful educational content
B. Effective AR object interaction with the real world
C. Added value over existing pedagogy

Our Pilot 1 primary school cohort are identified as having 'reading and/or spelling' difficulties, which are the foundation literacy skills everybody needs for learning going forward. We will address this issue as follows (A) **Content:** Using the content contained in our WWL evidenced-based literacy programme, which incorporates the 5 Pillars of 'Science of Reading Instruction' approach indicated below:

SCIENCE of READING INSTRUCTION				
Phonemic Awareness	Phonics	Comprehension	Vocabulary	Fluency

National Reading Panel 2000

and (B) **Technology:** by extending the Web-AR objects and procedures, previously developed for our WWL online programme and (C) **Pedagogy:** by improving literacy attainment for the age group, specifically the remediation of 'reading and/or spelling' difficulties.

1. Introduction

The ARETE Pilot-1 AR-App is developed from WWL's online Web-AR programme, which is a complete 'end to end' literacy programme that is being used in mainstream education (schools and at home) and also for remedial purposes. It's conversion to a mobile AR App is heavily "front-loaded", with redesign, redevelopment and redeployment tasks from the very start of the Project. It is effectively a Learning Management System (LMS) that contains: 100+ audio/video tutorials and scripts, multiple unique rules and novel perspectives on known rules, 330 literacy reading and spelling exercises, 8000+ audio word files, 12 multiple-choice questionnaires, 90 AR phoneme icons and rule-based flashcards. Some of the content had to be modified, in some way, to be delivered as an AR-App.

In the last few years AR has been growing rapidly, gathering momentum in the gaming and commercial sectors. In more recent times AR technology has been expanding across many sectors e.g., Education (EdTech), Healthcare, Travel, Marketing, Air and Space and the technical skill sets required to create Apps are in high demand. For the Arete Project Pilot 1 App we began to focus on the following:

- State of the art infrastructure and AR-tools to develop an AR-App that will be used on mobile Tablet devices (iOS or Android)
- The availability of up-to-date technical "skill sets" required to create the AR App i.e., Graphic Design, UI/UX, AR/App S/W Development and AR /3D Modelling and Animation.
- The advancement of the state of the art for key functions within literacy skills programmes that could be utilised with the advancement of the technology (Hololens) and the provision of open source MirageXR platform.

Notwithstanding COVID 19, and the scenario above, it has been challenging to recruit and retain skilled and experienced AR Software Developers, Designers, UI/UX Developers, AR/3D Modeller / Animators, especially considering availability, salary costs, project deliverables and the budget.

2. Systematic Literature Review on AR and Literacy Skills

We conducted a systematic literature review (SLR) involving the use of AR in primary school education, particularly for English language literacy in the 9 to 12 year old age group and specifically for the cohort with identified or diagnosed reading and spelling difficulties. Given the exponential growth and advancement of AR over the last six years, we decided to focus our attention on that period. In general, over the last few years there has been a significant growth in the functionality and use of hand-held AR devices, specifically iPad and Android tablets. In a previous EU Project (AHA ADHD-Augmented) we implemented a Web-AR "marker-based" version of the WWL programme which was developed and deployed, with mixed results (Tosto et al. 2019). In the interim, with the advent of more advanced 'markerless' opportunities on those mobile devices, we decided to research the impact of a markerless AR-Apps and Tablets are the devices that will be utilised in the ARETE Pilot 1 project. To portray the latest trends in AR for literacy development, we have conducted a SLR covering the last 6 years **(2014 to 2020)**, with a focus on the following:

1. Identify relevant evidence based AR literacy apps available and reviewed.
2. Identify the methodologies, technologies and environments:
    a. commonly deployed
    b. considered to be 'State of the Art' and beyond.
    c. suggest future related research ideas or directions.

2.1 Methodology

Inclusion Criteria

1. Primarily, only papers published from 2014 to 2020 were considered.
2. The term Augmented Reality must feature
3. The cohort was ideally for Primary School Children, however broader age bands were considered if the content was relevant.
4. Exclude the term 'disability'(when referring to intellectual disability), but 'disorders' and 'difficulties' are acceptable as the terms carry very different meanings, nuances and presentations.
5. The nature of the APP was to concentrate on the oral language-literacy continuum with a focus on improving literacy.

Exclusion Criteria

1. Papers not related to AR
2. Papers not covering the Pilot 1 Cohort:
    a. not English Speaking
    b. not related to English Language or Literacy
    c. Apps for Disabilities (e. intellectual disability, severe hearing impairment / deaf community, visual impairment / registered blind community, requiring sign language or braille)

Number of papers that fulfilled this selection criteria = 80

Papers were reviewed with a reference to the following characteristics:

1. Studies involving apps for literacy development
2. Marker versus Markerless studies
3. Type of data collected: Qualitative or Quantitative
4. Benefits of AR educational tools

5. Challenges of AR educational tools
6. Literacy / teaching pedagogical approaches in use and integrated in AR applications
7. Participant demographics: age, gender, number
8. Devices used: hand held, head mounted, desktop etc
9. Platform and Software Development Kit (SDK) in use

Population Intervention Comparison Outcomes (PICO) Search Engine Questions:

1. “Are AR literacy resources better than traditional teaching methodologies at increasing primary school children's reading accuracy skills”
2. “Are AR literacy resources better than traditional teaching methodologies at increasing primary school children's reading comprehension skills”
3. “Are AR literacy resources better than traditional teaching methodologies at increasing primary school children's reading rate skills”
4. “Are AR literacy resources better than traditional teaching methodologies at increasing primary school children's spelling skills”
5. “The use of AR in English literacy interventions for primary school children”
6. As the results were exceptionally low for the above PICO’s, the search was altered and the question minimised to include only Augmented Reality and language, vocabulary, reading accuracy / comprehension / rate or spelling.

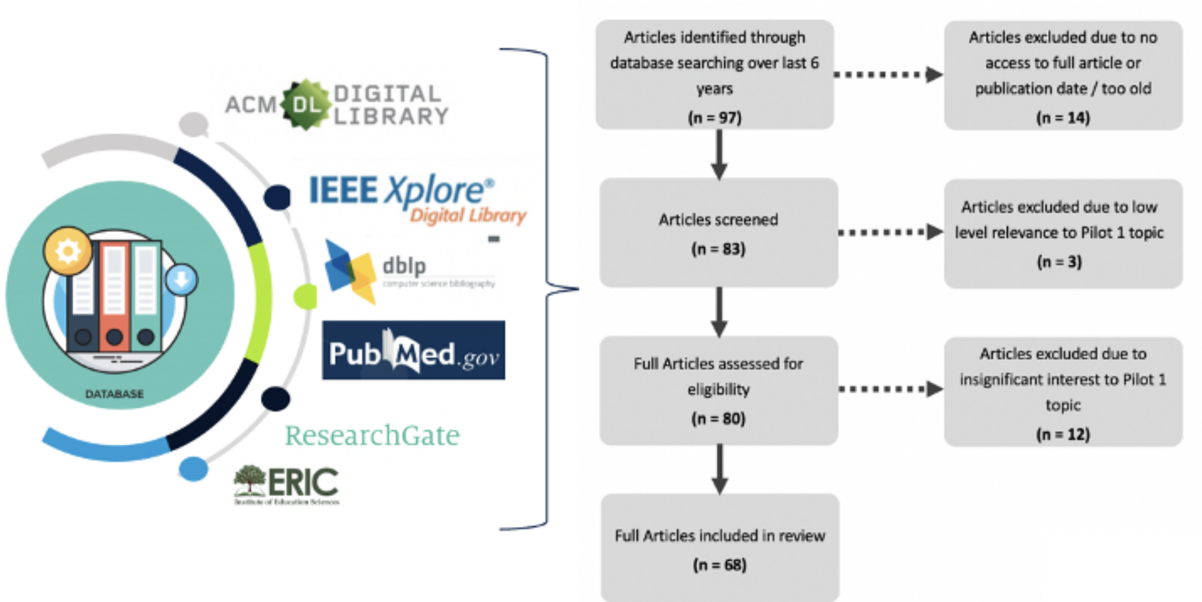


Figure 2.1: SLR Primary studies selection based on 6 sources

2.2 Results - Benefits and Challenges

The SLR showed that there are few literacy articles relating to Pilot 1 cohort, which is 9 to 12 year old students with reading and spelling problems. This was confirmed by a number of researchers in more recent SLR articles (Fan et al., 2020; Parmaxi et al., 2020; Quintero et al., 2019; Khan et al., 2019; Santos, 2016). The primary focus of the review was to consider any advancements and recommendations reported and evaluate those against the Pilot 1 AR-App with regard to identifying its position as "State of the Art".

In this context it is important to remember that the 'stakeholders' for Pilot 1 are Primary School children (9 - 12 years of age) that have been diagnosed with English language reading and spelling difficulties and that 'Education Policy' for **children of this age precludes the use of wearable AR/VR devices**. This obviously reduces the prospect for introducing "State of the Art" advancements within the AR/VR wearables domain.

Fan et al. (2020) reviewed 45 English-focused articles, out of those, 40 articles focused on the topic of English as a foreign language (EFL), while only four of the articles discussed learners with special educational needs (two for autism, one for dyslexia, and one for attention deficit hyperactivity disorder). 28 of the studies explored, evaluated the learning effects of AR applications, affective outcomes, and/or usability testing, 11 focused on usability testing results, 6 focused on affective outcomes, while 8 presented **AR prototype design without any evaluating studies**.

The benefits and challenges associated with the AR interventions for participants with disabilities / Special Educational Needs (SEN) are listed below (a copy for quick access is provided in Annex 2):

Benefits	**Challenges**
Improved motivation, (Parmaxi et al. 2020, Quintero et al. 2019, Howorth et al. 2019, Sommerauer et al. 2019, Khan et al. 2019, Awang et al 2019, Safar et al. 2017, Akçayir et al 2017, Saltan et al. 2017, Lin 2016, Diegmann et al 2015, Solak et al. 2015, Bacca et al 2014, Wu et al 2012, Schmitz et al. 2012). **Increased interaction** (Parmaxi et al. 2020, Quintero et al. 2019, Howorth et al. 2019, Safar et al. 2017, Saltan et al. 2017, Wu et al 2012). **Increased collaboration** (Parmaxi et al. 2020, Li et al 2017, Safar et al. 2017, Santos et al. 2016, Diegmann 2015). **Increased interest and engagement.** (Quintero et al. 2019, Howorth et al. 2019, Sommerauer et al. 2019, Li 2017, Akçayir et al 2017, Safar et al. 2017, Saltan et al. 2017, Wu et al 2012, Schmitz et al. 2012, Bacca et al 2014). **Comprehend concepts faster** (Parmaxi et al. 2020, Quintero et al. 2019, Hrishikesh et al. (2016), Li et al 2017, Safar et al. 2017, Akçayir et al 2017, Lon 2016, Bacca et al 2014, Schmitz et al. 2012, Specht et al. 2011).	**Technical problems,** inability to recover from various types of tracking loss and control difficulties. (ChanLin 2018, Quintero et al. 2019, Sirakaya et al. 2018, Akçayir et al 2017, Saltan et al. 2017, Fitzgerald et al. 2015, Phon et al. 2014, Bacca et al 2014). **Lack of research on using mobile AR in education with students with special educational needs**. (Fan et al 2020, Parmaxi et al. 2020, Quintero et al. 2019, Khan et al. 2019, Akçayir et al 2017, Cihak et al 2016, Schmitz et al. 2012). The **need for educational staff to have basic digital knowledge** for adopting ICT in the classroom. (Lee et al 2021, Quintero et al. 2019, Howorth et al. 2019). The **difficulty in recruiting participants** for a study and the complexity of getting permission documents etc. from parents, (Quintero et al. 2019). Resulting in **diminished sample sizes**.

Has the potential to **decrease the complexity of a concept** by affording the ability to visualizing unobservable objects and concepts (Park et al. 2019, Luna et al. 2018, Akçayir et al 2017, Safar et al. 2017, Phon et al. 2014,Wu et al 2012). **Holds / improves attention** (Parmaxi et al. 2020, Quintero et al. 2019, Sommerauer et al. 2019, Khan et al. 2019, Li 2017, Santos et al. 2016, Tentori, 2014). **AR benefits students who have SEN**, evidencing the work with the following populations Quintero et al. 2019 cites: (*auditory limitation* (Carvalho and Manzini, 2017), *visual limitation* (Lin et al., 2016), *autism* (Tentori et al., 2015), *attention deficit hyperactivity disorder* (Lin et al., 2016b), *dyslexia* (Persefoni et al., 2016). **Low cost of implementing this technology in the classroom**: despite the high cost of vision devices, hand held devices and laptops are good tools to support learning processes in the classroom. Quintero et al. 2019 cites (Zainuddin et al., 2010; Ab Aziz et al., 2012; Chen et al and Wang, 2015; Hsiao and Rashvand, 2015), Akçayir et al 2017). **Helps with short and long-term memory** (Parmaxi et al. 2020, Howorth et al. 2019, Sommerauer et al. 2019, Quintero et al. 2019, Cihak et al et al. 2016, Diegmann et al 2015, Bacca et al 2014, Vullamparthi et al. 2013). **Innovative use of AR applications, to integrate evidence-based teaching strategies can transform learning** for students (Howorth et al. 2019). The lesser reported areas of benefit are: **Efficiency in the learning process** (Sommerauer et al. 2019, Quintero et al. 2019 cited Fernandez et al., 2015; McMahon et al., 2015; Wang, 2016), Akçayir et al 2017, Wu et al 2012, Schmitz et al. 2012).	**Luminosity difficulties** / insufficient appropriate lighting. (Quintero et al. 2019, Fitzgerald et al. 2015). It is **generally not possible for the user to change or add 3D images to the AR application.** (Quintero et al. 2019). **Long-term results of the use of AR are needed** to prove its effectiveness as a teaching methodology in order to promote long-term educational inclusion. (Quintero et al. 2019). **Requires student training in digital competence.** (Quintero et al. 2019). The **novelty effect could produce research results bias.** (Quintero et al. 2019). **Often only one tool to collect data information is used** e.g. surveys or interviews, however, in the case of children with SEN's it is recommended to access a variety of qualitative and quantitative data collection tools in the same study. (Quintero et al. 2019). **More robust research is needed** to prove acceptability in school environments. (Quintero et al. 2019). **High cost of tablets and high-speed internet availability** (Lee et al 2021, Howorth et al. 2019, Saltan et al. 2017, Fitzgerald et al. 2015). Concerns regarding **'cognitive overload'** (Hsu 2019, Chen et al 2019, Li 2017, Akçayir et al 2017, Fitzgerald et al. 2015, Phon et al. 2014, Wu et al 2012). **Female students have more trouble learning to use the AR platform**, as girls are reported to have lower 3D spatial ability than boys on average. (Hsu 2017.) **Physical problems in using mobile AR,** such as grip and posture strains (ChanLin 2018). **Problems integrating AR into traditional learning methods and teaching pedagogies** (Lee

Development of cognitive skills (Quintero et al. 2019 cited Benda et al., 2015; Bülbül et al., 2016), also Saltan et al. 2017). AR and QR codes **provide a scaffolding tool** to printed text to supply the student with additional digital materials so that students do not need to distance from the text to find more information e.g. the meaning of the unknown words etc. (Park et al 2019). **Promote student inclusion** in the community (Howorth et al. 2019). **Improved language / vocabulary learning performance** (Parmaxi et al. 2020, Solak et al. 2015, Chen et al 2015). **Enjoyment in the training process** (Quintero et al. 2019 cited Sheehy et al., 2014), Li 2017, Bacca et al 2014). Provision of **compelling learning experiences** (Santos et al. 2016). **Improves student attitude to learning** (Saltan et al. 2017). AR may **lead to better retention of words** (Santos et al. 2016, Bacca et al 2014). AR Games can **provide educators with powerful new ways to demonstrate relationships and connections,** thus promoting learning through a highly interactive and visual methodology. (Diegmann et al 2015). **Student satisfaction** (Quintero et al. 2019 cited Chang et al., 2013; Sahin et al., 2018), Khan et al. 2019, Akçayir et al 2017, Safar et al. 2017, Santos et al. 2016). **Increased Confidence** (Khan et al. 2019, Li 2017). **Decreases Cognitive Load** (Akçayir et al 2017). **Decreases learning frustration for children** with special educational needs (Lin et al 2016). **Students preference for digital learning:** The explosion in the use of smartphones, tablets and	et al 2021, Saltan et al. 2017, Akçayir et al 2017, Fitzgerald et al. 2015). A **deficit of appropriate AR educational resources** (Safar et al. 2017). A general **resistance to new technologies** (Saltan et al. 2017, Safar et al. 2017, Wu et al 2012). **Ineffective design of AR application** – leading to distractions and frustration (Saltan et al. 2017) **AR requires reasonably up to date smartphones or tablets** – may be prohibitively expensive for some learners, risking a digital divide between learners from different socio-economic backgrounds (Fitzgerald et al. 2015). **Limited availability of AR experts** (Safar et al. 2017). Taking cognizance of the **diversity of students and differences in learning preferences and learning styles**, that AR might not constitute an effective teaching and learning strategy for some students (Safar et al. 2017, Li 2017, Bacca et al 2014, Wu et al 2012). **Reading performance on AR can be different and slower** from that on a traditional desktop display or from paper, due to the 3D display, the pixel density, the field of view, the distance to the eyes, and background texture. (Rau 2018).

apps for education have demonstrated that these new technologies have more effective features to enrich learning environments resulting in the majority of school aged students preferring digital learning (Evans, 2019).	

Concerning the availability of suitable State of the Art technology within the education sector, WWL will **in summary for pilot 1** address the following recommendations that are contained in the SLR regarding future development and research:

a) The lack of research data concerning the use of mobile AR-Apps in the education system, for students with special educational needs. *Note:* The Pilot 1 focus is specifically for students that have literacy difficulties and probable neuro-diversities. Research data will be collected and uploaded, also via xAPI to the project's learning record store (Learning Locker).
b) Look at medium term retention of information: for Pilot 1, post testing will occur approximately 6 months after the initial assessment. Whilst there is certainly a place for further reassessments to evaluate the long-term results regarding the use of AR, this is not within the remit of this project.
c) Student usage of the WWL AR-App will span approximately 6 months and it can be assumed that any 'novelty effect' should have disappeared over that period and results should reflect any benefits from using the AR App.
d) Clinical research data will be collected via an assortment of qualitative and quantitative data collection tools and technical research data will be collected via xAPI.
e) Due to the 'scaffolding' design for the WWL AR-App delivery, combined with multiple interactive exercises and a deep focus on the 'over learning' teaching approach – the likelihood of 'cognitive overload' should be minimal.
f) From our experience, working for decades in collaboration with schools, teachers, parents and children – we have found that resistance to new technologies in education is normally due to the fact that the technology on offer is (i) not always accessible due to network or device issues or (ii) not easy to use within the confines of a busy classroom environment. The former is not something that can be controlled, however for the latter the ARETE Pilot 1 AR-App has been designed in such a way that it is intuitive, easy to follow with short lessons. There will also be an online teacher training package explaining how the AR-App will work, no other training is required.
g) For Pilot 1 the stakeholders will require Tablets (iPad or Android) that have AR functionality – unfortunately this is the reality of using "state of the art" technology for "research". This will continue to be a problem until governments are able to tackle digital poverty in the school environments. This, of course, has become more apparent during the COVID -19 pandemic and may be the catalyst that is required.
h) Exploring the areas of diversity of students, differences in learning preferences and learning styles is of particular interest from the research perspective and will be a major focus for Pilot 1.
i) The concern regarding reading speed of students utilising literacy material containing AR is mitigated within the app as no lesson, exercise or game has a time restriction. Students can access the app on their own mobile device and learn at their own pace and in their own time.
j) The WWL AR-App is based on the original WWL Web-AR programme which is evidence-based and has an established and recognised literacy pedagogy. It is a Learning Management System

(LMS) that starts with teaching speech sounds and progressing to reading and spelling words and sentences in stories with up to seven syllables. It is a comprehensive programme that has been converted into an AR-App for use on iOS and Android tablets – and we believe it will substantially address the reported deficit of appropriate AR educational resources for the particular cohort involved.

2.3 AR Flashcards

Chen et al. (2019) reported on a study undertaken to compare the effectiveness of using animal-related vocabulary AR flashcards as opposed to just using traditional card flashcards found that while both approaches could significantly improve children's vocabulary learning, there was no significant difference in effectiveness between either approach. On the other hand Ibrahim et al. (2018) conducted a study to assess the potential benefits of AR technology for immersive vocabulary learning in a foreign language. He compared the effectiveness of an AR vocabulary prompter with traditional paper flashcard-based learning approach for learning nouns in a foreign language. His findings were that the use of AR technology to provide virtual labels on real-world objects was more effective and enjoyable for the student and their retention over time was also better. In addition, He (2014) in an earlier study found a significant difference in performance for vocabulary learning in EFL students who used mobile-based AR learning as opposed to traditional flashcard instruction, in favour of the former. What can be taken from these studies is the fact that AR technology integrated into traditional flashcard strategies can only bring about a positive learning effect for the student, ergo the use of AR flashcards as a feature should be considered in learning app design.

2.4 Qualitative/Quantitative Data collection

When employed to substantiate AR methodologies for learning, there were very clear data collection trends observable throughout the literature. Sirakaya et al. (2018) found the following main data collection tool preferences in descending order:

1. Surveys / Questionnaires (29.9%)
2. Achievement tests (16.9%),
3. Interviews / focus groups (13.3%),
4. Attitude, personality or aptitude tests (10.2%)
5. Observations (9%)

Whereas Li et al. (2017) noted that the most commonly used measurements for learning achievements were pre-test and post-test regarding knowledge content, while observations, questionnaires, and interviews were all frequently used to determine motivation and changes of attitudes before and after using the AR games. Dey et al. (2018) in their literature review noted that questionnaires were the most popular data collection method employed.
Khan et al. (2019) concurred with this finding and opted for pre and post questionnaires as their study was evaluating motivation. Fan et al. (2020) also reported that the most frequently used measurement of learning achievement was the application of pre and post-test measures for vocabulary knowledge. However, these measurements often only tested whether students could remember learnt literacy knowledge (e.g., remembering the trained vocabulary) rather than whether students could apply 'higher order thinking' to their knowledge base (e.g., using the learnt phonemes / letter correspondence and rules to spell out similar new words or use the learnt words in contexts). They also went on to report that the majority of studies measured the learning outcomes immediately after

the use of the AR applications, thus demonstrating short-term memory gains only and not providing proof of retention over time.

This is an essential factor to consider in future research methodology design, ensuring collection of the fullest data possible across domains, providing both qualitative and quantitative data and allowing for time lapses between pre and post testing to accurately evaluate retention over time. As the literature reviews so far have exposed major challenges in this area vis a vis both the lack of research and the research methodologies utilised so far to validate AR for literacy intervention, it is now crucial going forward to accurately judge and justify the use of AR in education as an effective teaching methodology in order to promote long term acceptance within the school environment, (Fan et al. (2020), Parmaxi et al. (2020), Quintero et al. (2019), Khan et al. (2019), Akçayir et al. (2017), Cihak et al. (2016), Schmitz et al. (2012)).

2.5 Software Development Kit (SDK)

The most preferred development tools are Unity and Vuforia plugin (Fan et al., 2020). Quintero et al. (2019) reported some studies were multiple tools were used: The SDKs used to develop the AR applications were Vuforia with Unity for mobile apps - reducing technical limitations (Amin and Govilkar, 2015), ARToolkit, FLARToolkit, Vidinoti, NyARToolkit, ARTag, ARToolkit for Unity. Programming and Development languages used were Scratch, Visual Studio, C#, UnityAR, Java or JSP, Flash, but very little difference were reported between them. Registered Authoring Tools used were Aurasma (now HP Reveal)/HP Reveal, which is one of the most used tools for the web browser, available for Android and iOS and free (Delello et al., 2015), Layar, Author AR, Wikitude. Software for 3D modeling: "Blender", "Irrlicht3D, OGRE3D". "Blender is a multi-platform computer program, dedicated especially to modelling, lighting, rendering, animation and creation of three-dimensional graphics, it is a free software" (Rosales, 2015); in recent years this system has gained more followers (Dovramadjiev, 2015). 52% of studies do not mention the software tools used to create the AR applications.

Vuforia was used to detect and track the marker on the lowercase letters and pass its identity to Unity to run the app (Fan et al., 2018). In their study various markers were used. They initially tried a marker-less approach to detect various lowercase letter fonts, but experienced problems in the AR scenarios for lowercase letter detection. OpenCV, Vuforia, ARTookit only allow for whole-word detection not single letter detection. Detected single letters using Machine Learning but lag-time was too long in real-time video AR scenarios. They found that several lowercase letters are very similar and more likely to be mis-detected. As a result they switched back to the marker-based solution for their App.

Note: This review recommended further research should continue to explore potential solutions for lowercase letter detection in AR designs and this is something that was addressed and remediated in later versions of Unity and ARkit framework which was a primary consideration and subsequently employed for the Pilot 1 App.

WWL created a new AR app for iOS and Android devices. Taking account of the review recommendations from the previous studies and due diligence from our commercial perspective, our decision was to use the ARFoundation (2019) framework and the ARKit and ARCore SDKs which offer free, open-source AR SDKs. This is now one of the biggest iOS AR platforms and has a significant active community of developers. It offers developers stable and fast motion tracking, SLAM tracking, support for Unity, plane estimation with basic boundaries, scene understanding e.g. placing virtual objects on vertical surfaces, true depth camera with light estimation and rendering optimisations..

A major update in 2020 provided AR developers with additional key tools for creating an augmented reality app:

- RealityKit helps integrate photorealistic rendering and camera motion effects with a native Swift API;
- Motion Capture allows tracking of people's arms, legs, head or torso in real-time.
- Reality Composer – is a library of objects and animations with 'drag-and-drop' tools to facilitate creating interactive environments;
- People Occlusion provides layering functionality for placing virtual content in front of and behind people;

2.6 Marker and Markerless Apps

Phon et al. (2014) state that there are two taxonomies of AR: marker based and markerless. Markerless relies on the real environment as the target to project a virtual object.
Bacca et al. (2014): Most of the studies at that time used "Marker-based AR" (59.3%) which means that most of the applications developed for educational settings use markers. A possible explanation for this result is that currently the tracking process of markers is better and more stable compared to the marker-less tracking techniques. "Markerless AR" has not been widely used in educational settings (12.5%). Markerless AR needs some improvement in algorithms for tracking objects.

Note: Regarding AR SDKs that provide "Markerless AR", the situation has evolved since 2014 with considerable improvements in mobile functionality for applications that need 3D tracking support and the ability to recognize 3D objects. Image tracking functionality can expand opportunities in AR apps to a greater extent. Moreover, SLAM (Simultaneous Localization and Mapping) allows mobile apps to map an environment and attach AR objects in the real-world environment and track movements in it. This technology can also create indoor navigation.

Sommerauer et al. (2019) to date reported that only a few empirical studies have investigated the potential of Markerless AR for supporting learning.

Saltan et al. (2017): This review included different technologies used in AR applications e.g. print-based, marker-based, location-based, gesture-based, image-based, and haptic-based. The majority identified in the review used marker-based AR technology to enhance the teaching and learning processes in formal education.

Sirakaya et al. (2018): This review indicated that Marker-based AR was preferred in the majority of educational AR studies (86%) with location-based AR (11%) and hybrid AR (3%). It also states that Marker-based AR is a relatively easy technology to use and compared to others is easier to develop marker-based AR applications (Lu & Liu, 2015). Location-based and hybrid AR applications were used less and this may have been related to lack of technical skills on the part of researchers in developing these applications. However, location-based AR presents an important advantage to students allowing them to learn outside the classroom (Chiang et al., 2014).
The review of Fan et al. (2020) classified AR interfaces based on their tracking techniques:
(a) Marker-based augmented reality or recognition-based or image recognition AR. A marker is an object or image with features that the mobile device can recognize. The device camera discovers the marker and replaces it with a 3D model, and can provide additional information about the object on the App screen.

- For Pilot 1, although Marker-based Apps are common, from previous experience using a Web-AR marker-based approach our cohort (schoolchildren) experienced occasional difficulty in keeping the marker within range of the camera and losing the AR experience.
- Always needing to have the marker readily available can also be an inconvenience, especially for parents and children.

(b) Markerless location-based AR where virtual content is related to a specific location. The technology utilizes GPS and other positioning systems, as well as information from the device's network to identify the user's location.

- *Note:* From previous experience and feedback from stakeholders (AHA Project) where we introduced marker-based WeBAR to our programme, we decided to implement markerless AR for Pilot 1. We felt a markerless AR App will provide more interaction and deeper immersion for the user directly from the device, without the need for additional material and it would be more advanced, i.e., more 'State of the Art'.

2.7 Displays – Hand-held, Head Mounted - Trends

The most preferred display technology in educational AR studies are mobile devices (57% of the studies reviewed by Sirakaya et al. in 2018, similarly Akçayir et al. (2017) noted 60%) due to their portability, interactivity, context sensitivity, connectivity and individuality.
Hsiao et al. (2015) review found the majority of devices used for educational inclusion purposes were handheld devices (68%) which confirms that using AR applications on mobile devices supports educational inclusion, tablets and smartphones being the most widely used.
Wu et al. (2012) promote portable technologies as they are less obtrusive and they enhance a sense of immersion and presence. Mobile devices are more accessible to the 'everyday user' (Specht et al., 2011).
Akçayir et al. (2017) found that mobile devices were more cost effective and easy to use, in particular for younger students. Although the requirement for relatively recent models of hand-held mobile devices that can provide AR technology and functionality can be a significant issue for school engagement due to Government/Educational fund limitations. Currently, head-mounted devices such as the HoloLens remain only accessible to research institutions and large organisations due to their current prohibitive costs.

- *Note:* For Pilot 1, there are educational restrictions that prohibit access to head-mounted devices for children under the age of 12 years, and this has certainly reduced the scope for including additional 'State of the Art' advancements in our research from this domain.

2.8 Voice recognition for children

There is increasing recognition that the voices of children should be included in matters that affect their lives, and this must start at the earliest age. There is very little research available in this area however, Purnapatra et al. (2020) found that one of the biggest challenges in speaker recognition for children is the change in the voice properties at a child age.
We have introduced voice recognition into our AR-App to increase engagement for the Pilot 1 cohort. From research we found:

- that most of the voice recognition products available to the market are designed and developed for an adult voice e.g. Google voice assistant, Amazon Alexa, IBM Watson.

- an EU Horizon 2020 SpeechTech4Literacy Project entitled "Multilingual Children's Speech Assessment Platform for Literacy and Language Learning" which was coordinated by SoapBox Labs Limited (SBL).

We intend to introduce a voice recognition product that is suitable for the stakeholder age-group (9-12 years) and will also provide research data for improving this innovative domain.

2.9 Further recommendations for future research

Explore the design and evaluation of AR for education: Few research studies explore the design and evaluation of AR for educational settings (Santos et al., 2016).

Explore the use and effectiveness of AR for development on the oral-literate continuum: Fan et al. (2020) reported that there are no reviews specifically examining the use of AR technology in supporting student development on the oral-literate continuum, which is crucial for language learning. Parmaxi et al. (2020) also concur with this finding and could find no specific state-of-the-art review of the findings of academic research in the specific field of language-literacy learning. This area now needs to be explored.

Explore the potential of AR for teaching diverse populations, such as students with special educational needs from early childhood to lifelong learners (Quintero et al., 2019; Quintero et al., 2019; Sirakya, 2018; Akcayir, 2017).

Explore the use and effectiveness of AR apps in general: to investigate the use of AR apps to support ubiquitous, collaborative and informal learning, how they are best employed, which are the optimal methods of delivery and the most effective techniques for application (Akcayir, 2017).

Explore how AR is integrated into educational pedagogies: Educators need to consider how AR applications might be integrated with instructional strategies or pedagogical approaches in formal education (Lee et al., 2021; Parmaxi et al., 2020; Quintero et al., 2019; Saltan et al., 2017; Bacca et al., 2014).

Increase the number of study participants: To broaden the number of research participants (>200) in AR educational studies (Bacca et al., 2014).

Expand on the number and types of tools used to gather research data: To widen the range of evaluation tools administered in studies to use mixed evaluation methods (Bacca et al., 2014). To conduct more quantitative and qualitative research in order to define how AR educational apps may support or hinder teaching and learning (Quintero et al., 2019; Sirakya, 2018; Schmitz et al., 2012).

Evaluate pre and post-test measurements for establishing AR effectiveness in education: The pre and post-test measurement to evaluate AR effectiveness in education should not only assess immediate recall of information taught but also the students ability to retain it over time, consolidate and generalise what was taught in order to apply the concepts in a variety of situations, thus demonstrating higher cognitive processes and application (Fan et al., 2020; Parmaxi et al., 2020).

Design and connect AR literacy apps with sound pedagogical theories: As there appears to be a disconnect between pedagogical theories and practice in technology-enhanced reading and spelling instruction, research studies should explicitly reference the theoretical framework guiding the teaching methodology employed (Yang et al., 2018).

Focus on developing AR apps for the teaching of phonological awareness skills: Taking cognizance of the fact that reading comprehension and vocabulary enrichment are crucial to all language and literacy development, a greater focus should be placed on the development of phonological awareness, which is fundamental for reading and spelling skills development. According to Yang et al. (2018), only a few studies have examined how technology can support the instruction of phonological awareness compared with the prominent focus on teaching reading comprehension and vocabulary. Therefore, future research should direct more attention to the application of AR technology to this area.

Integrate AR into school curricula: Need to explore the possibilities of integrating AR into regular school curricula as an effective method of instruction delivery (Quintero et al., 2019; Wu et al., 2012).

Explore the possibility of training teachers to customise AR learning activities: To explore the possibility of providing support for teachers to tailor AR technologies, to create customized learning activities in the classroom (Wu et al., 2012).

Increase the use of AR flashcards as an effective educational tool: As AR flashcards have come to the fore as valuable educational resources for language and literacy learning. To explore how their application benefits early childhood education (Chen et al., 2019).

Explore the use of AR in a Collaborative learning framework: Few studies on the integration of AR to Collaborative Learning approaches to education (Dey et al., 2018). This area merits further exploration.

Explore the use of AR apps for teaching the reading and spelling of complex words: Explore and understand the learning effect of various multimedia AR design strategies, and how they may influence students' learning gains specifically (e.g., using 3D models or animation, colour cues to visualise high frequency and irregular words, etc., see Fan et al., 2020). They also noted that regular words were used in studies rather than the more complex irregular words and that it would be interesting to explore the use of AR applications to support the instruction of abstract words (e.g. bad, thin).

Investigate which is the optimal font for use in AR apps, particularly for neurodiverse students: As there does not appear to be a standard for the type or case of font used in language literacy Apps (although the use of lowercase letters in early language learning, especially for SEN students is the preferred option - Fan et al., 2016), it is important to understand the potential impact of letter choices such as letter case, font, size, and augmented perspective (e.g., 90 degree or 45 degree based on the ground) on students' language and literacy learning outcomes in future research (Fan et al., 2020).

Explore the use of AR integrated into a scaffolding teaching approach for literacy and numeracy instruction: A greater focus needs to be placed on utilising visual media as a methodology to scaffold the teaching of literacy and numeracy (Awang et al., 2019).

Explore the short and long term retention of concepts taught through AR educational materials: Research should be done focusing on both short-term and long-term impacts on the retention effects on students after learning with AR games (Quintero et al., 2019; Li, 2017).

Establish which are the most effective AR features and why for enhancing motivation, learning and collaborative communication (Parmaxi et al., 2020; Li, 2017).

Provide clear objectives for future AR design: Li (2017) also proposed in future AR design that the following five aspects should be considered: what are student groups, learning objectives, AR features, game mechanics, and social interactions?

Develop AR educational tools that can be used both in the home and school environment: As students spend a lot of time at home and play digital games, it might be more effective to design AR learning games that can be played at home (Li, 2017).

Study the potential benefits of integrating student / parent/ teacher interaction when using AR games. AR games should focus more on the interactions between student and teacher, or student and parents. Perhaps a focus then should be placed on ascertaining what are the resulting beneficial results for both sides? (Li, 2017; Sirakya, 2018).

Explore gender differences vis-à-vis their use of AR technology: Explore gender differences in their facility to adapt to AR educational platforms. Hsu (2019) demonstrated a statistically significant difference in the post-test between males and females using their AR game, and inferred that the possible reason was that the female students had more trouble learning to use the AR platform, as girls have lower 3D spatial ability than boys on average. This finding also requires further investigation and validation.

Explore cognitive overload. Further research into the conditions relating to the problem of cognitive overload in AR technology applications (e.g. topic choice, age group, interface characteristics, etc.) should be undertaken. (Parmaxi et al., 2020; Akçayir, 2017)

Explore the effectiveness of various AR game strategies: To gain an understanding of how various game strategies such as virtual tutors, role play, narrative, or gamification influence students' learning experience, motivation, and outcomes (Fan et al., 2020; Luna et al., 2018).

Explore instructional design differences vis-à-vis their use of AR technology: Future research should explore how AR applications account for and adapt to personalised instructional design methods, including students with special educational needs (Fan et al., 2020; Hsu, 2019; Bacca et al., 2014; Wu et al., 2012).

Engage in longitudinal case studies evaluation the effectiveness of AR apps: Longitudinal case studies could be conducted to increase our understanding of the contextual use of AR applications with teachers/parents and students in applied settings like the classroom or at home (Fan et al., 2020; Quintero et al., 2019).

Use a Control Group in AR studies: In order to evaluate AR applications, studies should have a Control Group to assess the effectiveness of the AR app in comparison to traditional approaches. Fan et al. (2020) found that more than half of the studies they reviewed did not contain any control groups.

Main design considerations for future AR Apps: Fan et al. (2020) proposed three main considerations (with subcategories) for future design of AR applications for early language and literacy learning:

- 3D multimedia content with presentation strategy and location-based design with the discovery strategy.
- Designers should capitalise on the use of unique qualities of AR to support language learning including:
  - o creating abstract language symbols and learning materials as 2D/3D augmented reality visuals with auditory sounds;
  - o presenting phonemes, words and sentences in an authentic learning environment;
  - o enabling a variety of hands-on interactions with virtual objects;
  - o physical learning materials with physical affordances;
  - o stressing essential phonological / phonemic awareness concepts and rules through an AR overlay;
  - o emphasising the embedded rules for accurate spelling in a physical and digital space.
- Literacy teaching approaches should focus on phonological awareness development as it is essential for early language and literacy learning;
- Designers should consider the use context of AR in the design process, including:
  - o providing a smooth transition between traditional instruction and AR instruction,
  - o considering teachers' role and level of participation in AR instruction
  - o applying a scaffolding approach to tuition, thus integrating the application of both the AR material and the teacher input,
  - o applying techniques to enhance positive collaborative learning,
  - o exploring AR design in specific learning contexts,
  - o allowing a facility for teachers to update AR content.

Be explicit about the design process to aid replication. To provide detailed explanation of the materials development process and the factors to be considered in design would facilitate accurate replication for future research purposes (Akçayir, 2017).

Develop a better understanding of multi-sensory experiences in relation to AR-apps. More studies aimed at understanding multi-sensory experiences in relation to AR-applications should be conducted, with a view to exploring their impact on learning outcomes (Akçayir, 2017).

Explore the development of solutions for acknowledged outstanding technical problems associated with AR apps: Explore solutions for reported technical problems encountered in AR applications (Akçayir, 2017). An example would be detecting and tracking the marker on the lowercase letters.

Further studies related to the development and usability of AR applications are required. As AR technology can be challenging for some students to use, students' opinions about usability and preferences should be explored in more detail and across learning environments (Akçayir, 2017).

Explore the use and educational outcomes of AR applications incorporating AR vision glasses and goggles. To determine what are the possible advantages/disadvantages (Sirakya, 2018; Akçayir, 2017).

Evaluate the novelty factor / bias in AR technology research. Some AR research results may be due to an uncontrolled novelty effect; further studies are required to evaluate this. (Akçayir, 2017).

Apply the ARCS model (attention, relevance, confidence, and satisfaction) to the design of the AR technology (Khan et al., 2019).

Explore the use of different types of AR to promote educational inclusion: Marker-based AR is preferred in almost all existing AR studies (Sirakya, 2018). The use of markerless AR merits further exploration as it is deemed that not requiring markers could facilitate greater ease of use for students (Quintero et al., 2019).

Focus on recognition algorithms to support the implementation of marker-less AR in education (Sommerauer et al., 2019).

Recommendations based on past 'trial and error': Based on past experience, Yang et al. (2018) recommend the following design goals:

- Minimize visual clutter on the display
- Support cognitive processes of selecting, organizing, and integrating information
- Allow interactions with the environment and objects in the environment
- Present multimodal information, namely, texts, images, and sounds
- Use animations when appropriate
- Apply cheap and accessible technology
- Make the contents easy to create
- Limit the interactions.

Conduct analysis of navigational buttons and clicks, when responding to tasks.
(Awang et al., 2019).

Explore the use of neuro-imaging techniques to capture students' perceptions of AR (Parmaxi et al., 2020).

Multidisciplinary approach to AR design for education: Kesim (2012) emphasised the importance of coordinating teams of technical and educational specialists to merge expertise when developing AR materials for education.

3. Learning Content and Pedagogy

For schoolchildren that have reading and spelling difficulties, Pilot 1 will deliver innovative content using an AR-App that has been developed using and adding to the Web-AR teaching content from our existing literacy programme called WordsWorthLearning©. The introduction of AR will make the literacy learning process more engaging and informative for students, by showing computer generated animated AR-3D Objects that are overlaid on top of the real world captured on their mobile device camera.

3.1 Educational Pedagogy Advancement in PILOT 1:

We carried out an extensive literature review and research on currently available state-of-the-art EdTech literacy products and direct consultation with industry experts (Mr. Tim Connors, Executive Director at EdTech Advisory Group (USA), Mr. John Carroll, Senior Vice President, Product Management & Strategy with XanEdu Inc (previously Senior VP at Houghton Mifflin Harcourt and VP of McGraw-Hill Education and Pearson Education) and Prof. Timothy Shanahan, Distinguished Professor Emeritus currently with McGraw Hill Education (a world expert on literacy). A summary table can be found at **Annex 1: EdTech Research - AR for Literacy.**

Effective learning in the school is dependent on the pedagogical approaches a school or teacher adopts in the classroom. Employing a variety of pedagogical approaches would be common practice, particularly in the area of literacy instruction, however some strategies are more effective and appropriate than others. The effectiveness of pedagogy often depends on the instructor's knowledge base and a recognition of the diverse needs of different students, along with the ability to pivot their instruction to meet those individual needs. Currently the onus is on the teacher to be able to deliver a 'fit for purpose' literacy strategy that will encapsulate the needs of all students under their care. This is the holy grail of literacy intervention.

The overriding aim of the WordsWorthLearning programme (WWL) is to provide evidence-based literacy instruction that considers individual students learning styles and the individual teaching competencies of the 'facilitator', in the case of the ARETE project, the primary school teacher / SNA and parents involved. To reach this aim the WWL programme focuses on multisensory instruction (auditory, visual, orally tactile and cognitive/ linguistic props) that follow a clear hierarchical path, which reflects the normal stages of literacy development and incorporates detailed instruction for even the most inexperienced 'facilitator' to follow and succeed. In addition to this, the uniqueness of the ARETE project has afforded the development of additional features to enhance the learning process, that being the integration of Augmented Reality features to help consolidate and generalize even the most abstract literacy concepts being taught. The ARETE Pilot 1 AR App is designed to provide a 'scaffold' for the student, to facilitate 'collaborative' learning and to enrich their learning experience, thus enabling them to meet their learning objectives. Observations from the SLR that are relevant to Pilot 1:

1. As Fan et al. (2020) noted there are no reviews specifically examining the use of AR technology in supporting student development on the oral-literate continuum, particularly in the early stages of literacy development required for word decoding (reading) and encoding (spelling). Parmaxi et al. (2020) also concurs with this finding and could find no specific state-of-the-art

review of the findings of academic research in the specific field of English language-literacy learning.

2. Although there are a plethora of EdTech products and computer assisted instruction (CAI) software to teach English literacy skills or remediate literacy difficulties (Inns et al., 2019; Alqahtani, 2020) only a small amount are, like WWL, currently following and aligned with the 'Science of Reading Instruction' pedagogy, which focuses on the five pillars of early reading: phonemic awareness, phonics, comprehension, vocabulary and fluency' (National Reading Panel, 2000). It is a pedagogy that stresses the importance of explicit and systematic teaching of decoding and encoding, which has consistently given students a clear learning advantage (Shanahan, 2020). It is now well accepted that effective, evidence-based instruction emphasizing phonemic awareness and phonics as foundations for literacy development are essential.
3. Focusing purely on the area of literacy development and available EdTech programmes, there are currently NO known available complete literacy products that offer AR as a feature. There are some 'bit part' literacy solutions such as the AR alphabet letter cards offered by, e.g., Octagon Animal 4D+ Augmented Reality Flashcards, OObedu World of Alphabet: 26 AR alphabet cards, or Indiegogo Alphabet Corner: AR for alphabet or very rudimentary spelling Apps such as 'Catchy Words' AR Game for Spelling, which from a content, UI and UX perspectives in our clinical opinion, would exhibit more challenges than benefits for this specific cohort.
4. WWL offers an evidence based, complete 'end to end' literacy programme, which has both a general educational and remedial focus – that from the outset follows the now widely accepted and most effective literacy pedagogy 'Science of Reading Instruction'. In Pilot 1, we explore how the Science of Reading meets AR and we are adapting a huge body of work, developing an AR App from scratch and supporting key learning targets with AR, to embed complex concepts in memory. The outcome of our research and consultation has shown that this disruptive, innovative and impactive 'modus operandi' is currently not available anywhere else.
5. To accurately evaluate the impact of using the ARETE Pilot 1 AR-App, we will use a variety of clinical/educational assessment evaluation tools to accurately measure its impact from both a qualitative and quantitative perspective, this judging from an extensive literature review in the area, is in itself a rare practice.
6. In addition to the development of the Arete Pilot 1 AR-App, we are identifying pedagogical innovations and answering a clinical/digital research question that can be evaluated through the ARETE research study, which could well contribute to "disruption" in education. Understanding that students' minds are complex systems with heterogeneous or diverse characteristics, helps us understand the need to offer learning material in ways that suit various learning styles. The expected data generated from the online interactive case-history form (ProfilED) explores the developmental profiles of Neuro-typical versus Neuro-diverse students and should help to define phenotypes to better understand AR application and impact with this cohort. It will provide research data to identify the learning needs and hopefully prove a positive impact of using AR as a teaching medium for multiple cohort groups, which is one of the primary objectives of the Pilot 1 project and will assist with answering the research question "How does AR Impact on Students Literacy Attainments''. From an Educational / Clinical perspective this is 'ground breaking'.

Table 3.1.1 Pilot 1 - Pedagogy Advancement below summarises the position, indicating which of the recommendations arising from the SLR will be addressed in the Pilot 1 AR-App, thus creating State of the Art going forward.

Systemic Literacy Reviews **Recommendations**	ARETE Pilot 1 AR-App **Education & Pedagogy Advancement**
Bruner's theory of 'scaffolding' (initially introduced in the 1950's), which was inspired by Vygotsky's 'Zone of Proximal Development' (what a child can do by himself and what can be achieved with the support of a knowledgeable peer or teacher). Scaffolding is defined as providing learners with necessary support and affordances to help the learner resolve the problems that they cannot tackle alone (Park, 2019).	Has a strong emphasis on an educational approach in which a supporting adult (teacher or parent) provides individualised assistance by incrementally improving a student's ability to build on prior educational knowledge on a topic, in this case literacy. The use of scaffolding and collaborative learning model (in Pilot 1 it is predominantly a student / parent or student / teacher/ grouping) is a focus throughout the ARETE Pilot 1 AR-App.
Fan et al. (2020), explore the use of scaffolding in previous studies. They found that the majority of AR applications reviewed contained different degrees of scaffolding primarily focusing on (a) scaffolding that enforced corrective actions, for example letters would be returned to their original location if spelt incorrectly and (b) scaffolding that provided partial/full answers for incorrect spelling attempts.	Employs both types of scaffolding in the multiple reading and spelling exercises to ensure the students receive maximum support while engaged with the programme and their efforts are positively reinforced throughout. There are over 150 AR objects in the programme, with a function to either support a speech sound, explain a complex rule or as a prefix or suffix flashcard to explain their complexity and enhance memory – through auditory, visual and linguistic means. A point of interest is that there were 90 AR objects developed for the AHA- ADHD Augmented project – that were developed for a Web-AR and a 'marker' based approach which had to be recreated / redeveloped to accommodate the new 'markerless' approach for the ARETE Pilot 1 AR-App.
Fan et al. (2020) recommend the use of 3D models or animation, colour cues to visualise high frequency and irregular words when teaching the reading and spelling of complex words. They further noted that to date regular words were used in studies rather than the more complex irregular words and that it would be interesting to explore the use of AR applications to support the instruction of abstract or irregular words. These are features that are also recommended in other recent	The ARETE Pilot 1 AR-App has this integrated and supports the teaching of more difficult words with the use of AR rules and AR flashcards. We also use Augmented dynamic colour cues and 3D physical lower-case letters that help to draw children's attention to how letters' positions in words change letter sounds thus providing additional scaffolding. Augmented letter animations are used to visualize the letter combining or separating actions during word decoding and encoding processes; augmented colour flash is used to illustrate grouped letter / phoneme

literature recommendations for future AR Literacy development.	patterns and there are pictorial associations to support rule concepts so as to diminish "Cognitive Overload" and the need for heavy linguistic input. The ARETE Pilot 1 AR-App also introduces a paediatric voice recognition product that processes regular and irregular word reading tasks from levels 3 to 7. The voice recognition software used (SoapBox Labs) is very important and has been tested on a large number of children in nearly 200 countries. It caters for speech impediments, delays and accents in a child's voice which is not a feature in the mainly adult voice recognition software available on the market.
Fan et al. (2020) also recommend the exploration of which is the optimal font for use in AR apps, particularly for neurodiverse students (e.g., those with dyslexia, dysgraphia, ADHD, ASD etc). They continue to stress the importance of the choice of type or case of font used in language / literacy Apps. They note that the use of lowercase letters in early language learning is preferred and recommend that the development of a standard for letter case, font, size, and augmented perspective (e.g., 90 degrees or 45 degrees based on the ground) is an important focus of future research.	Through many years of clinical experience working with a neurodiverse cohort and the ongoing development of computer assisted instruction (CAI) software we have explored, considered and trialled these factors. We chose predominantly lower-case letters and use the 'Monosten' font due to its letter clarity and unambiguous nature. Additionally we ensure that the letters can't rotate as it would be counterproductive for this cohort, where letter reversals is a common clinical observation and problem. We have overcome difficulties with markerless AR supporting lowercase letters that are essential for literacy development.
Hsu's 2019 study reported that students preferred to use their fingers to move and drag the letter icons to spell words rather than typing with the QWERTY keyboard.	A 'qwerty' keyboard is not used. Spelling exercises use a click or drag and drop method for students to move phonemes, rather than individual letters – this is a feature that we have not observed in any other literacy programme. Also there have been a number of interactive games and quizzes developed which are placed throughout the programme to promote 'overlearning', collaborative learning and decrease cognitive overload. They also facilitate collaborative teaching as the quiz results provide a logical basis for individual or group teacher led revision.

Fan et al. (2020) advocated four stages for learning phonological awareness and felt that these would be rich resources for future AR applications, these being (i) pre-alphabetic (sound symbol association), (ii) partial alphabetic (focus on onset and rime, letter insertion, omission, or substitution), (iii). full alphabetic, and (iv) consolidated alphabetic stages (teaching rules for decoding and encoding). This focus is also supported by Yang et al. (2018) and they state that future research should direct more attention to the application of technology in these domains.	Most AR applications focused on visualizations of whole words rather than phonological knowledge. Phonological knowledge is extremely important in early literacy instruction, particularly for children at-risk for reading difficulties. The four areas are the foundation of the WWL programme and are fully integrated throughout the seven levels in the ARETE Pilot 1 AR-App. Many current AR literacy materials don't support Higher Order Thinking Skills – the ARETE Pilot 1 AR-App follows Bloom's Taxonomy for the delivery of the content, progressing through the six developmental stages: remember, understand, apply, analyse, evaluate, and create. AR is available to support these steps, all the way through the 7 levels of the App.
Lin (2016) identified that they found only one AR learning game which was designed specifically for playing at home with the help of parents.	The ARETE Pilot 1 AR-App is designed to be used both in the home and school context, in fact it is actively encouraged in general and for this project in order to establish a "parent, teacher, student" collaboration for learning.
Fan et al. (2020) noted there were three favoured categories for delivery of instruction: (i) Instruction through presentation (i.e., teacher-centered informal instruction), e.g. the teacher led the educational instruction and used the AR application for demonstration, followed by the students practicing and applying the learnt knowledge under the direction of the teacher or facilitator. (ii) Instruction through discovery (i.e., learner-centered comprehensive instruction). The students were given an AR application to explore by themselves through interaction with a set of games or literacy activities. The App provided feedback/hints as required. The teachers/parents role was that of a facilitator and monitor, but not as an active educator. (iii) Collaborative learning (i.e., learner-centered group studies). Here students	The ARETE Pilot 1 AR-App incorporates aspects from all three approaches across the seven levels of instructional content of the literacy programme.

work in small groups to answer the tasks or solve the problems.	
Khan et al. (2019) ARCS Model of motivational design. The four foci of the model are that (i) the material must attract the students attention (providing challenging learning materials), (ii) it must be relevant to the students academic curriculum, (iii) the students must be confident that they can learn and achieve using the teaching material and (iv) the students must feel satisfied (feel a sense of achievement, receive reinforcement and be entertained)..	The ARETE Pilot 1 AR-App incorporates each of the four areas in the design and content
Rau (2018) explores the importance of considering "response time" as it would probably affect the user experience and as result recommends that it should be considered in the design of VR and AR programmes. Rau also suggests that users should be afforded approximately 10% more time to respond to text-processing tasks, compared with those programs for PC activities.	The ARETE Pilot 1 AR-App design has considered this aspect and consequently no items are timed or timed out on the App.

Table 3.1.1 Pilot 1 - Pedagogy Advancement

3.2 ARETE Pilot 1 AR-App

Our challenge is to establish how AR technology can facilitate students that have reading and spelling difficulties, with different learning styles, background knowledge, and abilities to deeply engage in the literacy content and then reflect and reinforce their knowledge of the content being learned. To this end WWL has developed a literacy App that is different in the following ways:

It is a complete Learning Management System for the teaching of reading and spelling in the English language. The students have seven stages to complete in sequence, and within each stage there are educational steps that must be completed in a hierarchical order, reflecting their complexity (in keeping with Bloom's Taxonomy). The App takes the student on a galactic journey, visiting planets where they will learn new English language literacy skills at each stage - as shown in the Figure 3.2 - A Galactic Journey:

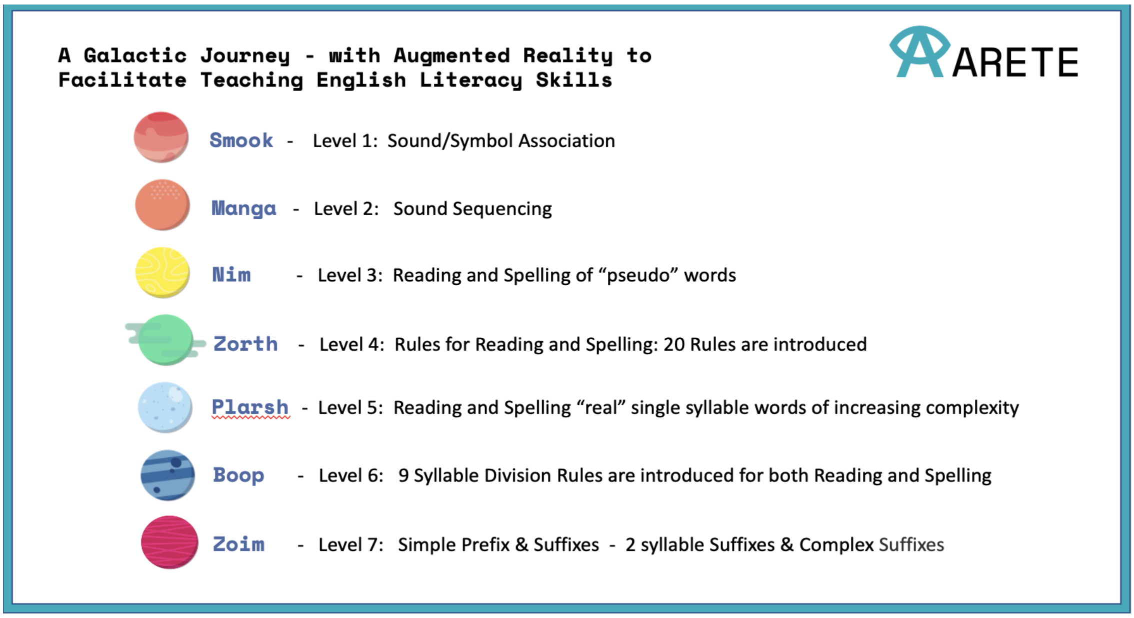


Figure 3.2 - A Galactic Journey

The ARETE Pilot 1 AR-App has been developed for the Arete Project, by adapting previously developed WWL and Web-AR content. It allows our software, audio, video and AR animations to be controlled (haptic) by the student to initiate animated visual scenarios designed to enhance their learning, to create a better understanding of the concepts being taught.

3.3 Sequential-Mission Gaming (SMG)

Level 2 - Sound Sequencing shown in Figure 3.1.1 involves a "counter" game to teach vowel and consonant sounds which was developed based on a sequential-mission gaming (SMG) design (Hsu, 2017) - it provides the students with stages to complete in sequence and, within each stage, there are educational steps that must be completed in a hierarchical sequence, to ensure key literacy learning milestones aren't overlooked or skipped. See Figure 3.3 below - Cognitive Impact - Gamification:

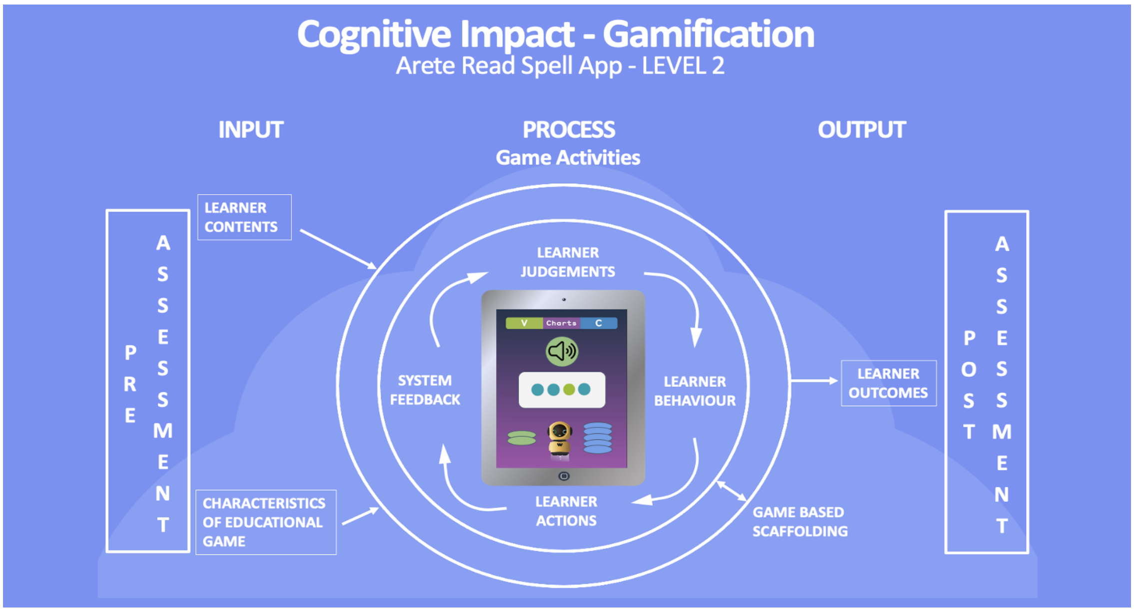


Figure 3.3: Cognitive Impact - Gamification

4. Technology

4.1 Initial Research

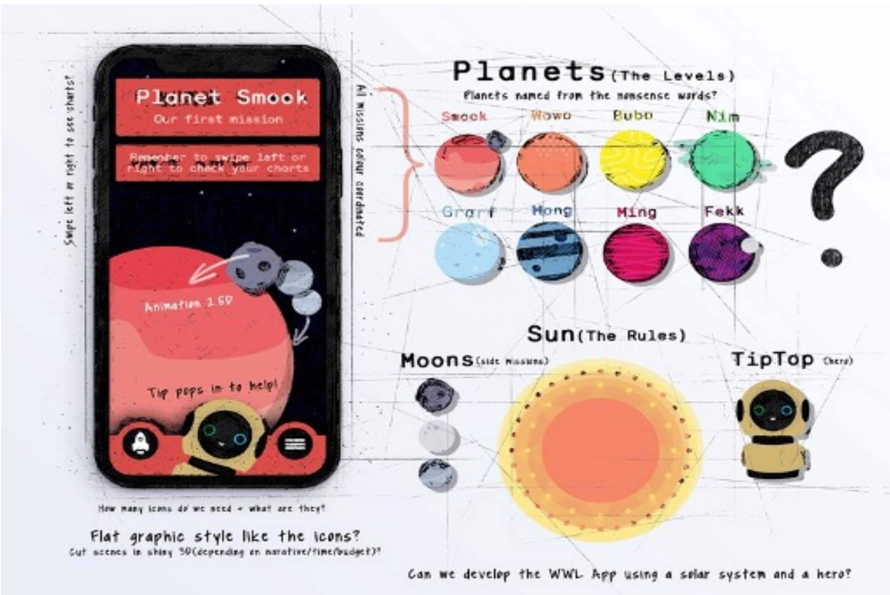
As this deliverable is heavily front-loaded, WWL began (late 2019) to research the availability of the Technical skill-sets required for the PILOT 1 AR-App: Graphic Design, AR-3D Modelling & Animation, AR S/W development and a part-time Research Analyst, for the "clinical" research data collected for Pilot 1. We also researched the App marketplace, to find AR Apps that operated in our sector specifically i.e. 9-12 year old primary school children, with reading and spelling problems. We found no literacy programme AR Apps operating in exactly the same sector, however, we used the opportunity to get an idea of the type of UI/UX graphic design that appeared to be popular with commercially available Apps, that were in someway literacy related – this included: Duolingo, Wonderscope, EpicWordAdv, Lingokids, teachyourmonstertoread, Osmo Word and MindNode.

duolingo wonderscope LINGOKIDS

4.2 Graphic Design

Pilot 1 AR-App contains multiple sets of information that are shown onscreen concurrently. Considering UI and UX, we decided to develop our native App for Tablet devices which offer more screen space, and will provide a better mobile experience when presenting the App.

For the Pilot 1 AR-App design, we worked with, and were guided by our Graphic Designer, who began to visualize the theme and main features and provided a storyboard with the approximate layout and structure of the App, which helped the "Team" to understand the mission and take control of the entire development process. The AR-App will provide a 'galactic' mission for the children, visiting a new planet for each stage of the application. The Initial Arete Pilot 1 - App design with Protagonist (TipTop) is shown in Figure 4.2 below:



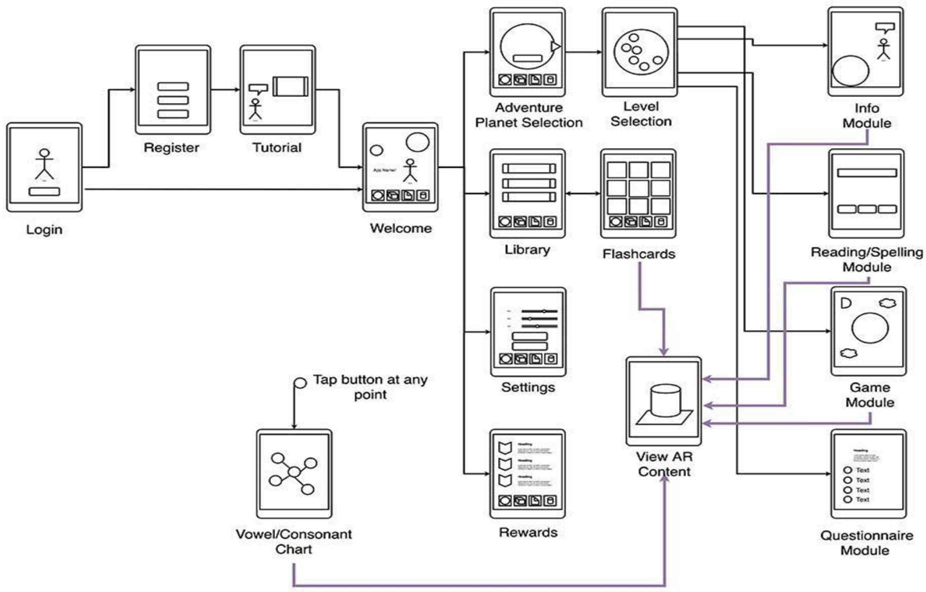
Pilot 1 AR-App Storyboard: Figure 4.2

4.3 Wire-Framing, App User Flow & Student Use-Case

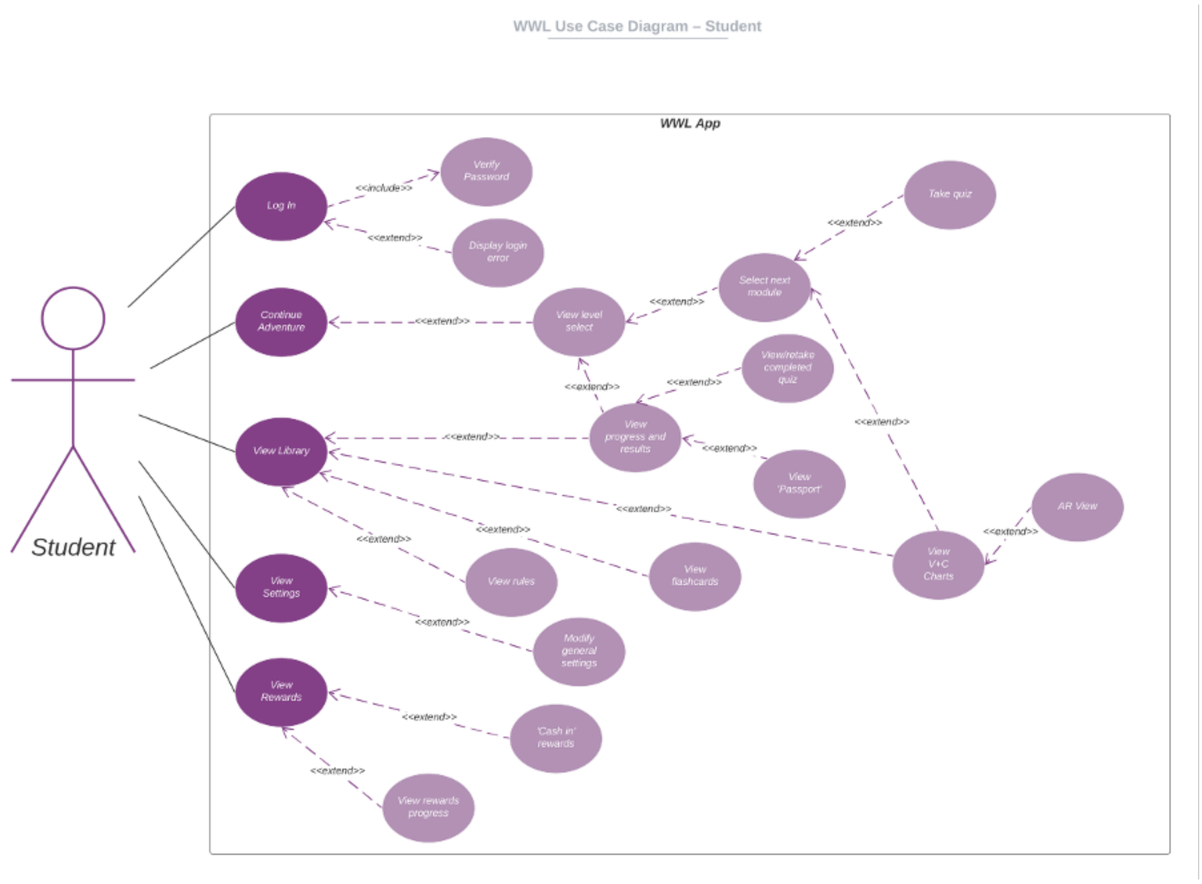
The next stage was the creation of an AR-App involving (i) the “Wireframe” giving an outline UI/UX prototype for the app with a visual representation of the user interface, showing screens of content and the connections between those screens then (ii) the User flow through the App and (iii) the Student Use-Case diagram. These are shown below in the diagrams Figure 4.3a, 4.3b and 4.3c:

Pilot 1 AR-App Wireframe: Figure 4.3a

Overview of Pilot 1 AR- App User Flow



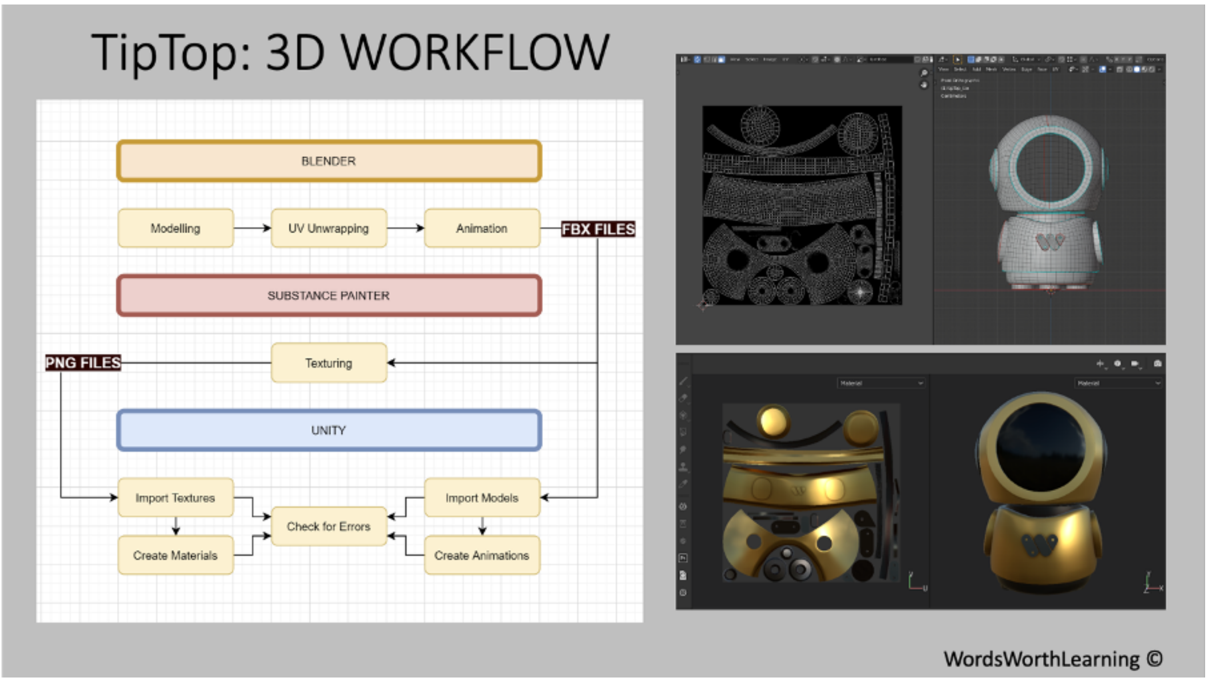
Pilot 1 AR-App Wireframe: Figure 4.3b



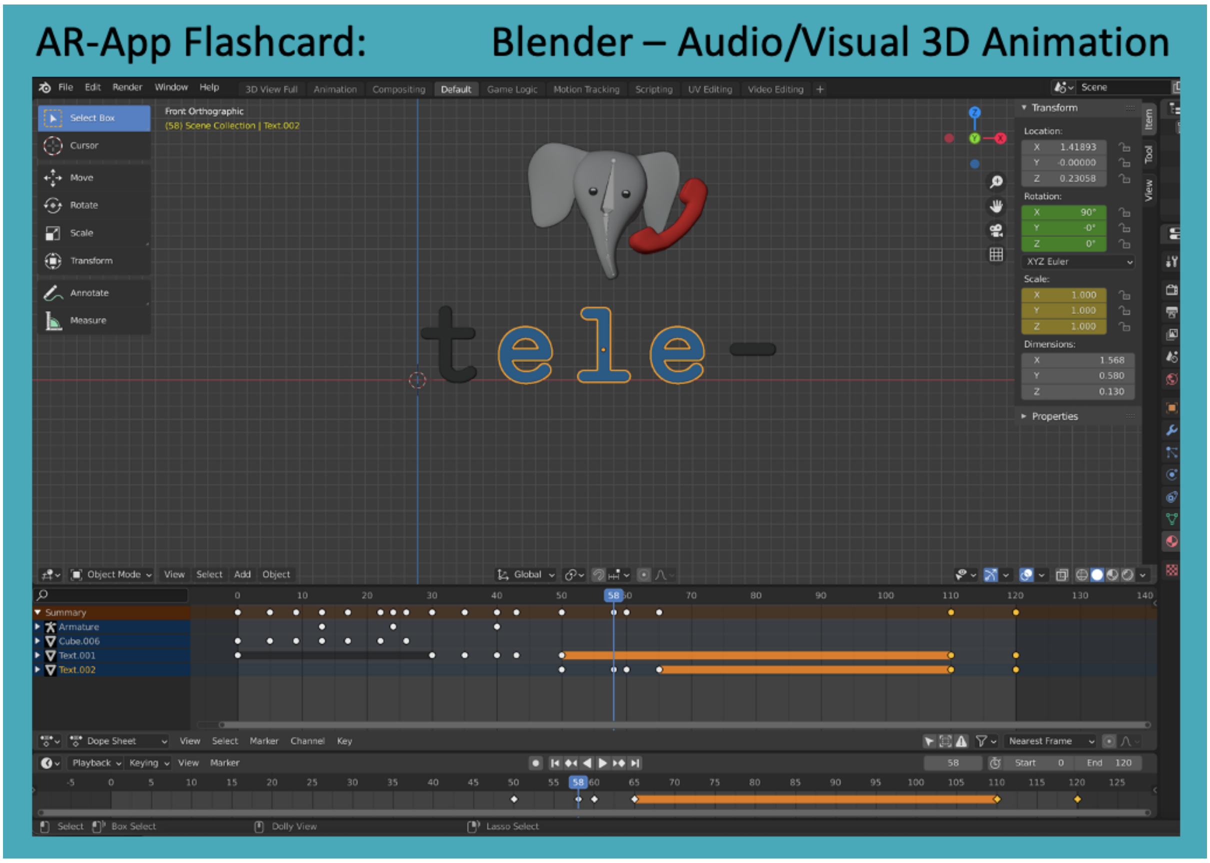
Pilot 1 AR-App - Student Use Case Figure 4.3c

4.4 Redesign and Development to AR-App

Then began the workload to redesign and develop more than 150 AR 2D/3D animated audio/visual models ranging across the seven pedagogical levels contained within the AR-App, that represent: speech sounds, rules progressing to flashcards for simple and complex suffixes. The small examples in Figure 4.4.1a and Figure 4.4.1b below show the 3D workflow for the development of TipTop the Hero character and the development of a 3D audio/visual animated 'Flashcard":



Pilot 1 AR-App - AR 2D/3D Modelling and Animation Workflow: Figure 4.4a



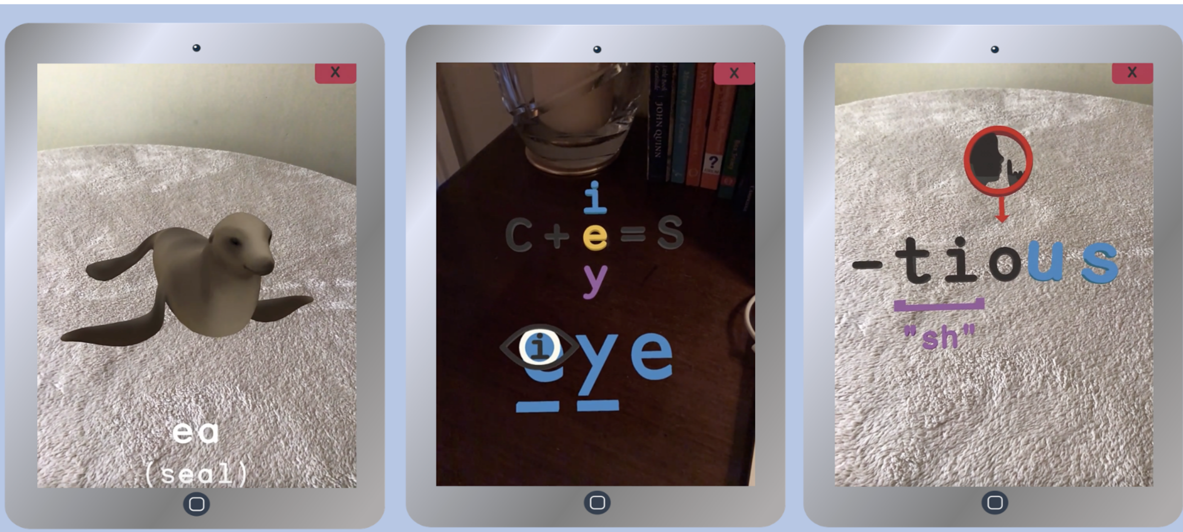
Pilot 1 AR-App - AR Audio/Visual 3D Animation Flashcard : Figure 4.4b

Arete Pilot 1 provides a native App which has been designed for use on a Tablet device. A sample of the AR-App for teaching literacy can be seen in Figure 4.4c below:

The Pilot 1 AR-App: Figure 4.4c

There are 150 AR 3D audio/visual animated objects created for Pilot 1, that are introduced at various key stages throughout the App. Some examples of the AR objects on screen can be seen in Figure 4.4d below:

PILOT 1 - AR 3D Audio / Visual Animated Objects



Using AR 3D audio / visual animated objects to enhance the retention of Vowel & Consonant sound / symbol association.

Using colour coded AR 3D audio / visual animated objects as 'memory hooks' to embed essential reading & spelling rules in memory.

Using AR 3D animated objects to explain and reinforce complex Prefixes and Suffixes through auditory, visual and linguistic modalities.

Pilot 1 AR-App - Examples of AR 3D audio/visual animated Objects: Figure 4.4d

4.5 ARLEM standard compliance

The Pilot 1 AR-App will generate research data which will be transferred, using xAPI technology, to an Arete project Learning Locker. The data relating to Pilot 1 AR Objects is in the process of being reformatted to JSON file format to become compliant with the ARLEM standard (IEEE P1589-2020). A sample of the code is shown in Figure 4.5 below:

ARLEM STANDARD - COMPLIANCE: PILOT 1 AR-App

```
{
  "workplace":{
    "id":"df",
    "name":"Default workplace",
    "origin":"001"
  },
  "things":[
  ],
  "persons":[
  ],
  "places":[
  ],
  "sensors":[
  ],
  "devices":[
  ],
  "apps":[
  ],
  "detectables":[
  ],
  "primitives":[
    {
      "id":"Animation"
    },
    {
      "id":"Audio",
      "volume":100
    }
  ],
  "predicates":[
  ],
  "warnings":[
  ]
}
```

```
{
  "activity":{
    "id":"seal",
    "name":"Seal",
    "description":"",
    "language":"en",
    "workplace":"https://wordsworthlearning/arlem/workplace.json",
    "actions":[
      {
        "id":"clickObject",
        "viewport":"actions",
        "type":"actions",
        "instruction":{
          "title":"Seal",
          "description":"Tap on seal to hear sound"
        },
        "enter":[
          {
            "activates":[
              {
                "target":"sealAnimation",
                "type":"primitive",
                "augmentation":"animation",
                "poi":"center",
                "url":"https://wordsworthlearning/arlem/object/seal.fbx",
                "state":"1"
              },
```

```
              {
                "target":"sealAudio",
                "type":"primitive",
                "augmentation":"audio",

"url":"https://wordsworthlearning/arlem/audio/seal.wav"
              }
            ]
          }
        ],
        "exit":[

        ],
        "triggers":[
          {
            "mode":"click",
            "type":"action",
            "viewport":"actions",
            "id":"clickObject"
          }
        ]
      }
    ]
  }
}
```

Pilot 1 AR-App - Example of code to align with ARLEM Standards: Figure 4.5

4.6 Technology: AR-App Design, Development, & Launch

In 2019, as an SME, we had to determine which infrastructure should be used, and what technical skills would be required for the development of the Arete Pilot 1 AR-App. We considered the cost of potential AR Platforms and SDKs, and the potential availability and estimated salaries for Graphic Design, AR/3D Modelling and Animation, AR S/W Development, UI/UX Design and Research Analyst (Part-time) - which would be fixed-term contracts. Other important important considerations for the AR-App development were:

(i) it is for young children (9- to 12-year-olds) in primary education
(ii) they will have literacy difficulties
(iii) the AR-App will be gamified
(iv) restrictions for children of this age using AR/VR wearables.

At that time, AR technology was growing exponentially, involving many sectors e.g. EdTech, Healthcare, Travel, Marketing, Air and Space and Academic research. Research indicated that the Vuforia Engine (AR SDK), had a predominance for the development of "Industrial" AR Platforms. It is used by many of the larger companies and, as a consequence, the availability and affordability of the technical skill sets required to develop an AR App was a potential problem. Costs also rose significantly when going commercial with their AR SDK.
The developer community of the Unity Engine was also growing exponentially, particularly in the gaming industry. From a commercial perspective, it was considered to be better suited and more affordable for smaller businesses (SMEs). ARFoundation and Unity provided the means for (i) an affordable AR development platform, (ii) better prospect for recruitment of AR S/W Developers and (iii) providing an AR-App with a gamified 'look and feel', more suitable for the Arete Project Pilot 1 cohort.

4.6.1 Infrastructure

We decided to proceed with the following technology infrastructure to build the AR-App:

- UNITY and AR Foundation: to provide state-of-the-art and affordable multi-platform tools and services for the creation of mobile AR Apps.
- Apple's ARKit: provided a free Software Development Kit (SDK) for our developers that contained core AR functionality involving device motion tracking technology, advanced camera scene capture and processing for the mobile iOS operating system to create better AR experiences. AR-capable devices (2019) offered a 'game changer' with improved Simultaneous Localisation and Mapping (SLAM) that could identify a mobile device location and place an AR object within it without the need for a marker. This opened up an opportunity for the introduction of markerless AR Objects being used in mobile Apps.
- Google's ARCore: another free and open-source SDK, for Android developers similar to the functionality of Apple's ARKit. Unity / AR Foundation provides full support for ARCore.

AR has become more accessible and we believe our stakeholders would benefit from an AR experience using the ARETE Pilot 1 AR App. To visualize the AR 3D models and other onscreen data, we decided that a Tablet mobile device (Android and iOS) should be used to provide a larger screen, and a better visual experience. The Tablet device must have (i) internet connection via WiFi and/or Mobile network, (ii) AR functionality installed, (iii) a camera with motion tracking functionality to determine Tablet movement, (iv) ensure that the Tablet has the latest versions of the iOS /Android operating system software installed. Later Tablet models will already have AR software integrated.

Note: A stable internet connection is required for the "voice recognition" technology for the student "reading aloud" for the reading exercises.

Figure 4.1 below is a current list of Mobile Tablet devices (Android and iOS) that have AR software functionality already integrated:

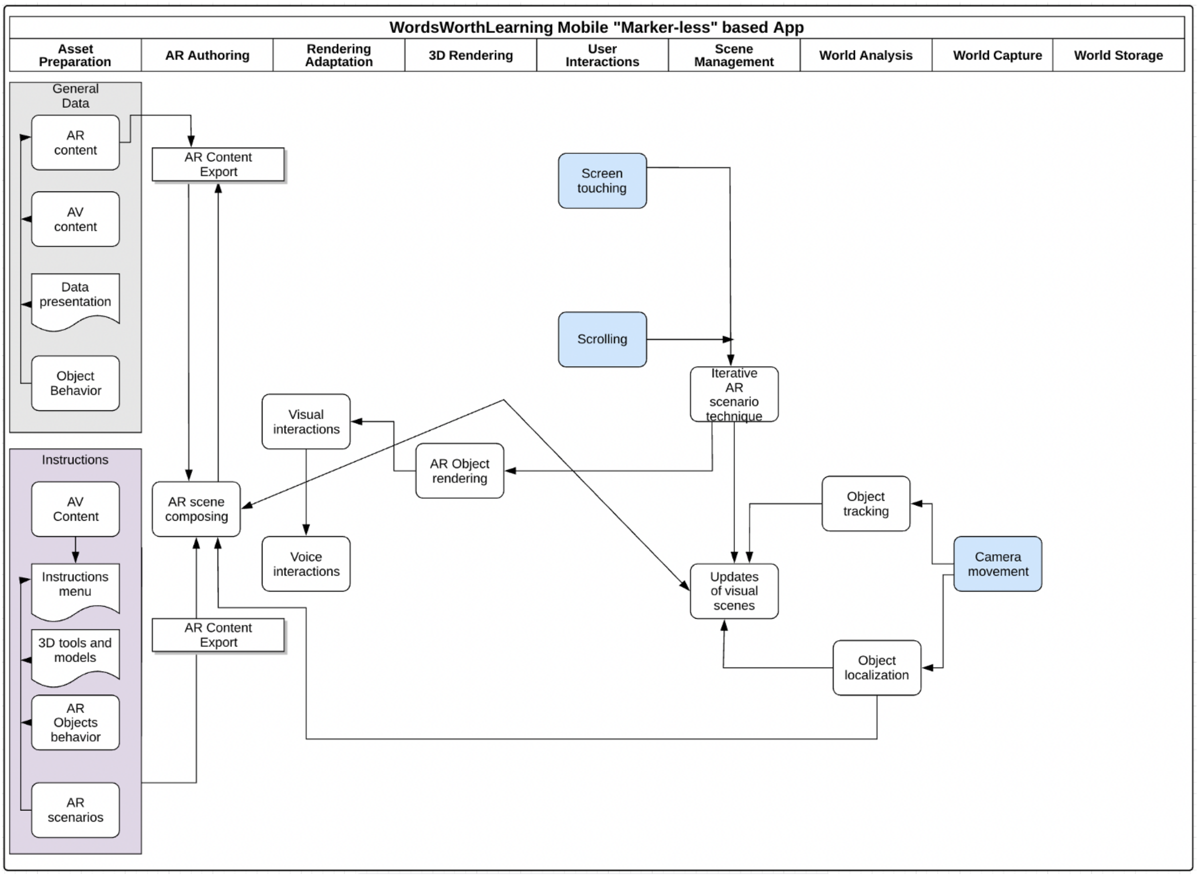
iPAD	ANDROID
• iPad Pro (all models) • iPad Air (4th generation) • iPad Air (3rd generation) • iPad (5th generation or later) • iPad mini (5th generation Processor Count	• Asus Zenfone 7/7 Pro • Google Pixel 4a 5G • Google Pixel 5 • LG WING 5G • Realme 7i • Realme X7 Pro 5G • Samsung Galaxy A20e • Samsung Galaxy Note20 5G • Samsung Galaxy Note20 Ultra 5G • Samsung Galaxy Tab A7 • Sharp AQUOS zero5G basic • Sharp AQUOS zero5G basic DX • Xiaomi Redmi Note 9S

Mobile Tablets with AR Software (Android & iOS) Figure 4.6.1

The Pilot 1 App - Privacy Policy is under construction and will be uploaded to the Apple and Google Stores for ratification, when the App is ready to upload. The App is in 'TestFlight' mode and currently targeted to be uploaded to the App Store at approximately the end of June 2021. As soon as the Privacy Policy has been approved by the App Stores, the link will be provided for the Arete website.

4.6.2 - AR Markerless App

WWL initially considered replicating the previous "marker-based" experience and reviewed the feedback from an earlier EU Funded Project that introduced Web-AR technology into our online WWL literacy programme. Although AR marker-based Apps are being used extensively across commercial and educational sectors, mobile device technology has now advanced so much that Markerless-AR is now being used more and more for image recognition in AR applications. Anyone with a modern mobile device (e.g. Tablet) running the latest Android OS or iOS will be able to experience Markerless-AR. Considering the state-of-the-art SLAM technology improvements for mobile devices, we decided to develop the ARETE-App for Pilot 1 using "markerless" AR technology as shown below in AR Mobile Markerless System Architecture - Figure 4.6.2



AR Mobile Markerless System Architecture - Figure 4.6.2

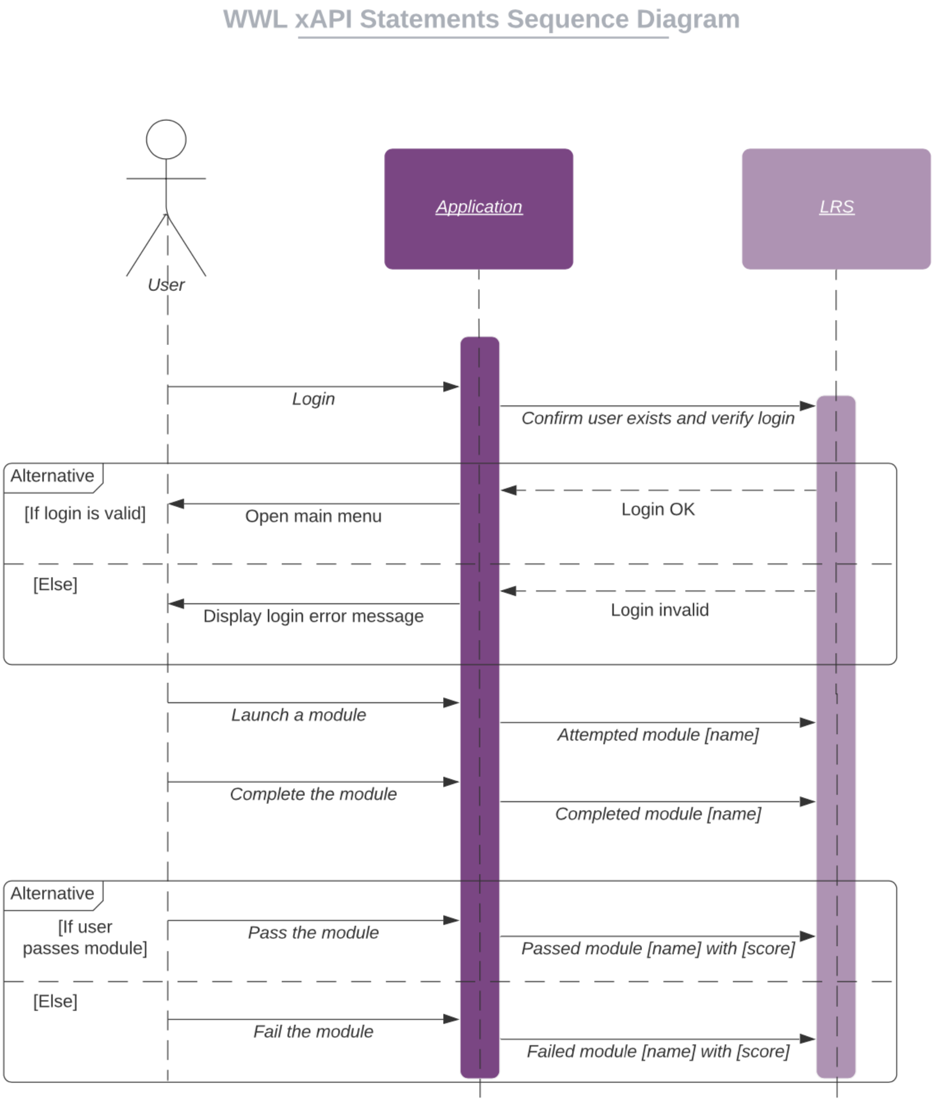
Benefits for this approach include:

- Markerless technology dispenses with the need to always have a usable 'marker' available when using the App e.g. in school or at home - which can be an inconvenience.

● Using markerless AR for our Tablet App allows our software, audio, video and AR animations to be controlled (touch) by the student to initiate animated visual scenarios designed to enhance learning and hopefully create a better understanding of the concepts being taught.
● The Arete Project stakeholders (Generation Alpha) are growing up with the technologies available today via the internet and using mobile touchscreen devices to access information.

4.6.3 Experience Application Programming (xAPI)

xAPI is becoming the standard for encoding and sharing research/educational data between learning systems and technologies.



xAPI Sequence Diagram - Figure 4.6.3

The main benefits for introducing xAPI for Arete Pilot 1 is as follows:
● xAPI will track selected learning activities that occur for each student using the mobile WWL AR-App

- Each xAPI statement is a JSON object which includes several metadata as well as information about who performed an action (the "actor"), which action was performed ("verb") and on which “object”. The structure of each xAPI statement is composed of these three main parts, together with additional information as, for example, timestamps on when the statement was generated.
- The AR-Tablet App will use xAPI statements to transfer learning data for each student directly from the App, into a Learning Record Store (LRS) or Learning Locker (LL).
- The LRS/LL holds the xAPI learning and performance data which can be interchangeable between other LRS/LL and also a Learning Management System (LMS e.g., Moodle)
- Learning and performance data collected from the WWL AR-App will include: pseudonymised information about the owner, student, videos, exercises, quiz results, rewards, duration and various timestamps reflecting progress through the App.
- We can selectively track which resources a student accesses within the App, and how much time they spend using and viewing the resources.
- We can also track and measure the actions and time each student takes for lessons, games, reading, spelling exercises and Quizzes.

The list of xAPI statements generated by the application is available in the following table.

Actor	Verb	Object	Result
Teacher/Parent	Log In	Access App	Success (boolean)
Student ID	Log In	Access App	Success
Student ID	Log Out	Close App	Duration/Completion
Student ID	Selected	Level: where left off	Success
Student ID	Completed	Lesson: learned	Completion
Student ID	Replayed	Lesson: learned	Completion
Student ID	Left	Exercise: marked unfinished	Completion
Student ID	Selected	Vowel chart: at any stage	Completion
Student ID	Selected	Consonant chart: at any stage	Completion
Student ID	Selected	Flashcard	Completion
Student ID	Open & Close	Ar 3D Object (id. attributes)	Experienced
Student ID	Completed with each Quiz result	Questionnaire	Pass / Fail
Student ID	Enabled	App library: Revision	Completion
Student ID	Selected	SBL API (%overall and phoneme)	Completion

All the xAPI statements are collected on a Learning Locker instance. Learning Locker is a conformant open source Learning Record Store (LRS) started in 2013 by HT2 Labs[2]; a type of data repository designed to store learning activity statements generated by xAPI compliant learning activities. The main advantage of using Learning Locker is that the installation is very easy, thanks to the tools provided by HT2Labs and the extensive setup available in the AWS community AMIs.

Once a Learning Locker instance is installed, any application or web page connected to the server can start sending xAPI statements. The maintainers of xAPI[3] provide tools for using their library in many different programming languages.

The main function of Learning Locker is the storage of statements, usually done in a Mongo database, but apart from this it also adds additional functionalities:

- Search with multiple filters (who, what, where, when, store, ...).
- Plot subsets of data. This allows the creation of both individual plots and dashboards that can be shared outside of the Learning Locker instance. The user can configure what to plot and select the appropriate diagram for the type of data he wants to represent in a figure
- Statement forwarding to other platforms.
- Download the raw data as csv.
- Control the access credentials for different types of users

For Pilot 1, we installed a Learning Locker instance on AWS using the Amazon Elastic Compute Cloud (EC2) wizard creator. The server is located in Frankfurt and it uses 1 GB of Ram and 30 GB of storage, expandable according to requirements and usage. The server was assigned an elastic IP, and it is reachable at https://learninglocker.vicomtech.org. All the data to the Learning Locker is sent via an encrypted connection, even if all the statements sent to the server are pseudonymized and only contain the ID of the users.

After installing Learning Locker on AWS, we proceeded to configure it according to the requirements of the ARETE pilots:

- Organization: Each organization is an instance that is isolated from the other organizations and it contains all the data and users. So far, we have created two organizations, one for testing and one for ARETE data
- LRS: This is a Mongo database that stores all the information. For each organization we created three LRS that follow this naming convention: OrganizationName_1 , OrganizationName_2 , OrganizationName_3.
- Users: These are the people that can access the Learning Locker web interface. Users can have different roles and permissions. Several filters can be added to each user allowing them access to only parts of the organizations. These filters are the same ones available in the search

[2] https://www.ht2labs.com
[3] https://rusticisoftware.com/xapi/

function. Two general administrators and two general observers have been created as well as one administrator for each member of the consortium that has asked it.

- Clients: These are the people that send the statements. Each client can only send data to one LRS. One client per LRS has been created as an example, and each client has a key and secret that, together with the information about the xAPI endpoint, is used for the statement sending. Each client has to be assigned an unique authority and for privacy concerns Open ID has been chosen.

Data can be sent from within Unity (using a plugin from Tin Can) or from the web. The data to be provided are the following:

- actor: This is the subject that is sent in the statement.
- verb: This is the action that is sent in the statement.
- definition: This is the additional information that is added to the statement.
- xAPI endpoint: This is the direction that the statement is sent to.
- Key: This is the user of the client that sends the statement.
- Secret: This is the password of the client that sends the statement.

4.6.4 Voice Recognition

The stakeholders for this project are schoolchildren between the ages of 9 to 12 years old that are having difficulties learning to read and spell, that is the 'foundation' for learning. As a consequence, they are underperforming and run the risk of underachievement. WWL has long promoted the maxim "Learn to read – read to Learn" and it is well known that factors such as reading and spelling (accuracy), fluency (rate), comprehension / understanding can indicate where a student stands with their literacy development. These were factors considered for selecting the voice recognition software, allowances for childhood speech immaturities, distortions and accents, along with ease of use, implementation & setup, child protection and cost. Children's voices are very different from adult voices.

We will introduce 'state of the art' voice recognition into our ARETE Pilot 1 AR-App to increase engagement for the schoolchildren and we researched the main players in this field. We found that most of the voice recognition products available to the market are designed and developed for an adult voice e.g., Google voice assistant, Amazon Alexa. We were determined that the voice recognition product must be suitable for the stakeholder age-group (9-12 years) and we discovered, after researching H2020 Projects in this field, an EU Horizon 2020 SpeechTech4Literacy Project entitled "Multilingual Children's Speech Assessment Platform for Literacy and Language Learning" which was coordinated by Soap Box Labs Limited (SME). UCD has provided the finances for the licence of the SoapBox API voice recognition tool (API), which was tested with the WWL mobile apps and the features include:

- SBL provides voice technology specifically to capture the voice of children from 2 to 12 years old, with their online 'security' for this age-group a top priority.
- Voice is an even more important tool for children than it is for adults. It allows them to interface with technology and control devices long before they're old enough to read or write.
- Voice gives children the means to develop, learn and play in the most natural way possible, giving them the opportunity to express their feelings.

- SBL provides an API that has been tested across approximately 192 countries, and which we have tested on our online version of the WordsWorthLearning programme.
- The SBL voice engine also caters for children with unpredictable speech patterns and behaviours, with more accuracy across global accents and dialects, which will also facilitate learning English as a second or foreign language.
- The Arete Pilot 1 stakeholders are between 9–12-year-old, and at that age, unless they have a speech disorder, would normally have a full repertoire of ‘speech sounds’ in their mother tongue.
- Within the Artete Pilot 1 AR-App, we send a request (C#) with the student recorded audio and receive a JSON file response with success/fail data from Soapbox Labs API. (www.soapboxlabs.com)


```
{
 "user_id": "1",
 "results": [{
  "category": "hoi",
  "hypothesis_score": 78.0,
  "word_breakdown": [{
   "word": "hoi",
   "target_transcription": "hh oy",
   "quality_score": 78.0,
   "phone_breakdown": [{
    "phone": "hh",
    "quality_score": 95.0
   }, {
    "phone": "oy",
    "quality_score": 57.0
   }]
  }]
 }],
 "language_code": "en-GB",
 "result_id": "1-277_1621839753340",
 "time": "2021-05-24T07:02:33.673Z"
}
```


SoapBoxLabs research data:

WWL are currently testing “nonsense” single syllable words e.g. - HOI pronounced HOY

The JSON file results derived from the audio file relating to the word (HOI) voiced in a reading exercise, can give us the opportunity for rule and morpheme analyses:

- Percentage success/fail data
- Phoneme/s breakdown
- Time to deliver response
- Identify “patterns” of errors

Note: More data will be derived from multi-syllabic words.

SoapBoxLabs - Rules & Morpheme Research Data: - Figure 4.6.5

5. Exploratory Research

5.1 Vowel Pronunciation Trainer

Mastering the English language at an early stage of education with **proper pronunciation** is the key for effective communication. Vowels are very important as they can be found in every syllable of every word in the English vocabulary and understanding the vowel sounds is highly linked with reading skills. Within this breakout project, ARETE has researched, developed and experimented with the vowel trainer, which is an augmentation for Mirage-XR (possibly changing to become a ‘plugin’), to allow a user to be assessed on the pronunciation of selected 3D learning objects and provided with meaningful feedback. Through interacting with these objects (created based on the WordsWorthLearning literacy programme), leveraging Soapbox API, and Orkestra it aims to advance current paper-based assessment methodologies and assist users in learning the correct pronunciation of vowels. Each user selects from the options of Student and Teacher. The Teacher and Student interact with each other using Orkestra. The Teacher selects which objects the Student can choose from, while the student receives a score from Soapbox API on their attempt after selecting an object. The Teacher then receives a more detailed analysis of the Student's attempt.

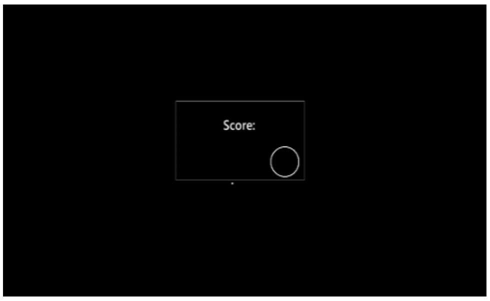


Figure 5.1.1: Initial Student Screen

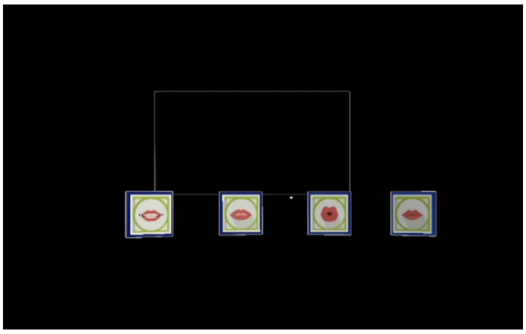


Figure 5.1.2: Initial Teacher screen

When a Teacher selects a menu option, objects relating to the vowel shape appear to the Student. The Student can press an object and audio plays stating how to pronounce it and a 3D face model plays an animation to highlight the vowel shape as highlighted below.

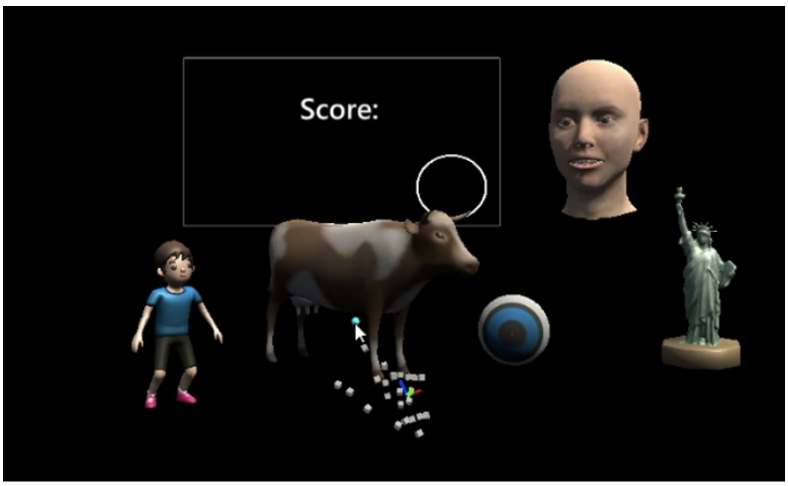


Figure 5.1.2: Selecting an item triggers mouth animation when selecting Cow

Each Teacher menu option contains different objects that refer to the shape of the mouth when pronouncing a word. WordsWorthLearning has utilised word icons to facilitate the student in extracting the target phoneme / vowel in this instance. UCD has tried to simulate this process within an AR scene, in order to investigate whether the users responded better to learning when the word icons are supplied with 3D model face/mouth movement.

Figure 5.1.3: The Menu options: Moving, Resting, Round, and Spread

Unique facial animations were created for the purposes of the vowel training development. The face model has been developed utilising the Character Creator 3 software, blending some main characteristics of male and female models. The textures of the mouth were edited and polished on photoshop. Moreover, reference poses were exported from cc3 and imported to 3dsMax. All poses of the mouth linked to morph targets with the morpher modifier. Therefore, all morph targets have been placed into the timeline as keyframes to define the order, the intensity and the duration of the motions. The result of those steps was the creation of some complex animations for the representation of every vowel. Additionally, the next step was to export the model from 3dsMax (with the morpher modifier animations) as fbx and make the animation keyframes on it. Then, the models were imported into unity to be tested with some changes and tweaks, to find the right speed and pauses. Finally, it has been created an alternative model, with the mouth separated from the head to be further utilised if the users prefer not to view the full-face model. The above steps were followed once again with the new detached model. Using the vowel charts provided by WordsWorth Learning and 3D modelling software, we created a model with 4 different animations relating to the vowel shape the user would be expected to make.

Vowel Shape	**3D Objects**
Spread	Bee, Ink, Apple, Mail
Round	Tooth, Bald, Sauce
Resting	Bird, Cup, Hammer
Moving	Boy, Cow, Eye, Statue*

*Diphthongs (Moving sounds) are always represented last.

Spread	Round	Resting	Moving
			

Figure 5.1.4: Vowel trainer – Face models

Once the user presses an object, a countdown begins. Once the users are finished with the task, they can record their attempt at pronouncing the object. The audio is then analysed using the Soapbox API and a score is received. The higher the score the better the pronunciation.

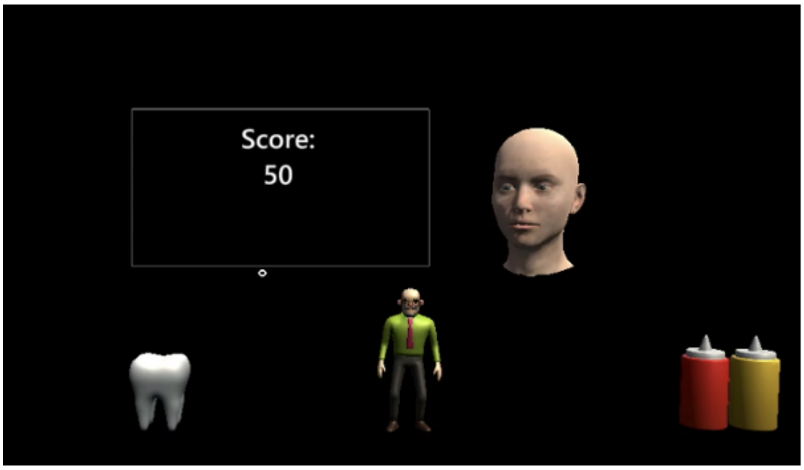


Figure 5.1.5: Received score from SoapBox

The Soapbox API interaction is done by sending a Unity Web Request containing the recorded audio to SoapBox Labs and receiving a JSON string that is converted to a class when returned. Based on this, the hypothesis score, which is the most relevant score, is displayed to the user.

```
SoapboxResponse soapbox = JsonConvert.DeserializeObject<SoapboxResponse>(request.downloadHandler.text);
Debug.Log("soapbox breakdown: " + soapbox.ToString());
string sendingText ="newline"+ "Target: "+currentObjectName.ToString()+"newline";
foreach (Result result in soapbox.results)
{
    Debug.Log("Score: "+result.hypothesis_score.ToString());
    scoreText.text = "Score:\n" + result.hypothesis_score.ToString();
    sendingText = sendingText +"Score: "+ result.hypothesis_score.ToString()+ "newline";
    foreach (WordBreakdown word in result.word_breakdown)
    {
        foreach(PhoneBreakdown ph in word.phone_breakdown)
        {
            Debug.Log("Phone: " + ph.phone);

            Debug.Log("Quality: " + ph.quality_score.ToString());
            sendingText = sendingText + "Phone: " + ph.phone +", Quality: "+ph.quality_score.ToString()+"newline";
        }
    }

}
gameObject.GetComponent<OrkUser>().SendToTeacher(sendingText);
```
Figure 5.1.6: Extracting and displaying hypothesis score to the user.

The Soapbox API also returns more detailed analysis of the Student's attempt. This is sent to the Teacher via Orkestra and displayed on their board. The analysis contains the target word, their overall score, and a breakdown of each phoneme in the word and a quality score relating to it.

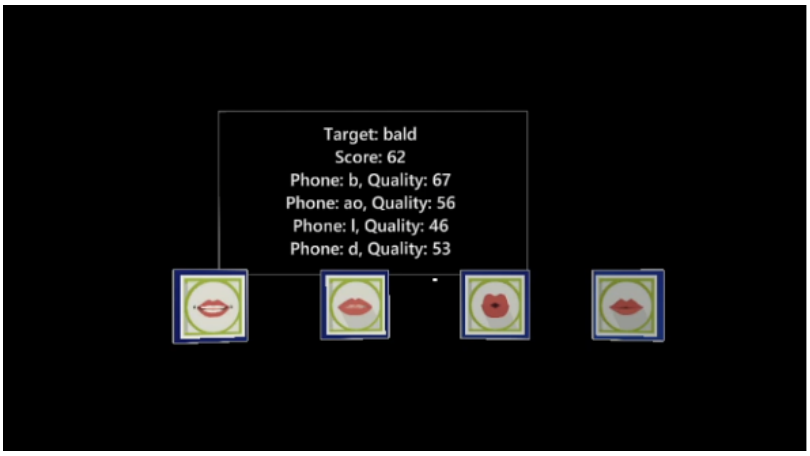


Figure 5.1.7: Detailed analysis of the Student's attempt displayed to the Teacher.

Orkestra is how communication is sent between the Student and Teacher. Orkestra allows a user to subscribe to events which are sent by JSON. Depending on whether the user is a Student or Teacher, a different JSON is sent, and a different method is called when received. The Student sends a JSON containing the Soapbox API, while the Teacher sends which objects to display. Each calls different methods when they receive the JSON: ChangeVowelObjects() for the Student and UpdateTeacherPanel() for the Teacher.

```
1 reference
private IEnumerator ChangeVowelObjects(string _test)
{
    Debug.Log("Change Vowel Objects called");
    JObject test = JObject.Parse(_test);

    if (test["event"].ToString().Equals("appEvent"))
    {
        if (test["key"].ToString().Equals("data"))
        {
            JObject data;
            try
            {
                data = JObject.Parse(test["value"].ToString());


                if (data["vowelObjects"] != null)
                {

                    string _vowelObjects = JsonConvert.SerializeObject(data["vowelObjects"]);
                    _vowelObjects = _vowelObjects.Trim(' ', '\t', '\n', '\v', '\f', '\r', '"');
                    Debug.Log("vowel objects: " + _vowelObjects);
                    Debug.Log("gameobject name: " + gameObject.name);
                    gameObject.GetComponent<VowelMenuDisplayController>().DisplayObjects(_vowelObjects, gameObject);

                }

            }

            catch (Exception ex)
            {
                Debug.Log("Warning value not parseable: "+ex);
            }
        }
```

Figure 5.1.8: ChangeVowelObejcts() method

```
private IEnumerator UpdateTeacherPanel(string _test)
{
    Debug.Log("Update Teacher Panel called");
    JObject test = JObject.Parse(_test);

    if (test["event"].ToString().Equals("appEvent"))
    {
        if (test["key"].ToString().Equals("data"))
        {
            JObject data;
            try
            {
                data = JObject.Parse(test["value"].ToString());


                if (data["soapbox"] != null)
                {

                    string teacherText = JsonConvert.SerializeObject(data["soapbox"]);
                    teacherText = teacherText.Trim('"');
                    teacherText = teacherText.Replace("newline", "\n");
                    Debug.Log("soapbox text: " + teacherText);
                    teacherScoreBoard.GetComponentInChildren<TextMeshProUGUI>().text = teacherText;


                }

            }

            catch (Exception ex)
            {
                Debug.Log("Warning value not parseable: " + ex);
            }
        }
```

Figure 5.1.9: UpdateTeacherPanel() method.

Anchors in the augmentation are determined by the user. For the Teacher, the menu and panel are always orbital and follow them around. The scoreboard and the menu follow the Student around but when the Teacher selects an option for the Student, the objects are anchored locally.

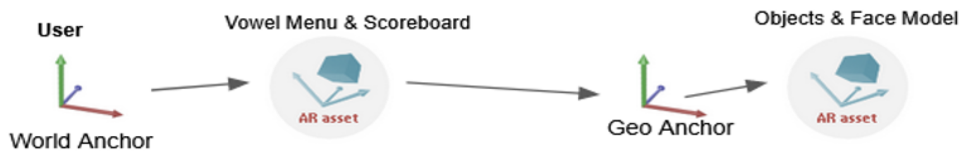


Figure 5.1.10: Vowel trainer Reference points

5.1.1 Future work

The Vowel Trainer is a simple and effective way of demonstrating teaching phonemes in an XR environment. Currently the Orkestra implementation only allows for sending information. The user cannot yet see each other's assets. Going forward, work will focus on creating a multi-user shared experience where the Teacher can see what objects are visible to the Student and which objects they are selecting. This would greatly enhance immersion. This extension of Pilot 1 was integrated into MirageXR before support for Orkestra was added. Currently, its not released yet in the stable release, as it still is in development. It will soon be added as an augmentation or app (using the new plugin system). Rather than use the full-face animation, we investigate just using a smaller mouth animation to highlight the mouth vowel shape which is selectable and triggers the mouth animation for the Student. Depending on the time limitations for further research, the UCD research team would like to investigate further reading assessment through voice recognition.

5.2. Speed Reading Assessment

The systematic literature review (SLR) has indicated that AR technologies are increasingly being used for educational purposes, and demand for more work in improving learning skills for students with specific disabilities/disorders has been identified. Pilot 1 is focusing on students in primary schools that have spelling and reading difficulties and Quintero et al. (2019) reported in their review of 50 clustered studies (2008-2018) based on the disorder investigated the following distribution:

- Hearing disabilities 20%
- **Autism Spectrum Disorder 18%**
- Intellectual Disability 14%.
- Visual limitations 8%
- Language deficits 6%
- Attention Deficit Hyperactivity Disorder (ADHD) 6%
- Physical or motor disability 4%
- Characteristic deficiencies (?) 4%
- Cognitive deficits 4%
- **Dyslexia 2%**
- Down Syndrome 2%.

UCD's research team is focused on the aspect of AR that is extremely crucial when working with children with ASD, who are less likely to devote time and attention to their weaknesses. AR has the potential to increase reading and assist children with ASD that are having difficulty studying. Based on Antão (Antão et al., 2020) work, such individuals can benefit from assistive AR game technology. Their findings show that children with ASD can play an AR game with English letters and numbers and improve their reaction time after completing a task with the AR game. These results are critical for children with special needs in school, especially those with poor basic skills or low motivation and engagement. The use of AR serious games has been widespread, and they offer an active learning environment. This distinguishes it from other games whose main purpose is to provide entertainment. According to Khowaja (Khowaja et al., 2020) research, the use of video modelling by teachers has been identified as an evidence-based method for training students with ASD and supports more choices for student engagement and concept representation. Furthermore, in a research study by Howorth (Howorth et al., 2019) - they define suggestions for how to use a particular AR application to (a) teach phonics and word identification (b) support reading fluency (c) embed videos into texts as cues for reading comprehension (d) teach content area vocabulary words and (e) use video models during transition planning. Tang et al. (2019) discussed another study that used a lightweight virtual reality-based word-learning app to help children diagnosed with ASD to learn words at any time and in any environment, mostly outside of classrooms. According to the findings of their study, the app inspires children's interest, which could encourage them to learn outside of the classroom. Furthermore, the observations of both special education teachers and parents emphasized the importance of learning while playing and learning at any moment and in any environment, not just for children with ASD but also for those with other special needs.

5.2.1 Research Gap, Challenges, and solutions

Assessment is a critical component of education that is used within learning plans (Cain, 2007). Identifying students' baseline performance is the first step in providing effective reading teaching. Assessments provide teachers with the information needed to develop appropriate lessons and improve instruction for all students, including students with disabilities. Reading evaluation allows us to better understand each of our students' skills and needs. Micai (2019) identifies a **research gap in reading monitoring particularly for students with special needs.** Moreover, Afflerbach (2016) states that "reading monitoring is poorly explored, but it may have an impact on well-documented reading comprehension difficulties in autism".

The purpose and benefits of assessment includes the following:

- Identify skills that require revision.
- Keep track of students' development.
- Guide teacher training
- Demonstrate the efficacy of education.
- Provide guidance to teachers on how to enhance education.

Moreover, in terms of the **advancement of reading assessment**:

- Reading assessment allows us to make inferences about students' needs and strengths and determine students' motivations, self-efficacy, and developing sense of the self as a reader.
- Beyond diseases or disorders that affect the eye directly, **abnormal reading patterns have also been found in individuals with dyslexia, ASD, Developmental Coordination Disorder (DCD) and visual processing difficulties (in the absence of visual acuity deficits).** These abnormal reading patterns have also been found to have predictive power, opening the possibility of an objective, non-invasive diagnosis tool.

An effective, comprehensive reading program includes reading assessments for four purposes: Screening, Diagnostic, Progress Monitoring, Outcome. Currently, **there are no available toolkits with reading assessment methods for students with disabilities and special needs specifically with new technologies and tools like HMDs or VR/AR.**

5.2.2 The advancement of the technology

The global head mounted display market is expected to grow at a compound annual growth rate of 48.4% from 2014 to 2020 to reach USD 11.8 billion by 2027. Integrated eye trackers are becoming more common in HMDs for use in virtual and augmented reality (VR/AR). **Eye tracking target scenarios in HMDs** include foveated rendering and gaze-based interaction. However, the number of research studies and functionality are limited in this area. There are some VR eye tracking toolkits available which include Tobii, Pupil Labs for the HTC Vive HMD (Tobii VR, 2021; Pupil Lab, 2021). Because of the growing interest in using eye tracking in HMDs, Magic Leap 1 (Magic Leap, 2021) and Microsoft

HoloLens 2 (Microsoft, 2021) are equipped with eye trackers. The aim of this research could be providing an AR toolkit to simplify eye tracking in AR based on Microsoft HoloLens 2 to fill the research gap in this area.

Microsoft HoloLens 2 and MRTK

In the HoloLens 2 there are two infrared (IR) cameras that provide a close-up view of the user's eye (Microsoft, 2021). HoloLens 2 has a new eye tracking feature that allows users to interact with holograms rapidly and easily across their field of vision, which - if applied right - can make the system smarter by better understanding a user's intention. The MRTK is an open-source toolkit that enables gaze-based interaction via an easy-to-use API for developers. Developers get access to a single eye-gaze ray (gaze origin and direction) at approximately 30 FPS (30 Hz) with a spatial accuracy that ranges "approximately within 1.5 degrees". There are number of features that MRTK provides for developers:

- Eye-Supported Target Selection
- Eye-Supported Navigation
- Eye-Supported Positioning

Also, useful properties of the Eye Gaze Provider are outlined below.

Data Column	Description
Gaze Origin_(x/y/z)	Origin of the gaze ray
Gaze Direction_(x/y/z)	Direction of the gaze ray
Gaze Point Hit	Raycast hit an object and a gaze position exists
Gaze Point_(x/y/z)	Position of the gaze point
Hit Info, Hit Position, Hit Normal	Information about the currently gazed at target

5.2.2 Future work

Eye tracking in MRTK enables applications to track where the user is looking in real time. The UCD research team is investigating the development of an automated reading assessment methodology, based on eye gaze function within Mirage XR. We plan to assess the efficiency of the algorithm and this research will be in progress for the next year.

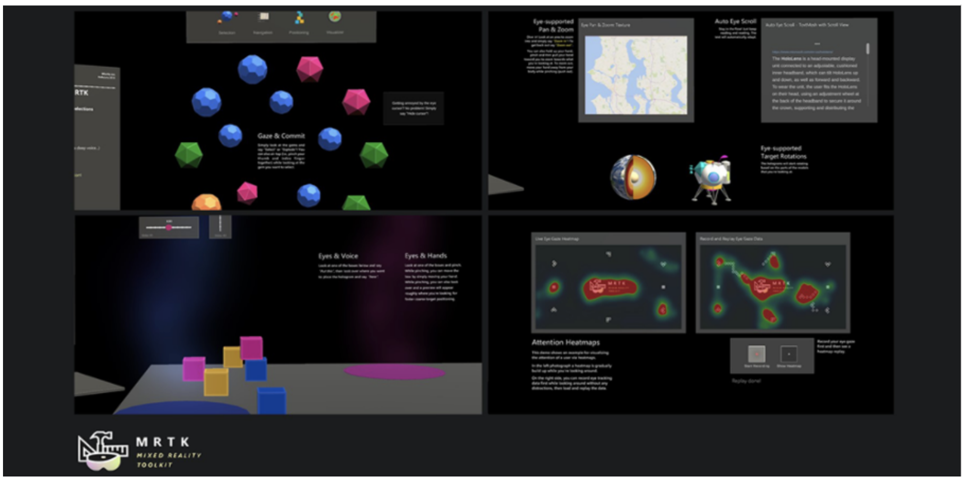


Figure 5.2.1. Eye tracking in the Mixed Reality Toolkit.

6. Conclusion

6.1 Technology

Pilot 1 AR-App: Considering our competitor and literature review and the 'State of the Art' AR software development tools at the time, we decided that ARFoundation & Unity met the requirements for the Pilot 1 AR app. Application of the AR 3D objects & animation was via Unity engine, with ARFoundation plugins ARCore and ARKit infrastructure. With the latest technical updates to AR enabled mobile devices, the app can use location data, SLAM and markers to merge content into the device camera feed, and introduce superimposed graphic elements based on its gyroscope, magnetometer, accelerometer, and GPS tracking. This gave us:

1. the opportunity to adopt 'markerless' technology for mobile devices (Tablets), which is a technology that is growing exponentially.
2. the introduction of a voice recognition API, specifically designed for children in the age-range of our stakeholders (9 to 12 years old).
3. the introduction of the xAPI technology for processing the research data that will be gathered from our stakeholder usage of the AR-App and transferred to the project Learning Locker.

The Arete Pilot 1 has a native AR-App designed for use on mobile Tablet devices with AR technology, which will be released on Google Play for Android devices and Apple App Store for iOS devices.

Exploratory research: Within this breakout project, UCD has:

1. researched, developed and experimented with a vowel trainer, which is an augmentation for MirageXR, to allow a user to be assessed on the pronunciation of selected 3D learning objects and provided with meaningful feedback.
2. Eye tracking in real time: the research team is investigating the development of an automated reading assessment methodology, based on eye gaze function within MirageXR and research will be in progress for the next year.
3. With a current research gap for using eye tracking in HMDs, there exists an opportunity to provide an AR toolkit to simplify eye tracking in AR, based on Microsoft HoloLens 2.

6.2 Adding Value Beyond Existing Pedagogy

Augmented Reality (AR) is at the cutting edge of disruptive education, and the exponential growth and use of this technology is anticipated to have a major impact on education as we know it today. There is currently a dearth of AR technology being used in the Primary school 'remedial' sector. Arete Pilot 1 will introduce a State of the Art AR-App for this sector, containing markerless AR, 3D audio/visual graphics, voice recognition (for that age group), and our WWL programme content.

The overall D3.3 objective is to provide research data to prove that our AR-App will help approximately 240 students that attend English language schools across Europe to overcome their reading and spelling difficulties. Pilot 1 could also strengthen collaboration between Teachers, Parents and Children, and help each student reach their academic potential.

Following our extensive SLR research including currently available state-of-the-art EdTech literacy products, we are confident that our original pedagogy that incorporates the selected SLR review recommendations for future development and research will add value beyond existing pedagogy for education in the Primary School sector.

WWL also intend that our action and results will be consistent with the UNESCO Strategy for reducing Illiteracy Worldwide, in particular “addressing the learning needs of disadvantaged groups”, in this case, for those primary school students that have reading and spelling difficulties that, for whatever reason, are not being addressed satisfactorily whilst in mainstream education.

Annex 1: EdTech Research - AR for Literacy

Considering the information gathered from the Systematic Literature Review, and as an SME with 30+ years clinical/educational experience and 10 years with an established Web-AR literacy programme, working with teachers, parents and children, WWL considered the following factors for the cohort involved in the Arete Project, i.e., age, educational limitations, access to technology in schools and at home, and the limited VR/AR technologies available to them.

WWL researched the commercial marketplace (late 2019) for information concerning proprietary products that were already being used in school and at home.

Table 1A: EdTech Literacy Research below is an extract from a Literacy Program Evaluation Guide that was supplied by our EdTech advisors, it was developed for Reading Rockets by Courtneay Kelly, Ed.D., Longwood University (June 2018). The full survey can be found here:

https://www.readingrockets.org/content/pdfs/Literacy%20Programs%20Evaluation%20Guide%202018.pdf.

Literacy Programs: Evaluation Guide

Name of Literacy Program	Grade Levels	Leveled Texts	Comprehension Strategies	Diverse Vocabulary Work	Fluency Work	Word Work/ Spelling	PA and/or Phonics	Writing Component	Embedded Assessments	Suggested Scope & Sequence	Differentiated Lesson Support	Technology
Achieve 3000	K-2	●		●	●	●	●		●		●	
Cooperative Integrated Reading and Composition (CIRC)	2-8		●		●	●	●					
DaisyQuest	PK-2						●					●
Dialogic Reading	PK-K		●	●								
Doors to Discovery	PK						●					
Earobics	PK-3	●			●		●					
Edgenuity/ Compass Learning MyPath	6-12	●							●			●
Fast ForWord	K-12				●		●					●

Table 1A. EdTech Literacy Research (Kelly, 2018)

In 2019, WWL researched each entry in the above table, along with other commercial products on the market at the time, to establish the extent of AR used in primary school level literacy programmes, The programmes / materials in the above table were revisited in 2021 to ascertain if there were further developments in the area - none were found.

Our latest summary is provided in the following Table 1B.

RESEARCH - LITERACY PROGRAMMES with / without AR for ARETE Project

Most Commonly used Literacy Programmes / Materials in Ireland & UK 2021	Uses Technology	Augmented Reality Features	Markerless	Primary 9 to 12 year olds (5th to 8th grade)	Evidence Based Content	Phonemic Approach	ONLY focusses on phonemic or phonic awareness	Literacy Program - 5 Pillars of Reading Pedagogy	Follows a hierarchy of difficulty	Complete Reading & Spelling Program	Uses AR Flashcards	Uses Voice Recognition	Uses Lower Case Font for AR Objects	Embedded Assessments	Differentiated Lesson Support / Scaffolding
ARETE AR App	●	●	●	●	●	●		●	●	●	●	●	●	●	●
WordsWorthLearning Program	●			●	●	●		●	●	●				●	●
Jolly Phonics - AR Research Version only	●	●			●	●	●								
PhonoBlocks Reading System - Research Version Only	●	●				●	●								
Octagon Animals	●	●					●				●				
Oobedu World of Alphabet	●	●					●				●				
Indiegogo Alphabet Corner AR for Alphabet	●	●									●				
Catchy Words AR for Spelling	●	●	●												
Wilson Method	●			●	●	●		●	●	●					●
Davis Method	●			●						●					
Reading Recovery				●	●	●				●				●	●
Synthetic Phonics				●	●	●			●	●					●
Letterland	●									●					●
Nessy	●			●	●	●		●	●	●				●	●
Word Shark	●			●		●				●					●
Alpha to Omega				●	●	●		●	●	●					●
Reading Rockets	●				●	●		●	●	●					●
Reading Eggs	●			●	●	●		●	●						
Literacy Planet	●			●	●			●	●	●				●	●
Orthon Gillingham				●	●	●		●	●	●					●
LiPS	●			●	●	●		●	●	●					●
FastForWords	●			●	●				●						●
Toe by Toe				●	●	●			●						●
Jolly Phonics - Commercial Version	●				●	●		●	●	●					●

Table 1B. WWL Literacy Research

It is important to note that our ARETE Pilot 1 cohort are schoolchildren between the ages 9 to 12 years old and as such, **they are subject to "Educational Policy" which precludes using AR/VR wearable technology in school**. **Nevertheless, the research team within ARETE (UCD and OU) have taken a step further in research to investigate the capabilities of MIRAGE·XR and Hololens for specific tasks within teaching and learning literacy skills (i.e. voice recognition within a vowel trainer and eye tracking for assessment of reading speed).**

Unfortunately, for the cohort of participants recruited for Pilot 1, the use of "State-of-the-Art" AR/VR technology that is commercially available for research is restricted in terms of accessibility and availability, so we are evaluating the **mainstream Pilot 1 apps based on the affordable mobile devices in schools** and further research on the advancement of the state of the art will be evaluated within specific focus groups and the results will be published at the final year of the project.

Annex 2: SLR - Benefits and Changes

Benefits	Challenges
Improved motivation, (Parmaxi et al. 2020, Quintero et al. 2019, Howorth et al. 2019, Sommerauer et al. 2019, Khan et al. 2019, Awang et al 2019, Safar et al. 2017, Akçayir et al 2017, Saltan et al. 2017, Lin 2016, Diegmann et al 2015, Solak et al. 2015, Bacca et al 2014, Wu et al 2012, Schmitz et al. 2012). **Increased interaction** (Parmaxi et al. 2020, Quintero et al. 2019, Howorth et al. 2019, Safar et al. 2017, Saltan et al. 2017, Wu et al 2012). **Increased collaboration** (Parmaxi et al. 2020, Li et al 2017, Safar et al. 2017, Santos et al. 2016, Diegmann 2015). **Increased interest and engagement.** (Quintero et al. 2019, Howorth et al. 2019, Sommerauer et al. 2019, Li 2017, Akçayir et al 2017, Safar et al. 2017, Saltan et al. 2017, Wu et al 2012, Schmitz et al. 2012, Bacca et al 2014). **Comprehend concepts faster** (Parmaxi et al. 2020, Quintero et al. 2019, Hrishikesh et al. (2016), Li et al 2017, Safar et al. 2017, Akçayir et al 2017, Lon 2016, Bacca et al 2014, Schmitz et al. 2012, Specht et al. 2011). Has the potential to **decrease the complexity of a concept** by affording the ability to visualizing unobservable objects and concepts (Park et al. 2019, Luna et al. 2018, Akçayir et al 2017, Safar et al. 2017, Phon et al. 2014,Wu et al 2012). **Holds / improves attention** (Parmaxi et al. 2020, Quintero et al. 2019, Sommerauer et al. 2019, Khan et al. 2019, Li 2017, Santos et al. 2016, Tentori, 2014). **AR benefits students who have SEN**, evidencing the work with the following populations Quintero et al. 2019 cites: (*auditory limitation* (Carvalho and Manzini, 2017), *visual limitation* (Lin et al., 2016), *autism* (Tentori et al., 2015), *attention deficit hyperactivity disorder* (Lin et al., 2016b), *dyslexia* (Persefoni et al., 2016). **Low cost of implementing this technology in the classroom**: despite the high cost of vision devices, hand held devices and laptops are good tools to support learning processes in the classroom. Quintero et al. 2019 cites (Zainuddin et al., 2010; Ab Aziz et al., 2012; Chen et al and Wang, 2015; Hsiao and Rashvand, 2015), Akçayir et al 2017). **Helps with short and long-term memory** (Parmaxi et al. 2020, Howorth et al. 2019, Sommerauer et al. 2019, Quintero et al. 2019, Cihak et al et al. 2016, Diegmann et al 2015, Bacca et al 2014, Vullamparthi et al. 2013). **Innovative use of AR applications, to integrate evidence-based teaching strategies can transform learning** for students (Howorth et al. 2019). The lesser reported areas of benefit are: **Efficiency in the learning process** (Sommerauer et al. 2019, Quintero et al. 2019 cited Fernandez et al., 2015; McMahon et al., 2015; Wang, 2016), Akçayir et al 2017, Wu et al 2012, Schmitz et al. 2012).	**Technical problems,** inability to recover from various types of tracking loss and control difficulties. (ChanLin 2018, Quintero et al. 2019, Sirakaya et al. 2018, Akçayir et al 2017, Saltan et al. 2017, Fitzgerald et al. 2015, Phon et al. 2014, Bacca et al 2014). **Lack of research on using mobile AR in education with students with special educational needs**. (Fan et al 2020, Parmaxi et al. 2020, Quintero et al. 2019, Khan et al. 2019, Akçayir et al 2017, Cihak et al 2016, Schmitz et al. 2012). The **need for educational staff to have basic digital knowledge** for adopting ICT in the classroom. (Lee et al 2021, Quintero et al. 2019, Howorth et al. 2019). The **difficulty in recruiting participants** for a study and the complexity of getting permission documents etc. from parents, (Quintero et al. 2019). Resulting in **diminished sample sizes**. **Luminosity difficulties** / insufficient appropriate lighting. (Quintero et al. 2019, Fitzgerald et al. 2015). It is **generally not possible for the user to change or add 3D images to the AR application.** (Quintero et al. 2019). **Long-term results of the use of AR are needed** to prove its effectiveness as a teaching methodology in order to promote long-term educational inclusion. (Quintero et al. 2019). **Requires student training in digital competence.** (Quintero et al. 2019). The **novelty effect could produce research results bias.** (Quintero et al. 2019). **Often only one tool to collect data information is used** e.g. surveys or interviews, however, in the case of children with SEN's it is recommended to access a variety of qualitative and quantitative data collection tools in the same study. (Quintero et al. 2019). **More robust research is needed** to prove acceptability in school environments. (Quintero et al. 2019). **High cost of tablets and high-speed internet availability** (Lee et al 2021, Howorth et al. 2019, Saltan et al. 2017, Fitzgerald et al. 2015). Concerns regarding **'cognitive overload'** (Hsu 2019, Chen et al 2019, Li 2017, Akçayir et al 2017, Fitzgerald et al. 2015, Phon et al. 2014, Wu et al 2012). **Female students have more trouble learning to use the AR platform**, as girls are reported to have lower 3D spatial ability than boys on average. (Hsu 2017.) **Physical problems in using mobile AR,** such as grip and posture strains (ChanLin 2018). **Problems integrating AR into traditional learning methods and teaching pedagogies** (Lee et al 2021, Saltan et al. 2017, Akçayir et al 2017, Fitzgerald et al. 2015). A **deficit of appropriate AR educational resources** (Safar et al. 2017).

Development of cognitive skills (Quintero et al. 2019 cited Benda et al., 2015; Bülbül et al., 2016), also Saltan et al. 2017). AR and QR codes **provide a scaffolding tool** to printed text to supply the student with additional digital materials so that students do not need to distance from the text to find more information e.g. the meaning of the unknown words etc. (Park et al 2019). **Promote student inclusion** in the community (Howorth et al. 2019). **Improved language / vocabulary learning performance** (Parmaxi et al. 2020, Solak et al. 2015, Chen et al 2015). **Enjoyment in the training process** (Quintero et al. 2019 cited Sheehy et al., 2014), Li 2017, Bacca et al 2014). Provision of **compelling learning experiences** (Santos et al. 2016). **Improves student attitude to learning** (Saltan et al. 2017). AR may **lead to better retention of words** (Santos et al. 2016, Bacca et al 2014). AR Games can **provide educators with powerful new ways to demonstrate relationships and connections,** thus promoting learning through a highly interactive and visual methodology. (Diegmann et al 2015). **Student satisfaction** (Quintero et al. 2019 cited Chang et al., 2013; Sahin et al., 2018), Khan et al. 2019, Akçayir et al 2017, Safar et al. 2017, Santos et al. 2016). **Increased Confidence** (Khan et al. 2019, Li 2017). **Decreases Cognitive Load** (Akçayir et al 2017). **Decreases learning frustration for children** with special educational needs (Lin et al 2016). **Students preference for digital learning:** The explosion in the use of smartphones, tablets and apps for education have demonstrated that these new technologies have more effective features to enrich learning environments resulting in the majority of school aged students preferring digital learning (Evans, 2019).	A general **resistance to new technologies** (Saltan et al. 2017, Safar et al. 2017, Wu et al 2012). **Ineffective design of AR application** – leading to distractions and frustration (Saltan et al. 2017) **AR requires reasonably up to date smartphones or tablets** – may be prohibitively expensive for some learners, risking a digital divide between learners from different socio-economic backgrounds (Fitzgerald et al. 2015). **Limited availability of AR experts** (Safar et al. 2017). Taking cognizance of the **diversity of students and differences in learning preferences and learning styles**, that AR might not constitute an effective teaching and learning strategy for some students (Safar et al. 2017, Li 2017, Bacca et al 2014, Wu et al 2012). **Reading performance on AR can be different and slower** from that on a traditional desktop display or from paper, due to the 3D display, the pixel density, the field of view, the distance to the eyes, and background texture. (Rau 2018).

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