ARETE – DELIVERABLE (D3.7)

WP3 – D3.7: Interactive collaborative ARETE mobile app for Pilot 2

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[1] Nature:
R = Report, P = Prototype, D = Demonstrator, O = Other
Dissemination level
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Executive Summary

This deliverable reflects the work in WP3 on task 3.2 regarding the interactive, collaborative ARETE mobile app for pilot 2 (for Android and iOS) covering STEM subjects for primary education in Geography and Geometry. Pilot 2 is led by CLB.

This document provides an overview on the following items:

- Pilot 2 ARETE mobile applications developed by CLB with simultaneous multi-user functionality
- Overview of their state of art of CLB apps for the ARETE project including pedagogical and technological advancement, the component of affordability and accessibility for wider public, learning contexts and architecture
- Deep dive in learning contexts and pedagogical innovation implemented in the ARETE apps
- Analysis of technology use and its application to educational matrix
- Comparative analysis of Geometry and Geography AR apps for primary education based on SLR conducted by CLB in 2021 (covers a decade of technological state of art analysis)
- Summary of incorporated SLR outcomes and how the gaps have been addressed by CLB in the ARETE apps
- Outline of UML diagram for CLB ARETE apps architecture and technology flow
- Overview of Orkestra developed by VIC with further potential integration and Photon replacement
- Experimental research work with IBM Watson, holographic AIs, and its use in Geometry teaching
- The generalisation of the pick & place quiz mode (implemented for MIRAGE·XR)

1. Introduction

This document represents a consolidated report of research conducted via systematic literature review and analysis of mobile applications covering Geometry and Geography subjects in K12 primary grades with the goal to identify state of art of the ARETE apps produced by CLB.

The document is organised as follows. Section 2 provides a comprehensive review of the state of the art. Section 3 describes the school context and pedagogical approach. Section 4 the technology and educational model, conflated into an overview table in Section 5. Section 6 provides system architecture diagrams. Section 7 then provides insight into ongoing research on the communication manager, holographic AIs, and the Pick & place quiz mode. Section 8 discusses the achievements and Section 9 provides an outlook on future work.

2. Review of the State of the Art

2.1 Methodology

The overall method for analysing state of art for Geometry and Geography apps produced by CLB for the ARETE project is based on the systematic literature and research studies review. The focus was on the technological advancement of the mobile applications for Geometry and Geography in K-12 primary grades identified during the period of 2010-2020.

2.2 Pilot 2 Apps Comparative Overview against Existing AR projects (2010-2020)

To create the state of art AR Geometry and Geography apps for the ARETE project, the existing studies of AR on the same subjects and K12 primary grades have been reviewed for the period of 2010 to 2020. Table 5 provides an overview of the state of art of Geometry and Geography apps with AR for elementary school from the point of technology implemented: target recognition, interactivity options, types of multimedia contents, collaborative or multi-user options. Overall, there have been analysed 26 AR mobile applications for Geometry and 11 for Geography:

- Geometry apps represent 24 marker-based solutions, 2 marker less; no collaborative activities inside the apps.
- Geography apps have 7 marker-based, 3 geo location based, 1 a combination of marker and geo location; 1 re-usable lessons shared via cloud, 1 group interactions outside app but sharing media like photos of GPS coordinates to peers through the app.

In the majority of the overviewed mobile applications marker or QR codes are used to provide Augmented Reality contents of different types. The augmentation with a marker is very popular due to the opportunity for a user to manipulate with a tangible object in the real space within the classroom environment (Prodromou, 2019, Petrov, 2020). Geo-location or maps geo-connected augmentation is gaining popularity for field trips (Echeverría et al., 2012) and for connecting augmented elements with real world scenarios, i.e., use a combination of marker targets and geo-located targets (Pellas et al., 2017, Boletsis et al., 2013). The mobile applications in the observed studies have been developed for mobile devices (tablets, mobile phones) for primary education.

In K-12 primary level of education there are multiple options of solutions with AR technology that cover different subjects not exclusive to nature, geography, astronomy, geometry, anatomy, biology, chemistry and others. The applications vary based on target options (marker-based, markerless and geo-location enabled), AR and media contents inside apps (3D, 2D, multimedia, annotations, videos, text, audio, and assessments). The applications of AR vary from simple flashcards to educational books. There were solutions with geo-location target recognition designed for classrooms, local school yards or city field trips. These AR applications allow for students to create, explore, investigate, and interact with a variety of content and artifacts.

AR applications for Geometry and Geography have been a particular focus for this SLR. At the point of conducting this SLR, 11 apps for Geography and 26 apps for Geometry with AR have been reviewed. Among the observed applications with Augmented Reality for Geography in primary school (11 in total), seven out of them are marker-based, one has a combination of marker-based target and geo location and three have geo-location targeting only. The application of Geometry learning with Augmented Reality in primary school has a wider selection of 26 applications among the reviewed ones in this SLR. The majority of them (24) are marker-based and two represent marker-less solutions. There have been no apps for Geometry with in-app collaboration or multi-user elements found. The apps for Geography have been used mainly for team work either outside AR or using AR for teamwork activities. In some cases, mobile apps with AR elements have been used for group information sharing (photos, geo-locations).

The status of Geometry and Geography apps observed shows that the AR solutions for K-12 education have progressed technologically compared to SLRs from previous years that have been reviewed as a part of this SLR. The solutions provide engaging media contents with AR elements, have multiple applications to educational materials like books, supplementary materials like flashcards or assessments, and advanced educational technology-based team activities with field trips using mobile devices and apps.

For further advancements of using AR for learning it could be interesting to observe team activities within the AR space that can be used for team and remote learning that is in demand due to covid-19 situation. Educators may utilize a screen mirroring type software, such as Reflector Teacher, to demonstrate virtually to students what the AR application looks like or how to utilize it. This can also be beneficial for classrooms that have limited devices.

AR technology is relatively new in the teaching and learning settings, thus further advancement will be seen in the future because AR technology as a tool has shown positive results in educational settings based on the observed case studies and apps reviewed. Students are more motivated to learn and retain content when they can physically manipulate, get closer to, create, and explore on their own. Some students may never have the opportunity to leave their country, state, or hometown to visit different historical landmarks, and augmented reality brings artifacts, and the landmarks right into their world in front of them. It also allows students to view content and models of things we can’t see without a microscope or by scuba diving into the ocean. Augmented reality gives students the opportunity to see and interact with plants and animals, sea creatures that live on the ocean floor, as well as many other ways to make learning more meaningful and create those memorable experiences.

The below table provides an overview of the apps analysed.

Study	AR Solution Name	Subject	Grade	Target Recognition	Multiuser, collaboration within AR space	Interaction	Content type
Vahldick & Bittencourt (2019, July)	Creating an augmented book from a geography textbook	Geography	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Adedokun-Shittu, et al (2020)	Augmented reality instructional tool in enhancing geography learners	Geography	Primary	marker	n/a	Visual, touch screen	3D, 2D, annotations, animations
Wang, et al. (2017)	GeoFARA (Geography Fieldwork Augmented Reality Application)	Geography	Primary	geo-location	**Group interactions**. Outside app	Visual, touch screen	photos, old maps, mobile digital maps, satellite images, notes, voice, registration of field walking routes
Ternier, et al (2012)	ARLearn	Geography	Primary	geo-location	n/a	Visual, touch screen	video, audio, open questions and multiple-choice question can be bound to a location, time or game action
Pendit & Bakar (2014)	Mobile AR for Cultural Heritage Site	Geography	Primary	geo-location	n/a	Visual, touch screen	photos, maps, 3D/2D images, notes, voice, games, text
Schnürer, et al (2020)	Swiss World Atlas	Geography	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Palaigeorgiou et al(2018)	TerraGuide: large-format multi-touch table with real-time 3D object recognition	Geography	Primary	marker	n/a	Visual, touch screen, 3D object manipulation	3D, 2D, annotations, animations

Kramarenko et al (2019)	GeoGebra application for learning 3D geometry	Geometry	Primary	marker less	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Kazanidis& Pellas. (2019)	HP Reveal and Blippar	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Sommerauer& Müller (2014)	Aurasma Studio	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation,3D objects manipulation	3D, 2D, annotations, animations
Rossano et al (2020)	Geo+	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation,3D objects manipulation	3D, 2D, annotations, animations
Gün& Atasoy (2017)	BuildAR	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation,3D objects manipulation	3D, 2D, annotations, animations
Purnama et al (2014, August)	OpenCv computer library vision	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Cahyono et al (2018, November)	3-Dimensional Geometry Space	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Rohendi et al (2018, February)	AR-based Geometry Learning Media	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Liu et al (2018, March)	Three-View	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations

Auliya & Munasiah (2019, October)	Mathematics learning instrument (AR Book)	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Rashevska et al (2020)	ArloonGeometry	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Flores-Bascuñana et al (2020)	Augmented Reality for the learning of 3D-geometric contents	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Radu et al (2015, June)	Cyberchase Shape Quest Game	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, gamified content
Dinayusadewi& Agustika(2020)	Augmented Reality Application As A Mathematics Learning Media	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Andrea et al (2019)	Magic Boosed (AR book)	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
İbili& Şahin (2015)	ARGE3D	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Önal et al (2017)	BuildAR PRO 2.0 software	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Sudirman et al (2020, April)	Ethnomathematics	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, media
Gecu-Parmaksiz & Delialioglu (2019)	Geometric Shape Recognition Task instrument	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Chen (2019)	AR apps on Keller's ARCS model	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations

Chao (2019)	AR Math App	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
ROSDI (2018)	Shaped Math AR	Geometry	Primary	marker less	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Le& Kim(2017, February)	Cabri3D	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Amir (2018)	3Dmetric	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Oppermann et al (2016, September)	Underwater Augmented Reality (UWAR)	Geography	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations
Zarzuela et al (2013)	Serious Game with Augmented Reality for children and handicapped people	Geography	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, quiz
Furió et al(2013)	Water cycle	Geography	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, quiz
Young et al (2016, October)	ARmatika: 3D game for arithmetic learning	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, quiz
Santoso et al (2012, May)	Tangram toy, Physical Book and the AR	Geometry	Primary	marker	n/a	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, quiz
Laine et al (2016)	ScienceSpots AR	Geography	Primary	marker, geo-location	Reusable lessons for AR storytelling	Visual, touch screen, marker manipulation	3D, 2D, annotations, animations, quiz

Table 1. AR Geometry and Geography Apps Overview 2010-2020

Based on the analysis of the observed AR mobile applications from research works the below table provides summary of the ARETE apps technical capabilities:

App	Target Recognition	Multi User, collaboration within AR space	Interaction	Content type
ARETE Geometry	Marker-based	In-app AR cooperation / multi-user activities through gamified knowledge testing contents; content curated by educator among devices	Visual, touch screen, marker manipulation, 3D objects manipulation, operation with 3D objects, **modification of 3D objects**	3D, 2D objects, annotations, audio, 3D animations, information, gamified tests, in-app quizzes, informal multiple-choice tests
ARETE Geography	Marker-based	In-app AR cooperation / multi-user activities through gamified knowledge testing contents; content curated by educator among devices	Visual, touch screen, marker manipulation, 3D objects manipulation, operation with 3D objects, **modification of 3D objects**	3D, 2D objects, annotations, audio, 3D animations, information, gamified tests, in-app quizzes, informal multiple-choice tests

Table 2. AR Geometry and Geography apps for ARETE

ARETE apps set focus on multi-user activities inside the mobile application. Teachers have the possibility to broadcast selected content for the required activities, for example overview of certain AR contents; or engage students by splitting them in teams for team activities on working on specific tasks together, for example playing a game online in Geometry or Geography with the goal to complete a team task simultaneously.

3. Learning Context and Pedagogical Innovation

The EU Digital Education initiative (European Commission/EACEA/Eurydice, 2019) provides outline of eight areas of focus of Digital Education in Europe:

1. evaluation of digital information, collaboration through digital technologies,
2. managing digital entity, developing digital content,
3. programming and coding,
4. protecting personal data and privacy,
5. protecting health and well-being
6. digital problem solving.

Existing technologies provide possibilities to proactively address the above-mentioned areas of modern education as well as have a centralized approach of managing educational data and supporting accessible personalized learning.

AR-based content and contribute to the objectives of the "Opening up Education'' initiative, designed to boost innovation and digital skills in schools and universities to facilitate Open Learning Environments (opportunities to innovate for organisations, teachers and learners) and Open Educational Resources (OER: opportunities to use open knowledge for better quality and access). The project aims at supporting individuals in acquiring and developing basic skills and key competences and at promoting the acquisition of students' skills & competencies in different subjects at school and at home with possibility to promote distance education and accessibility to educational resources anytime, anywhere and for anyone and not restricted to one educational system.

The CLB apps for the ARETE project incorporate the following fundamental types of learning to provide quality education and foster sustainable human development:

1. Learning to know (educational resources and training available)
2. Learning to be (resources available support digital skills development)
3. Learning to live together (collaborating together to achieve common goals)
4. Learning to do (using the educational resources to develop necessary digital skills in actual collaborative environment)
5. Learning to transform oneself and society (helping each other during collaboration, challenging each other with quizzes and knowledge checks, checking the impact of digital cooperation on team work in multi-cultural and multi-user environment etc).

Open education and innovative practices in a digital era: The European Commission's 'Opening up Education' action plan is aimed to tackle digital problems, which are hampering schools and universities from delivering high quality education and the digital skills. The plan acknowledges that approximately 90% of jobs will require digital skills by the end of the year, 2020. Between 50% and 80% of students in EU countries never use digital textbooks, exercise software, broadcasts/podcasts, simulations or learning games. Most teachers at primary and secondary level do not consider themselves as 'digitally confident' or able to teach digital skills effectively, and 70% would like more training in using ICTs.

The Digital Education Action Plan (2021-2027) is based on providing more accessible digital education in the EU. The plan is focused on developing digital literacy skills, intensive computer education alongside with understanding of emerging and data-intensive technologies.

CleverBooks suggests that the ARETE apps will innovate teaching and learning through technologies (reference), develop digital skills (reference) and will provide important training (reference).

CLB apps support a STEM educational curriculum by enabling easy-authoring and iterative improvement of class material. Collaborative workflow which leverages cloud technology and supports synergistic interaction modalities between instructors and students inspired by the pull-based development model.

CLB apps provide segmentation of information in bite-size pieces, the division of instructions in auditory or visual channels, or the elimination of extraneous material, animation pathways, segmenting the task information into bite size pieces, and allowing real-time modification of AR content. CLB apps support project-based STEM classrooms, which means that the AR authoring technology needs to cater to a learning-while-doing approach.

CLB ARETE apps support several types of teaching and learning activities:

1. visually-oriented tasks, which can be accomplished by direct interacting with AR objects within the apps in user-app mode;
2. knowledge-oriented tasks, where the students encode information to understand the instruction, which has to be delivered in longer format (e.g., textbox, annotation, description);
3. spatially-oriented tasks, which request motor performance and require expert demonstration (e.g., animation, tutorial, interactive exercise, gamified knowledge test);
4. multi-user content distribution by teacher to students for learning and comprehension of the material delivered;
5. multiuser gamified testing – team based simultaneous collaboration in AR space.

Specifically for the ARETE project, the contents of pre-existing CLB apps have been updated with TIMMS requirements (where visualization of the information was possible and suitable) so the apps can be a useful supplementary tool for diverse curricula in Europe.

CLB has implemented Bloom's taxonomy for interactive learning objects classification that have been used inside the ARETE apps.

ARETE Geometry App

Bloom's Taxonomy Level	ARETE app Application
Remembering	3D geometrical shapes representation, manipulation
Understanding	descriptive overview of geometrical shapes in 2D and 3D format, cross-section, shapes specifications, peculiarities
Applying	Illustration of relationships 3D geometrical shapes to 2D geometrical shapes
Analysing	dynamic visualization of 3D structures of geometrical shapes, gamified knowledge testing environments (single and multi-user options)
Evaluating	Explanation and discussion of geometrical shapes and their structures in AR space
Creating	Construct and design the 3D shapes and the objects in AR space

Table 3. ARETE Geometry App

ARETE Geography App

Bloom's Taxonomy Level	ARETE app Application
Remembering	Description of continents, plants, animals, water animals, planet Earth, weather, heritage, insects
Understanding	Learning informational modes with plants, animals, water animals, planet Earth, weather, heritage, insects
Applying	Interactivity modes with plants, animals, water animals, planet Earth, weather, heritage, insects

Analysing	Gamified knowledge testing environments (single and multi-user options), interactive problem-solving
Evaluating	Explanation and discussion of the apps contents through multi-user simultaneous activities. Interactive planet Earth scenario, analysis of the world of discovery
Creating	Designing activities based on app contents covering the world.

Table 4. ARETE Geography App

Based on the concept of learning context, the ARETE app for Geometry and Geography have number of elements:

- **Learning setting:** the apps are primarily designed for classroom environments and project-based STEM learning. Alternatively, there is a possibility for remote apps use which can be subject of additional communication software that schools are employing in the pandemic distance learning settings.
- **Learning activities:** AR content overview and consumption of pre-designed content and activities, interaction with 3D learning objects, multi-use content exploration curated by educators, single and multi-user gamified testing activities.
- **Pedagogical framework:** collaborative, inquiry-based, integrative and reflective.
- **Learning context features:** interactive, real-world examples, simulations, information provision.
- **Learning delivery:** mix of formal, instructional, gamified, individual and collaborative/team work.
- **Assessment:** informal testing assessment of the obtained knowledge via games and multi-choice questions tests.
- **Learning analytics:** data collection on users' interactions and time spent within the ARETE applications transferred via xAPI to Learning Locker.
- **Stakeholders:** learners/students, teacher type – formal, other stakeholder – school.

The image below represents the visually learning context of Geometry and Geography apps for the ARETE project.

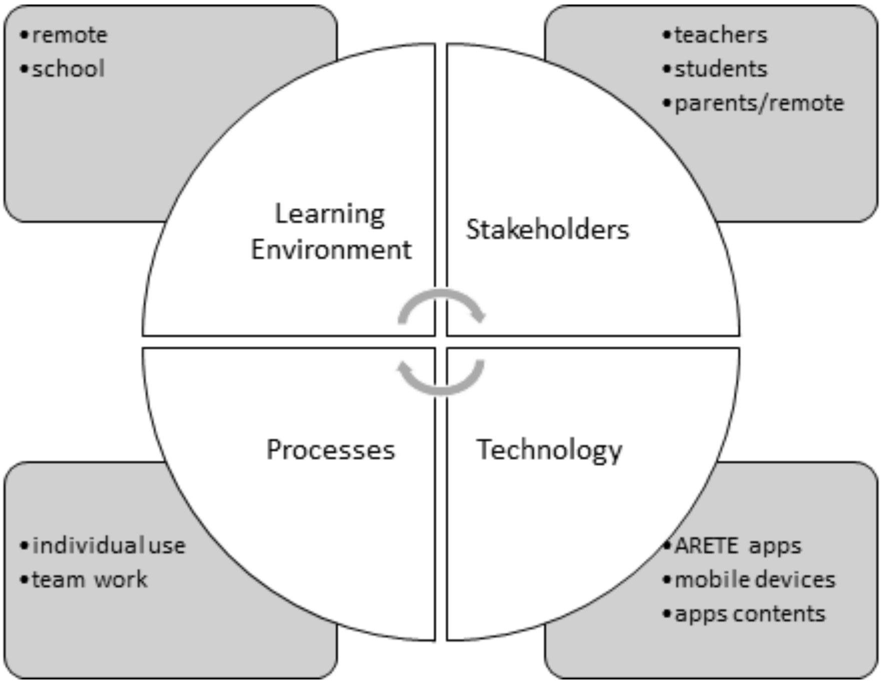

Figure 1. Learning context of the apps (Source: own image).

Additional pedagogical focus of CLB ARETE apps is on **meta-skills development** that highlights collaborative aspects, leading self, leading others and communicating with impact.

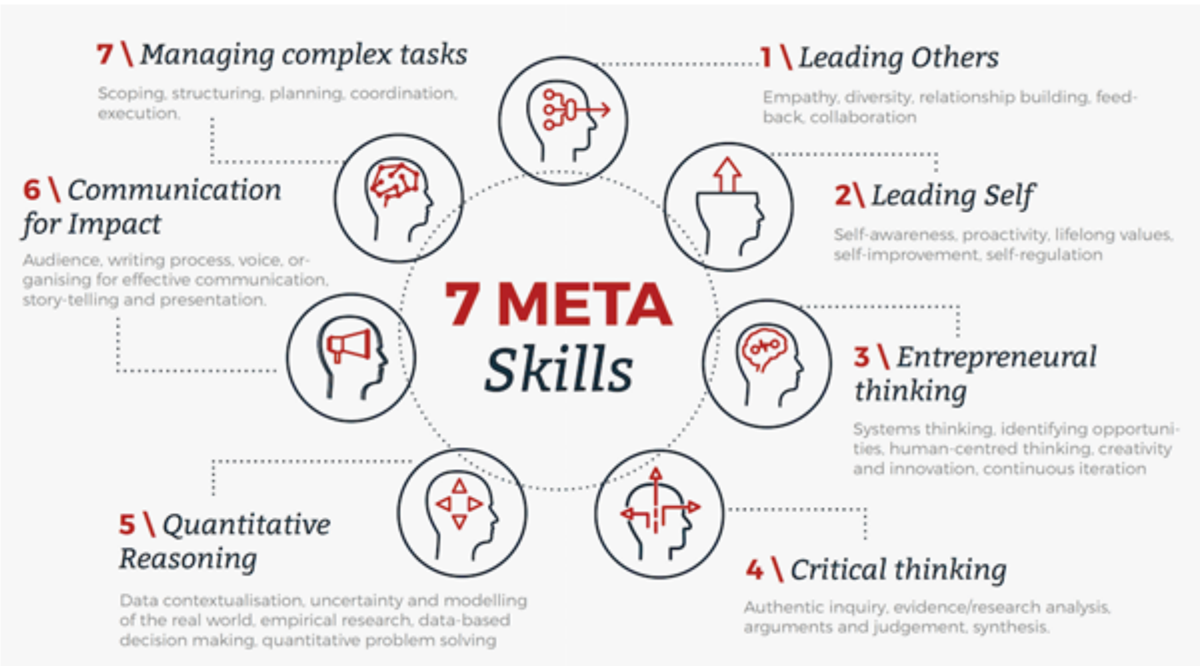

Figure 2. Meta-skills development (source: https://www.alueducation.com/about/our-meta-skills/)

Collaborating or team-based learning practices gain their importance because current teaching methods show the outcomes of lack of collaborative skills developed by students. The implementation of team work is not always focused on fostering effective collaboration, developing impactful communication and social digital skills (Ha Le et al., 2018).

CLB apps for the ARETE project supports the components of efficient team work using the advanced AR technology with pedagogical application in mind:

1. **establishing clear teamwork goals**: teacher, as the main facilitator, controls the content distribution and tasks assigned to the groups of students;

2. **managing group sizes automatically**: the students are automatically split in the groups by the system. This helps teacher to focus on the assignments and gives spare time without distraction of groups management and assignment;

3. **monitoring group sizes**: the sizes of the groups are up to 5 students. This supports efficient teamwork and collaboration;

4. **creating learning as a part of knowledge assessment**: the contents provided within the apps help have exploration and gamified testing that support knowledge test in an informal way;

5. **focusing on the real world**: exploring the information overlaid on the real world and connected to real world scenarios. This helps students to learn on real-world problems and obtain relevant knowledge and skills;

6. **developing critical thinking and problem-solving skills**: the contents of the apps provide clear goal settings, support information collection and analysis with further application of it on gamified testing, developing decision making and team work skills;

7. **using scaffolding technique**: teacher is serving as facilitator, provides direction to teams at the beginning and lets students explore learning topics and environments further on their own;

8. **including different learning scenarios**: the context of the apps provides multiple areas for experimentation within teaching practice and include ready to use lesson activities to start with;

Collaborative technologies need to support ideas exchange and teach learners to share by doing in digital space (Laurillard, 2009). Laurillard (2009) believes that AR with a design to support collaborative environments can efficiently facilitate team work.

4. Technology and Educational Model

4.1 Technical Requirements, Affordability, Resilience

ARETE apps for Geometry and Geography require hardware: mobile phones or tablets. The minimum hardware specification to operate ARETE apps has the following characteristics (see Table 1).

Processor (CPU) Manufacturer	Any
Processor Count	2
Processor (CPU) Speed	1.2 GHz
Minimum Display Resolution	1280×800
RAM Size	1 GB (2-4GB recommended)
FREE Memory Storage Capacity (Hard Disk size)	1 GB
Operating System	Android 4.1.x+, iOS 9+
Accelerometer	Not required
Gyroscope	Not required
Magnetometer	Not required
Other Sensor	Not required
Connectivity Type	Wi-Fi to download app, use multi-user interactivity and send statistics data
Camera	Any (HD recommended)
Front Webcam Resolution	Not required
Video	HD

Table 5. ARETE Apps Mobile Devices Characteristics

ARETE apps have been developed employing technology resilience in mind due to pandemic situation and risk of delivering Pilot 2 in remote setting as well as the hardware advancement: covering the possibility of operating low-end hardware devices to use the ARETE apps. This has been done with education technology resilience in mid to be able to operate between different learning contexts with the same level of effectiveness. The following imperatives for technology resilience plan have been implemented:

- affordability of hardware and software performance compatibility;
- get ready for remote Pilot 2 operations any time;
- critical incidents monitoring (development, configuration, capacity management, change management, hardware failure feedback);
- feedback and support management for end users (EUN will be trained to provide 1rst level of support and CLB takes care of deep technical issues support).

4.2 Technology Type

For the ARETE project CleverBooks is using range of technologies:

xAPI and Learning Locker

Pilot 2 is implementing xAPI to track learning activities. This will bring the user-app interactions into a single pool for research purposes. Further development of apps state of art in combination wih xAPI can support user interactions/selections, steps taken, eye tracking, gaze spots, frequency and duration of activities, and navigational data.

For the ARE project the following data will be collected:

- Apps interaction, content interaction and use
- Time spent within the app
- Time spent on specific activities within the app

Learning Record Store (LRS): Server, where all the xAPI collected data is transmitted provides inbuilt analytics on the captured data. Furthermore, xAPI data can be used to design innovative, engaging and effective learning experiences.

- Create a leaderboard for games and simulations
- Provide insight into the strengths/weaknesses of teams/individuals in Multi/Single-player Games/Simulations, other training formats.
- Assess effectiveness, use, and popularity of learning content, identify underperforming content.

UNITY & AR Foundation: bringing state-of-the-art affordable multi-platform tools and services for the creation of AR Apps.

EasyAR SDK: to support low end hardware at schools and provides quality AR experience:

- EasyAR Sense is a standalone SDK, it provides flexible dataflow-oriented component-based API and do not depend on any non-system libraries or tools like Unity3D.
- Sparse Spatial Map provides the ability to simultaneously generates point cloud maps for real-time location while scanning physical spaces.
- Use of Dense Spatial Map to do real-time reconstruction from the environment, which enables the effects of collision and occlusion, etc., to provide a more realistic AR experience without using a ToF camera.

- Motion Tracking provides multi-sensor fusion to solve position and attitude, reducing the drift caused by camera motion, making virtual objects more stable in space.

CLB is working on a built-in feature of device type recognition (low end hardware spec or released in 2016 or later) to provide the markerless experiences option on devices that can support it. This feature is in progress.

Orkestra Communication Manager from VIC will support multi-user interactivity within CLB apps for ARETE. Multi-user engagement for gamified testing is the advancement of the AR state of art for education sector for simultaneous content management, testing, gamification with the interactivity and collaboration in teams at the same time in AR space.

Photon engine: is a game engine specializing in multiplayer game development. The Photon Realtime SDK is used to provide simultaneous multi-user functionality in the ARETE apps. Photon Realtime is the base layer for multiplayer games/interactions and higher-level network solutions. It supports users' matchmaking and fast communication with a scalable approach.

Technology type	**Technology Features**	**Technology Readiness Level (TRL)**
xAPI and Learning Locker	Research data collection and transfer	TLR 9
Learning Record Store (LRS)	Research data repository	TLR 9
UNITY	Engine for creating AR contents	TLR 9
EasyAR SDK	SDK for tracking images and producing 3D objects in real time	TLR 9
Orkestra Communication Manager from VIC	Real time SDK for multi-player activity	TLR 2
Photon RealtimeSDK	Real time SDK for multi-player activity	TLR 9

Table 6. Technology Data TLR on Pilot 2 ARETE apps

5. Technology and Educational Matrix

Given the affordances, functionality, data, and their benefits/challenges, the matrix listed in Table 7 below can be populated accordingly to ensure that it accurately represents the current landscape.

Tech	Feature	Learning Setting	Learning Activity	Pedagogical Framework	Stakeholder	Benefits	Challenges
AR app	Interactive media	Primary education, in-class	Learning contents, multi-user collaboration within AR content	Collaborative, instructional, inquiry-based, integrative	Teachers, students	Pedagogical, STEM learning, access to AR multimedia contents	Hardware, connectivity for simultaneous collaboration
Learning Record Store (LRS: Learning Locker)	Data management	Education process	n/a	n/a	Researchers	Data repository collecting behaviour traces from connected systems; Analytics	Connectivity, connection security, storage security
xAPI	Data collection	Education process	n/a	n/a	Researchers	Receiving and sending data from apps to LRS	Connectivity, connection security
Photon Engine	Realtime SDK for multi-user activity	Education process	n/a	n/a	Teachers, students	Pedagogical, simultaneous multi-user work within AR environment	Hardware, connectivity for simultaneous collaboration

Table 7. Matrix of the technologies and their application in education.

6. App architecture & multi-user support

Figure 3 below depicts the high-level system architecture of the CLB ARETE app and remote servers. Figure 4 adds a more detailed perspective on the components.

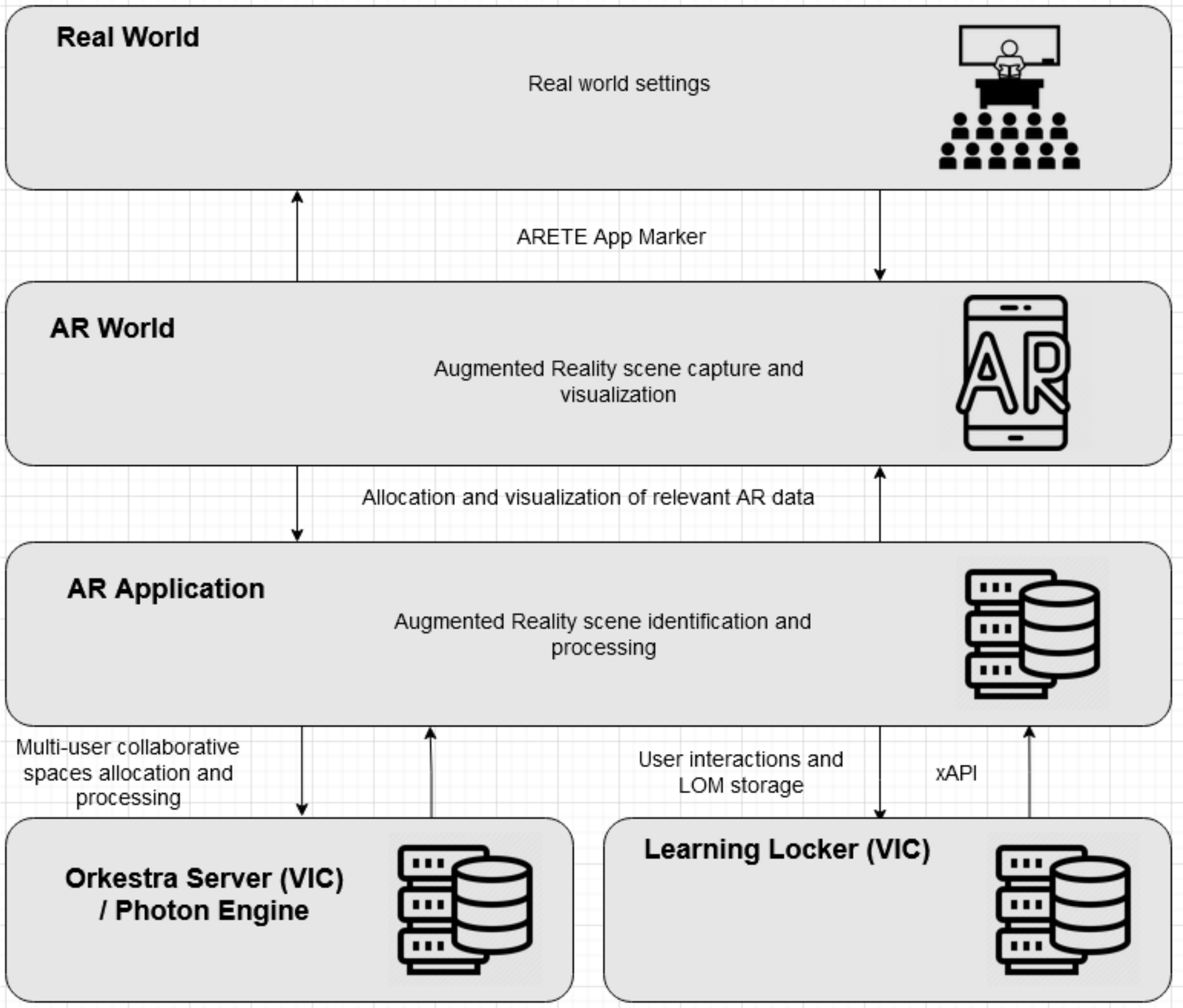

Figure 3. ARETE CLB apps architecture.

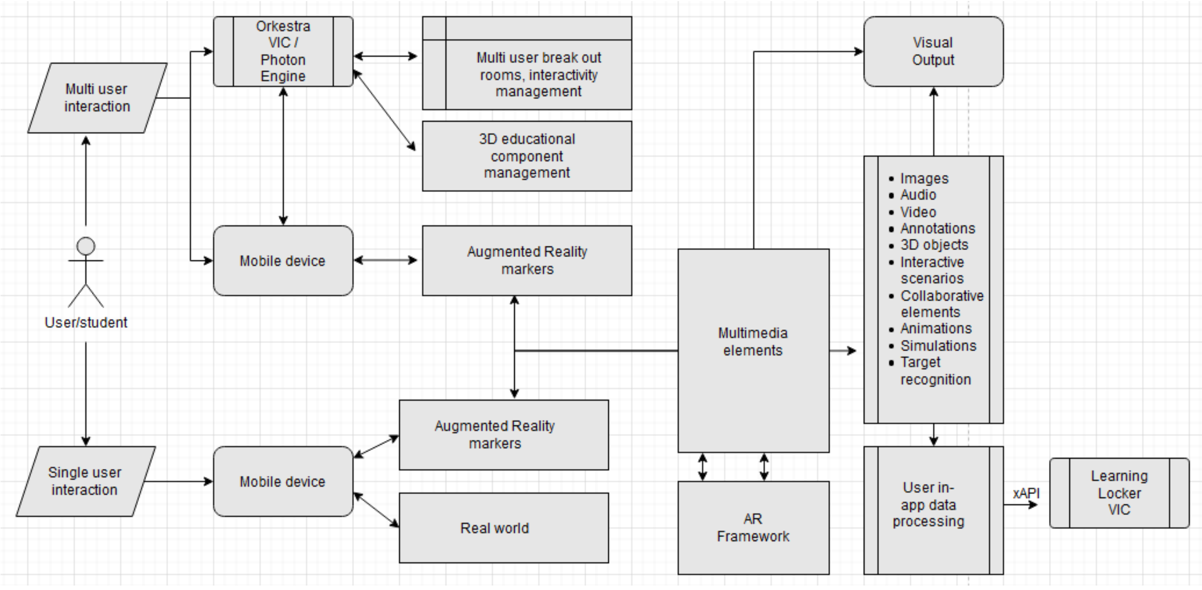

Figure 4. Components of the ARETE CLB apps.

7. Experimental Research

In order to push the envelope regarding innovation in interactive media (and AR in particular), we are conducting additional R&D work, which is described here. This involves work towards a novel, classroom/school focused communication manager (Orkestra, Section 7.1: developed by VIC), work on holographic intelligent agents (Hanna, Section 7.2: work by TOU), and work on more generic quiz mode services in AR that can be flexibly reconfigured as part of the authoring toolkit in MirageXR (Pick & place, Section 7.3: work by UCD and TOU). This work in progress is documented below, further results will be reported for D3.8, MirageXR.

7.1 Orkestra

Orkestra is an open source library developed by Vicomtech that allows multi-user communication and interaction. Its main function is to make the development of multi-device or multi-user applications easier. To do this, it abstracts the communication complexities that arise when trying to develop cross-device applications, helping the developer to focus on the application development. Therefore, Orkestra is seen as one of the modules of the communication manager in the common architecture of ARETE. The library is currently optimised to work with web technologies but in the context of ARETE some of its main functionalities have been ported to C# in order to simplify the integration with the apps created for the ARETE pilots, currently developed using Unity.

Orkestra is made up of different mechanisms that facilitate modular development such as under coupling, plugin based system, modular injection and basic support for complex functions like component management, distribution and layout functions. User interface support is optional and currently available only for the web version of Orkestra. This service is offered as one more layer to facilitate development, but its greatest virtue is abstracting the complexity of synchronized multi-device application communications. Orkestra is compatible with many web frameworks such as Angular, React, es6 (as well as vanilla Javascript), and can be used in multi frameworks environments, too.

Orkestra web client

We will now briefly present the main functionalities of the web version of the Orkestra library, as it is the one providing the most functionalities. We will then briefly present the porting to Unity and how to use the library in AR applications.

API

The API to use Orkestra in an existing application is straightforward:

```
var app = new Orkestra(options);
```

Where options are the following:

- url: server url (optional, default use hosting url). For ARETE, a dedicated server has been deployed managing the connections incoming from different apps
- channel: channel (room) to connect to (if empty the app will not connect to application context). Each application using Orkestra connects to a different room, and a room hierarchy can be defined to manage different groups using the same application. For example, in the context of Pilot 2 it makes sense to keep students of different classes in separate rooms within the application
- agentid: set user agentid (optional)
- profile: define profile (optional)
- master: true/false (is master or not, master receive all notifications)
- Debug: true/false (shows a shared data panel)

It is then possible to subscribe to observe changes from the connected devices or from the application context:

```
app.userObservable.subscribe(change=>{

    user_table.users = app.getUsers(); });

app.appObservable.subscribe(x => {

  console.log("application attribute change",x);

  app_table.data = app.getAppData(); });
```

Where changes could refer to an agent joining or leaving the applications, a change in its permissions or in its properties. The application context data are stored as dictionary entries. App developers can also define easily which user and device data to share. Here is an example of how to share textual data across devices, for example:

```
app.data('textShare',TextData,[document.querySelector('input')]);
export function TextData(element){

    let text = {
     init:function(){
        this.setCapability("textShare", "supported");

     },
     on:function(){
        element.addEventListener('change',(txt)=>{
             this.setItem('textShare', element.value);
        })
        //this.setCapability("deviceProfile", "supported");
     },
     off:function(){
       element.removeEventListener('change',(txt)=>{
            this.setItem('textShare', element.value);
       })
     }
   }
```

```
  return {"textShare":text};
}
```

In a similar fashion, the app developer can change, retrieve and define both user and application data.

Agent Context

The agent context provides information about a specific agent, its capabilities and events. It is used to store and send data related to a specific agent.

Application Context

The application context represents an execution of a multi-device application, where all the participating agents contribute. It can be shared between multiple devices of a single user or multiple users, whatever is suitable for the application. It is used to share data between all the agents connected to the application.

Shared State

The Shared State maintains distributed agreement concerning dynamic, online application resources in multi-device applications. Application resources may for instance include application data, context, data, or timing resources. Agreement about the current state is maintained continuously, even if the resources are dynamically changing.

Shared State is based on two parts

1. an online service
2. a local proxy for that service. The proxy provides a local representation of the current state of the remote service, and programmers may always depend on this representation being updated as soon as possible.

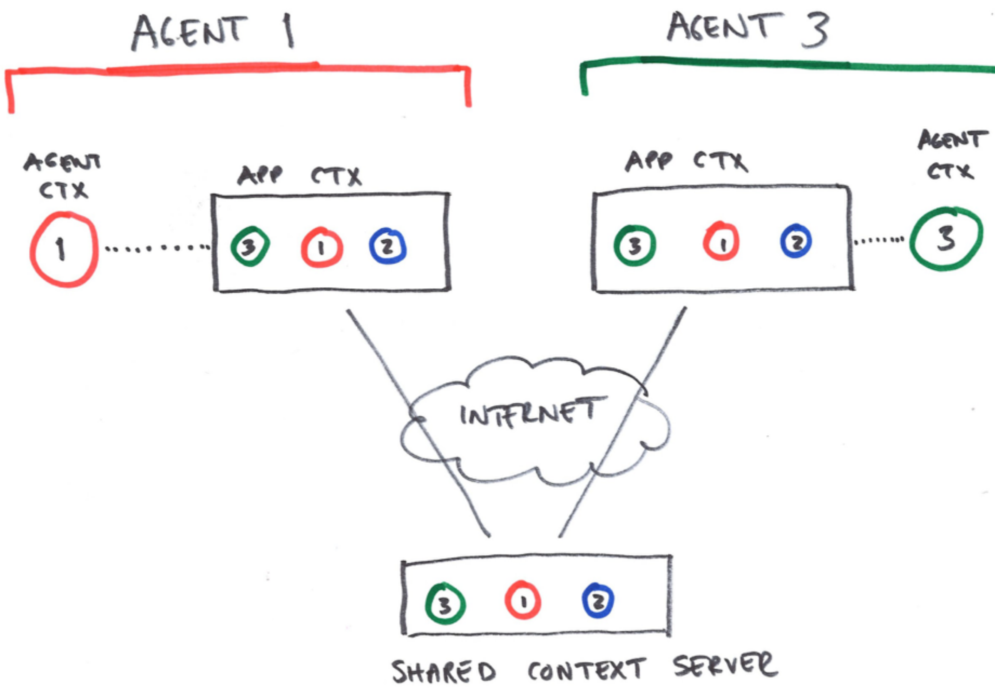

Figure 5. Share state.

Mapping service

The mapping service provides URLs for Shared State channels, and creates them if they are not already created. Applications can request different scopes for such channels in order to simplify both implementation of the services and ensure a flexible and scalable solution.

Motion service

The library also offers the possibility of synchronizing events on a centralized time server. Synchronized objects can be multimedia or not. Multimedia objects do not support synchronization adjustment but the maximum lag between devices is less than 60ms. If the object to be synchronized is of media type, a synchronization of about 15ms can be achieved.

WebRTC services

OrkestraLib offers real time multimedia consumption through a WebRTC protocol. It implements a JanusGateway solution that allows to manage WebRTC connections effectively and transparently for users. Therefore, orkestraLib allows to publish and consume this type of service through its own Web Components.

User Interface

Orkestra provides an extra layer that enables to make decisions on:

- Assignation: how to distribute content over different devices / users

- Presentation: how to render the content on each of the devices

To do this, it provides a plugin system based on the form of expressjs, which consists of injecting modules and using them when reacting to different types of events.

The assignation step will enable to inject modules that define different rules to decide which component is shown on which device and the presentation will allow to inject modules that define different layout templates to present the components on each screen. Since there could be more than one module for each of the steps, by default the priority is established in the order they have been registered. Finally, for the library to be able to read the components, it is necessary to encapsulate the components within a component called *<orkestra-ui>*:

```
<orkestra-ui>
 <user-table [user]='user'></user-table>
<user-table [datos]='data'></user-table>
</orkestra-ui>
```

Orkestra server

The server of Orkestra enables communication and coherent sessions between all the connected devices. As the server code is transparent to the type of application, it can be used with applications developed in any language, provided that they use the same API specification. The following are the main modules of the server side of Orkestra.

Core

Central part of the server that integrates and communicates the Sockets Server, the database and the express server. It is implemented in Node.js.

Sockets server

It provides communication with the clients through Web Sockets. It is the main part of the multi-device logic that ensures coherence between connected devices and sessions. More in detail, this module has different functionalities:

- **MappingService:** It is a way to connect to a new session or recover an existing one. It is allowed to enable a security layer for private sessions. (not implemented for orkestraLib)
- **Sockets Events**: A socket is enabled to receive different events coming from the client side:
    - **join**: This event is received whenever a new user is joined.
    - **disconnect**: This event is received whenever a user is disconnected.

    - **changePresence**: This event is received whenever a user changes its own status from online to offline or vice versa.
    - **changeState**: This event is received whenever a user changes the status of any shared variable.
    - **initState**: This event is received whenever a user asks for the initial status of a variable.
    - **getState**: This event is received whenever a user asks for a variable value.
- **Persistence Data**: All the data shared between websockets are collected at a mongodb database. Any event received from connected users is saved in the database. When the data is saved, an event is triggered to be shared to other users. This approach guarantees to recover any session information although the connections are over.

MongoDB

This module provides persistence through a MongoDB database. It is used by the Rest API as a persistence database and also to manage websocket's asynchronous events with persistence.
Express Server

This module enables several web services such as:

- **Static web server**: Allows to host static files.
- **Rest API**: Enables functionality as end-point based on RestAPI.
- **Dynamic web server**: Allows users to use templates to create dynamic web pages.

Motion Server

It provides online timing resources to synchronize different contents. A timing object is instantiated on each of the devices, and each instance is connected to a single, shared online timing resource. If the timing object pauses, all the connected local components are notified and react accordingly. Furthermore, when timing objects are connected to an online timing resource, they merely act as local representatives. For example, when requested to pause, the timing object will simply forward the request to the online timing resource. As the online object pauses, notifications will be multicast to all connected clients.

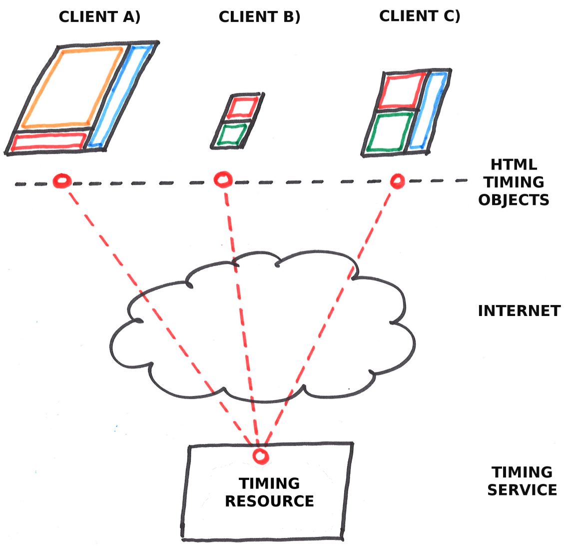

Figure 6. Synchronisation.

Janus Server

Although it is not part of Orkestra it is widely used for publishing and consuming real-time media flows through WebRTC. OrkestraLib, Orkestra's client side, offers several utilities to publish, consume and configure WebRTC through Janus GateWay transparent manner, so on many deployments of Orkestra this server is included.

Orkestra Unity

In order to include Orkestra in the application developed for Pilot 2, a port of the implementation of the client code to Unity was necessary. The Unity port does not include all the functionalities of the Orkestra web client, and it focuses mostly on allowing an application to share global and user data across devices. The Unity version of Orkestra defines an API following the same structure and the original API, and relies on the libraries WebSocketIOClient-Csharp[2] and Newtonsoft[3] for functionalities not provided natively.

The following diagram shows the high-level architecture of the Orkestra functionalities used in Unity applications:

[2] https://github.com/doghappy/socket.io-client-csharp

[3] https://www.newtonsoft.com/json

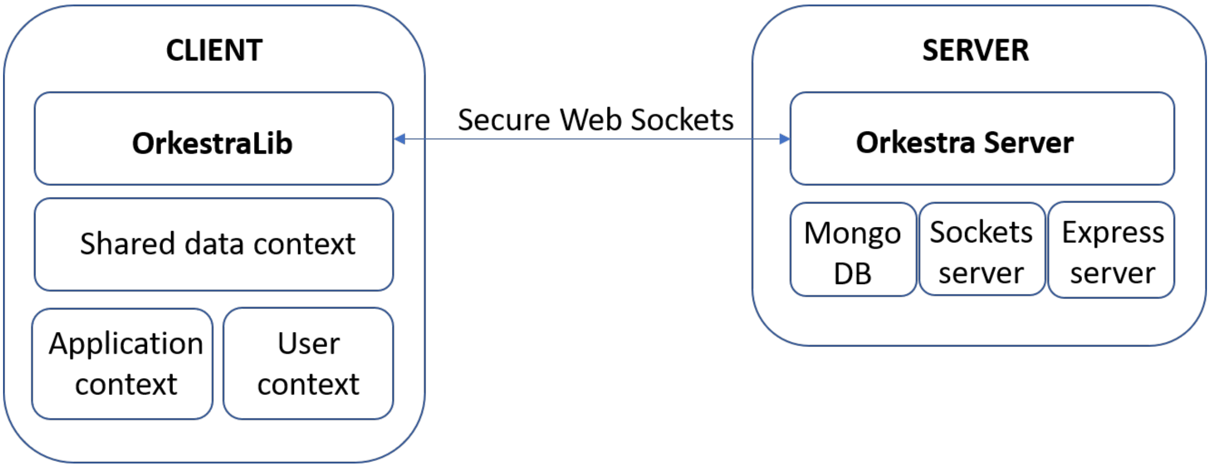

Figure 7. High-level architecture.

The first version of the Unity port has been implemented as a rough "translation" of the web version functionalities, and it was tested for correctness by implementing two demos (available in the code repository[4]) as well as by integrating the code into MirageXR codebase.

Unfortunately, the current version of the library is not production read, since the C# implementation is not optimized for Unity and there are portability as well as latency issues. For this reason the development team is now busy performing a code refactoring and including a suite of unit and integration tests to guarantee that the release 2.0 of the library solves the current issues and can be used in production. The aim is to release the library as a Unity Package that can be seamlessly integrated in existing apps and allow them to provide multi user functionalities.

The Orkestra server is currently centralized and hosted on AWS, but the possibility of releasing its code as open source is being considered. Therefore, once the Unity client refactoring is complete, every interested shareholder might be able to deploy its own server and have full control of the data exchanged.

In order to check the amount of concurrent users that can be managed by the server, we performed a stress test, exchanging the maximum amount of traffic expected to be sent by each student while using CLB app for pilot 2 (about 4Kb per second per user). The server was tested with up to 800 concurrent users and no noticeable decrease in performance was detected. The server was then tested specifically for how it is able to handle sharing multimedia content through a Janus server. In this case we generated streams from 6 cameras (with resolution ranging from SD to 4K) and streamed the content together with 4 additional pre-recorded videos. In this case, while some clients experienced delays while playing multiple streams at the same time (probably due to an excessive strain on the mobile device

[4] https://github.com/tv-vicomtech/orkestralib-unity/tree/develop

CPU), the server was able to manage the workload and distribute the content to all the 10 clients connected, adapting the bitrate according to the number of videos sento to each device and the layout chosen.

7.2 Hanna & Character Models

Traditional methods deployed in the curricula for primary school students sometimes struggle to effectively stimulate students' interest and curiosity. With immersive technologies, novel opportunities arise that, if validated, can positively impact on engagement - at scale. There are novel interaction techniques possible that may be beneficial particularly for knowledge that involves spatial reasoning and imagination. Moreover, it is also hard for teachers to concern each student's learning levels and progress. Communication and interactive ways are key for establishing a cooperative and positive relationship between teachers and young kids. Virtual tutors simulate real teachers who are able to communicate with students, provide technological competence, informative feedback, monitoring learning, and student support (Roddy, 2017).

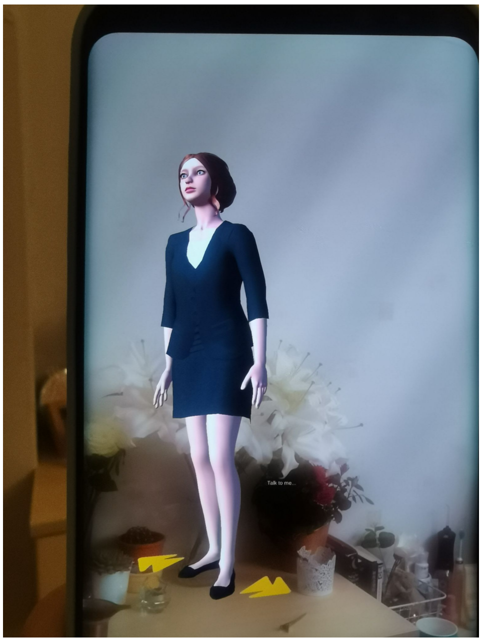

Figure 8. Hanna

Therefore, we created a photorealistic 3D character as an Augmented Reality hologram to interact with students on HoloLens and phones. Hanna is an intelligent virtual teacher (see Figure 8), who is able to teach and help primary students obtain indispensable academic knowledge, interact with students, and virtual and physical objects.

This intelligent virtual tutor is capable to respond to students, predict their needs, record their behaviours, implement different learning scenarios, as well as generate real-time feedback for real teachers in order to accurately grasp students' learning situations.

The main work for her is to teach Year 4 (9-10 years old) geometry, help students, identify, classify, and create different shapes of 2D/3D.

The teaching contents have four aims:

- **Identification** --- It will firstly teach 3D shapes, including cube, cuboid, pyramid, cylinder, cone, and sphere. And then identify 2D shapes based on 3D. It includes counting faces, edges, and vertices.
- **Relationship** ---- The relationship between 2D and 3D. (unfold 3D shapes). For instance, what 2D shapes can make a pyramid? If we drag out this triangle, what does a 3D shape be?
- **Comparison and Analysis** --- It will compare 3D shapes and 2D shapes. For example, how to use 2 triangles to make a square or a rectangle. I have a cheese block, could you help me cut it into four triangular prisms.
- **Mensuration** --- It will teach students to measure the length and volume. For example, how many dogs can sit on this long chair? And which 3D shape can fit the max number of dolls.

In this project, we create 6 visemes and 12 emotions, containing AI, O,K, E, L,TH, happy, angry, eye blinking, smile, ect. Hanna thus can perform appropriate body languages, facial expressions. A basic dialogue script is necessary to develop natural language processing and implement free talking in a topic or teaching content (see Figure 9). We use IBM Watson services for dialogue understanding (see Figure 10), which is able to activate corresponding responses by identifying the user input. For example, Hanna will introduce herself when students say 'hi, Hanna' or 'Hanna' for the first time.

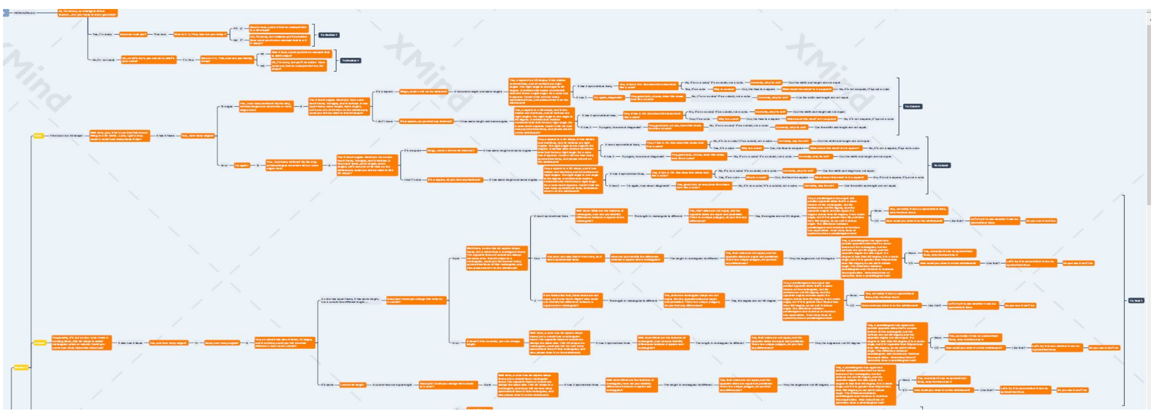

Figure 9. The dialogue script.

Kids can change virtual 2D or 3D to different shapes by gestures, such as dragging, picking, rotation, and air-tap, and Hanna will gradually guide them how to analyse and evaluate these objects they create. Next, we will investigate children's user experience towards intelligent virtual teachers.

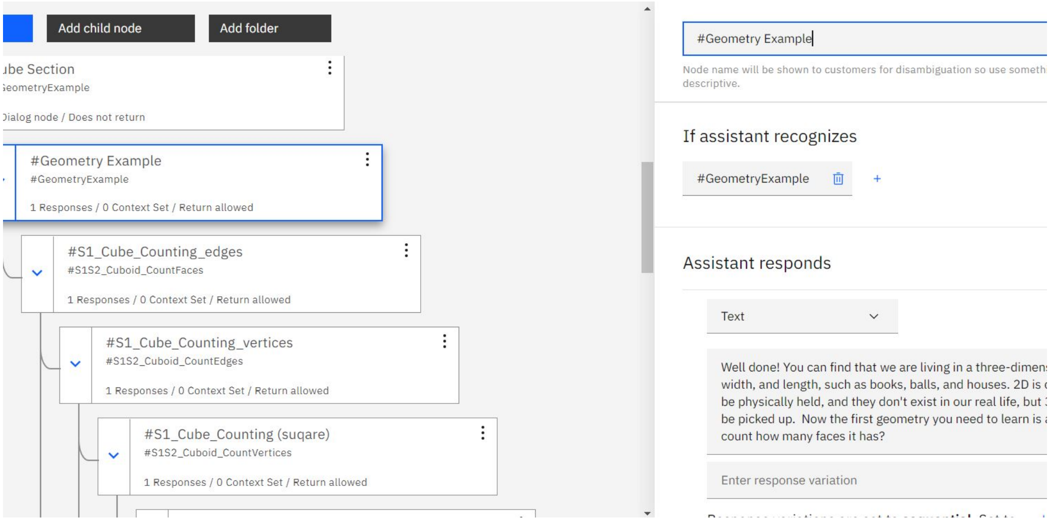

Figure 10. IBM Watson dialogue model.

7.3 Pick & Place augmentation for MirageXR

Pick & place is a new augmentation type for MirageXR which allows creating interactive goal- orientated content. The augmentation was designed with the requirements of Pilot 2 in mind to further improve upon the authoring tools for educational content within Mirage·XR.

Edit Mode

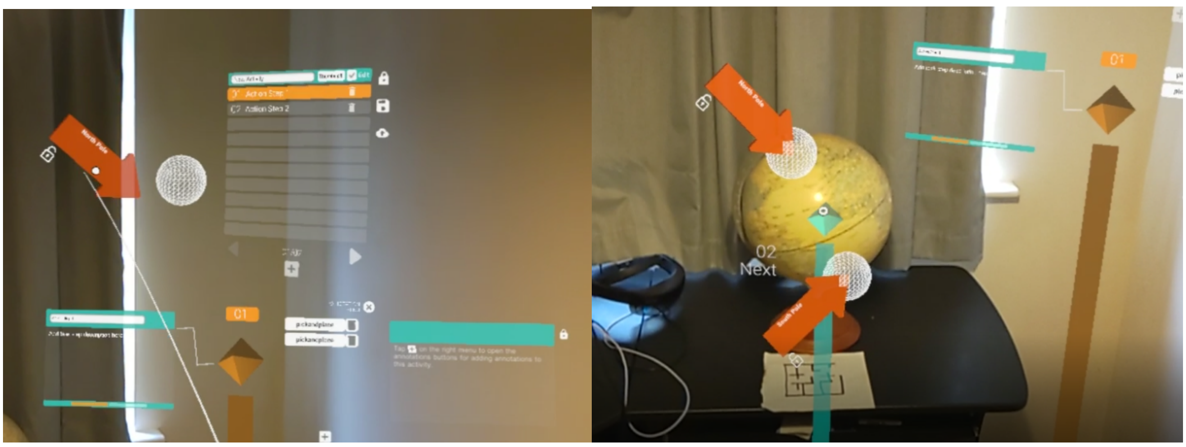

Figure 11. Pick & place editor.

When a user creates a pick and place augmentation two objects will appear; an arrow and a sphere. The arrow is given a label before creation that describes where the target location will be set. The target location is determined by the location of the sphere object, which can be moved and placed in/on a real world location/object or a virtual object. To illustrate this the images above show the creation of two pick and place objects labeled "North Pole" and "South Pole" with the target spheres being placed in the location of the north and south poles on a globe. Once the targets have been set the user can place the arrow objects at any location in the activity and use the lock button attached to the arrows. This causes them to bounce back to their original location if they are not placed at the correct target location.

Play Mode

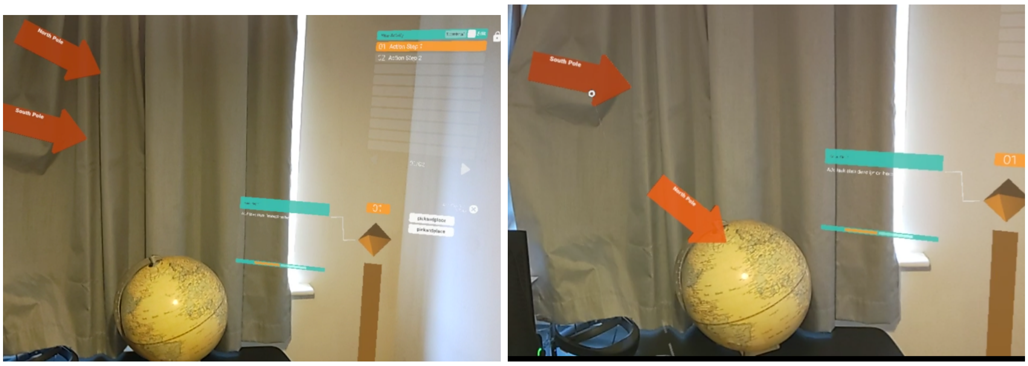

Figure 12. Pick & place playmode.

The functionality of the pick and place objects is much the same in play mode as it is in edit mode, however, the possible interactions are limited. In play mode, the target spheres disappear so that the user cannot move them or know where they are. The Lock buttons attached to the arrows are removed so that the model will always bounce back.

Data Model

The pick and place object is defined in ARLEM as a single object for which the predicate, position, action step and label text are all saved. However, the children of this object required additional saved data to behave and be positioned as intended between action steps and activities. The data required for these objects is stored in the form of a JSON file defined in the following table.

Pick Object Position	A Vector3 used to store the local position of the pick object which in the current state of this feature is the arrow object
Pick Object Rotation	A Quaternion used to store the local rotation of the pick object which in the current state of this feature is the arrow object
Target Object Position	A Vector3 used to store the local position of the target sphere
Reset Position	A Vector3 used to store the local position of the target sphere
Lock	A Boolean which is used to determine whether or not the the lock toggle is on or off for a given pick objects

Future work

Pick & Place is a simple yet effective way to allow users to author goal-oriented interactions within their activities. In its current state this feature opens up possibilities for authoring of interactive educational tasks within Mirage·XR. Future plans of allowing a user to change the Pick object to a 3D model of their choice will further improve the feature to be more adaptable to a variety of tasks.

8. Discussion

To conclude this report, Geometry and Geography AR apps for the ARETE project have the following advancement in state of art areas:

- **Technological**: ARETE apps introduce new in-app educational multi-user simultaneous experience for content review and collaboration using AR objects. The AR technology has been designed with the hardware in mind and equal education accessibility act.

- **Pedagogical**: ARETE apps provide two-dimensional methods of delivering educational information in collaborative settings, offer more contextual experiences with specially designed learning objects applying Bloom's taxonomy, support interest in STEM learning through engaging and interactive AR experiences, understanding details, functions and features of 3D objects and promote peer-to-peer learning channels through multi-user experiences. Special focus of CLB apps design is on collaborative work with the focus on meta-skills development on team work, collaboration, efficient communication.

- **Experimental research work** adds up to the state of art of the ARETE apps by including holographic AI with IBM Watson component to provide user to technology inquiry-based interactivity, Orkestra developed by VIC that can substitute Photon engine for multi-user activities and MIRAGE XR Pick&Place that adds extra functionality.

The ARETE applications have been architectured to support pedagogy in opening new possibilities for teaching and learning with AR technology.

9. Outlook

This deliverable covers the state of art of CLB ARETE apps for Geometry and Geography preceded by a decade time frame SLR. The main focus of the SLR conducted by CLB was on Geometry and Geography mobile apps for primary education covering technological and pedagogical advancement.Apart from SLR, CLB conducts regular commercial research in the area of AR apps for primary education.

For further top state of art positions of the ARETE apps it is important to continue experimental research work and integration of its outcomes in the ARETE ecosystem. Based on the nature of the school subject areas, there can be more multi-user functionality integrated. Although the multi-user aspect is quite popular in the consumer-facing gaming industry, it has not been implemented for educational purposes prior to the ARETE project. The known software component for game-engine can advance the results of pedagogy for AR applications.

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