A Novel Architecture for Collaborative Augmented Reality Experiences for Education

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Euskal Herriko Unibertsitatea

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1. INTRODUCTION

Scope of the research

MOTIVATION

AR can improve the retention and engagement of students

MOTIVATION

But it has not yet seen widespread adoption in education

MOTIVATION

MOTIVATION

PROS

- Wide hardware support
- Software libraries
- AR standards available
- Different AR types

MOTIVATION

PROS	CONS
Wide hardware support	Single user experiences
Software libraries	Hard to develop content
AR standards available	Device specific solutions
Different AR types	Limited free content

MOTIVATION

01 **Enable interactive and collaborative mechanisms** for AR solutions

02 Allow **interoperability** across different platforms

03 Discover **limitations of current AR applications** for education

04 **Identify the requirements** to simplify adoption of AR in the classroom

05 **Develop and evaluate** working solutions

7

ARETE supports the interactive technologies efforts, through the multi-user interactions within AR technologies evaluated in education

OBJECTIVES

- The main objective of this work is to explore and propose innovative solutions which use AR in the educational sector, with a strong focus on collaborative, multi-user interactions

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- Define a software architecture that simplifies the creation and adoption of collaborative AR solutions for education

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Main objective

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Identify the causes behind the lack of adoption of AR solutions in schools.

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Develop a software library enabling the creation of multi-user AR applications.

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Objective 3

Define a modular architecture that fulfils the requirements and design objectives for AR in education.

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Objective 1

Identify the causes behind the lack of adoption of AR solutions in schools.

Objective 2

Develop a software library enabling the creation of multi-user AR applications.

Objective 3

Define a modular architecture that fulfils the requirements and design objectives for AR in education.

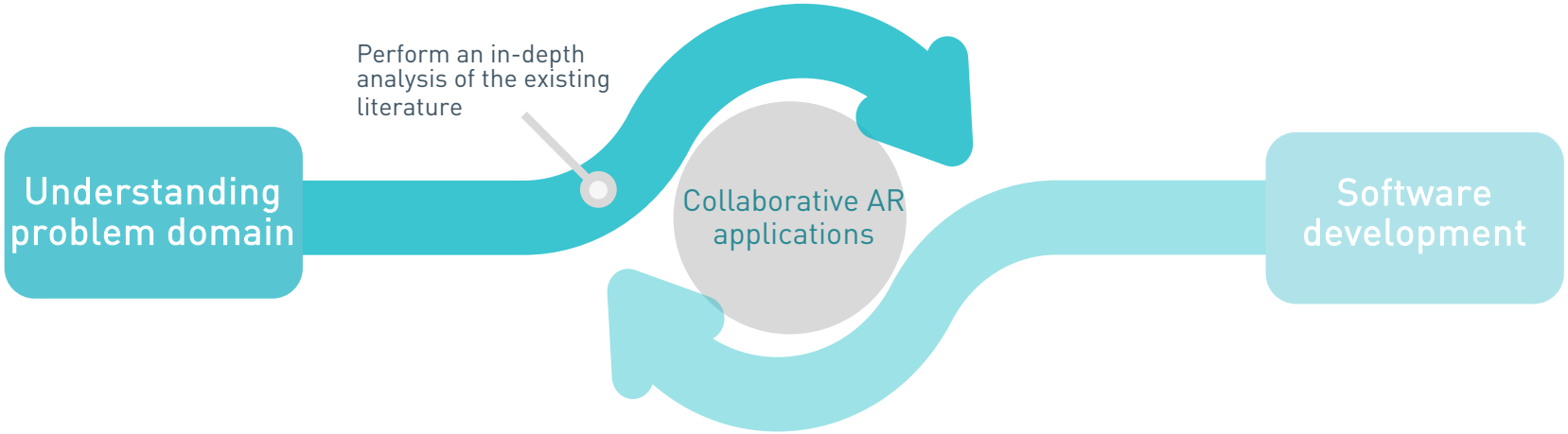
Objective 4

Validate the architecture by creating and testing a collaborative multi-platform AR application.

Main objective

METHODOLOGY

METHODOLOGY



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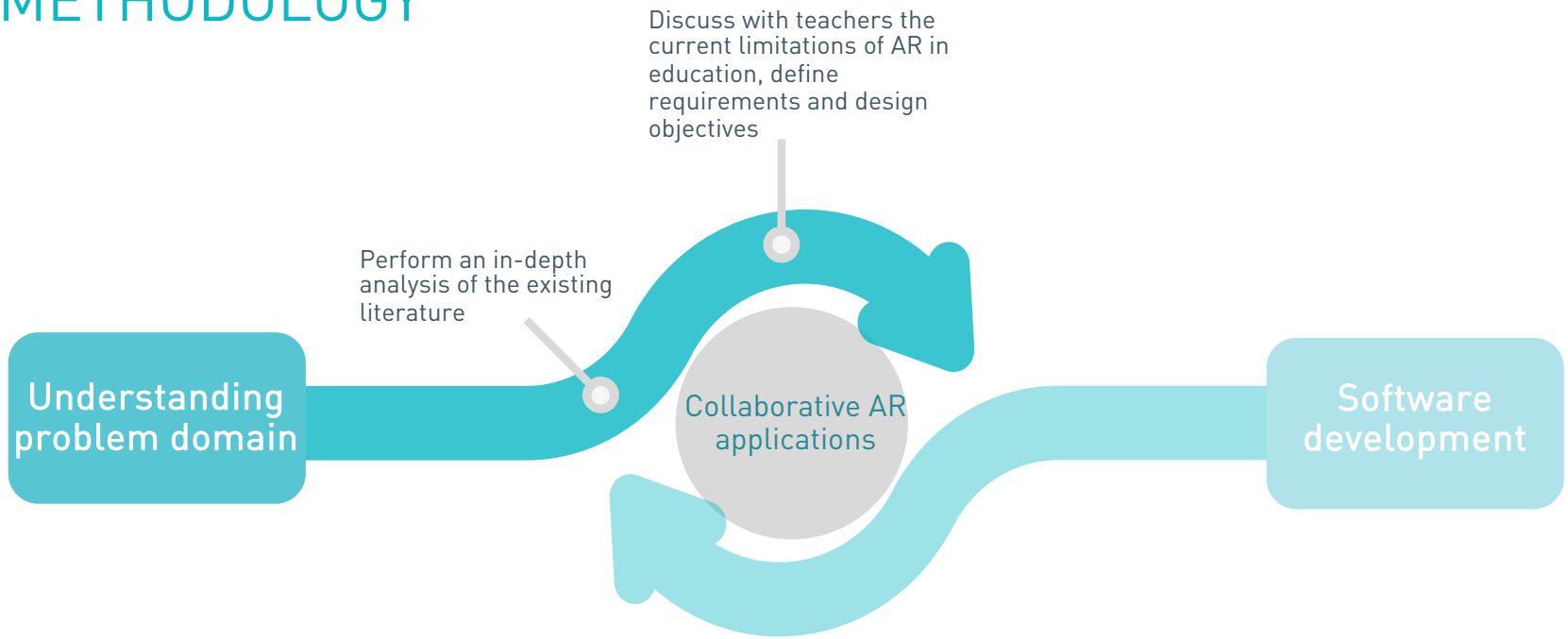

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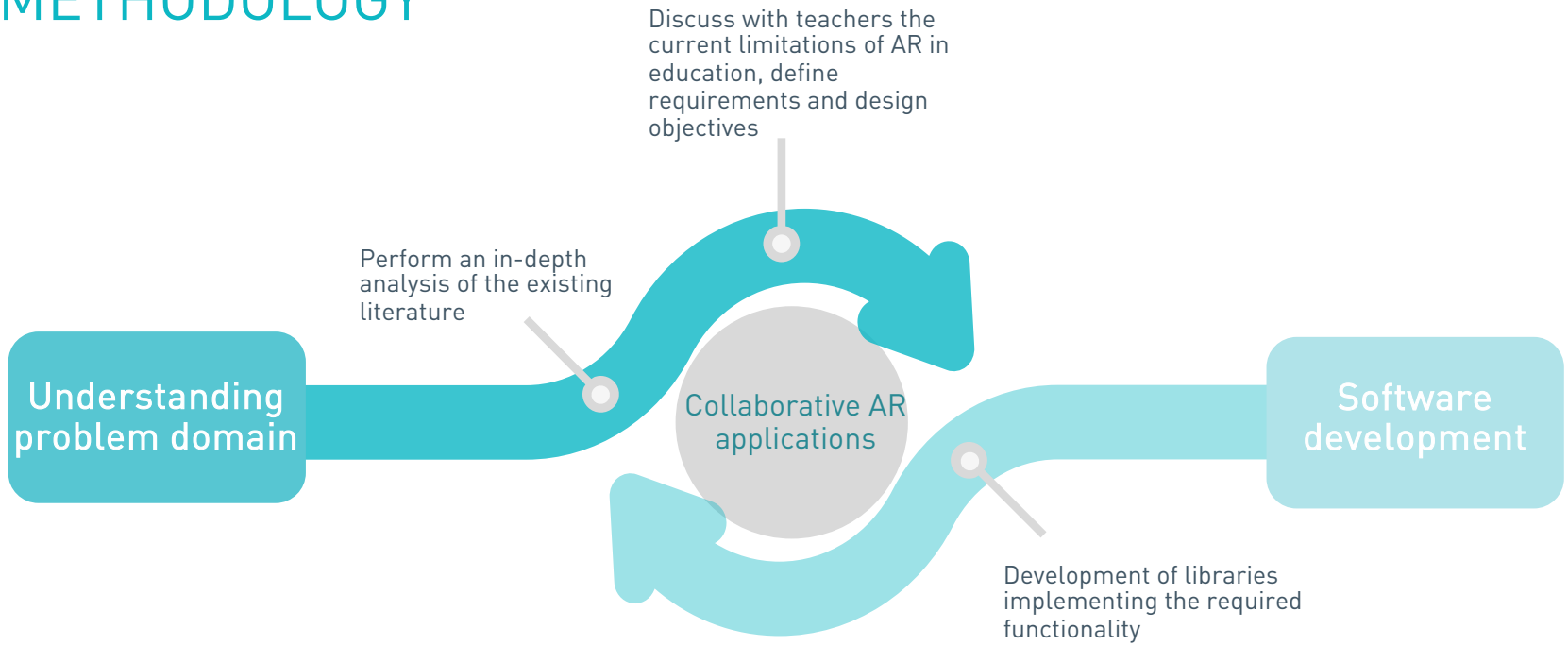

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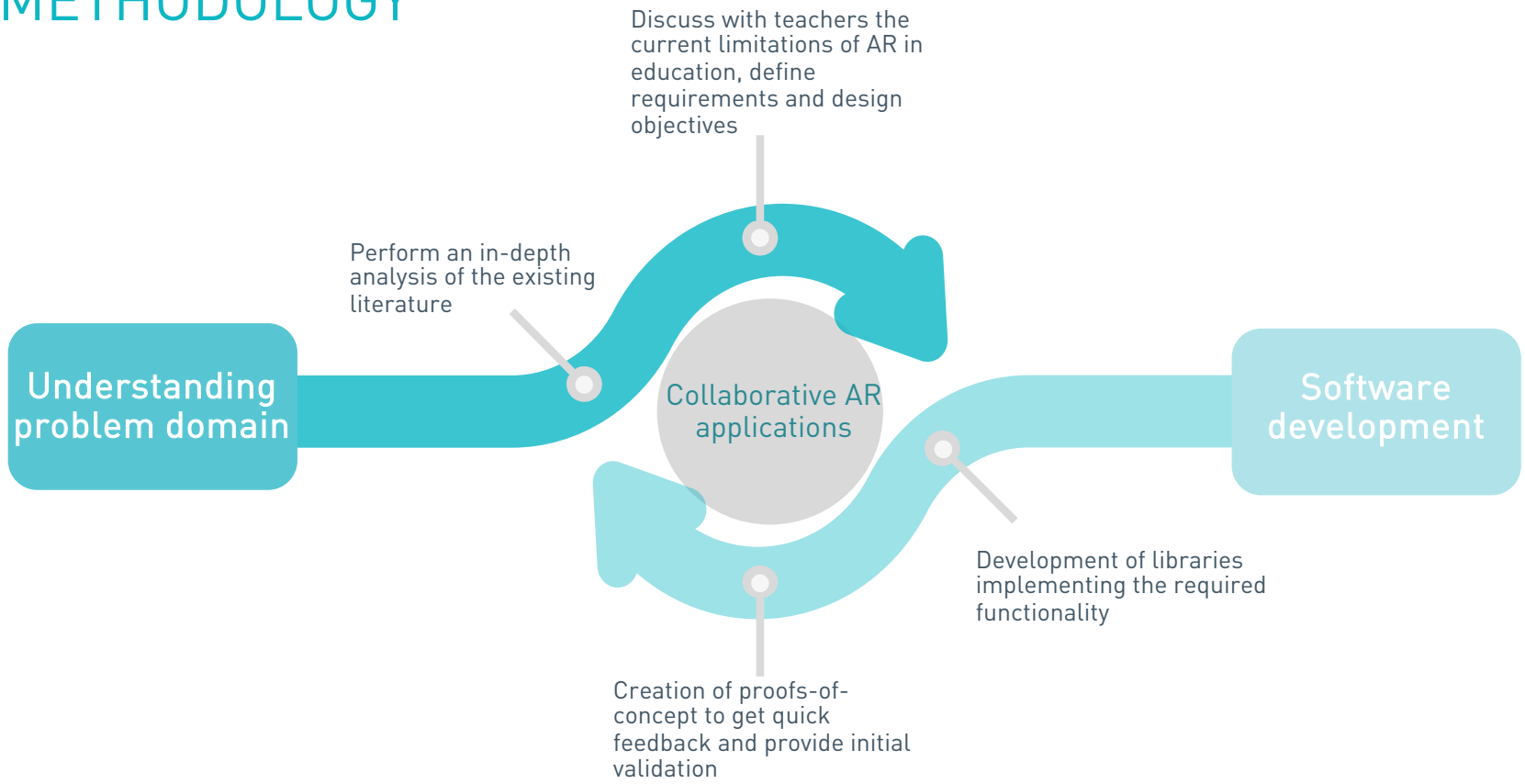
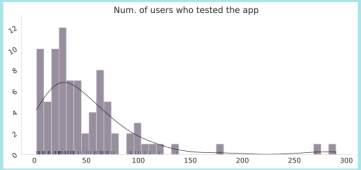


12 CONTRIBUTIONS

CONTRIBUTIONS

C1

In-depth analysis of the state-of-the-art



- State of research on AR applied to education
- Motivation for using AR
- Effects of AR on motivation and retention

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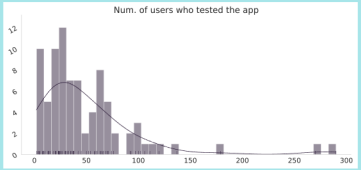

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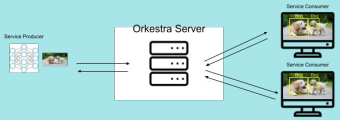
Orkestra: library for multi-user interactions



- Low-latency
- Media synchronization
- Multiplatform

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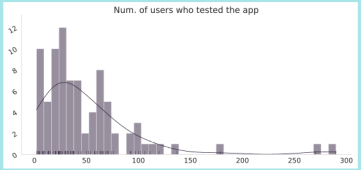

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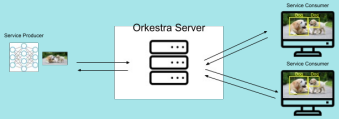

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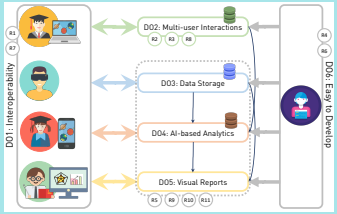
cleAR: modular architecture for AR solutions



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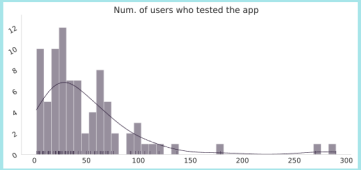

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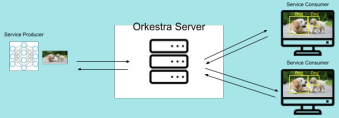

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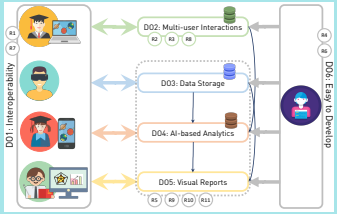

- Satisfies teacher requirements
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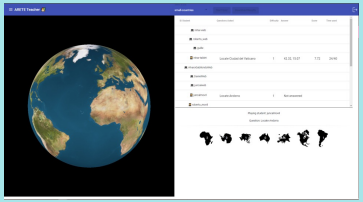
C4

ARoundTheWorld: implementation of an AR app based on cleAR



- Tested in 3 educational institutions
- Validates cleAR design objectives

2. STATE OF THE ART

Related Work

Literature Review

C1

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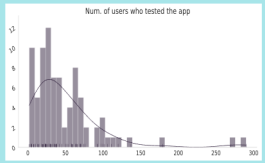

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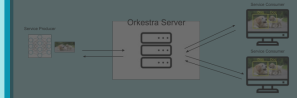

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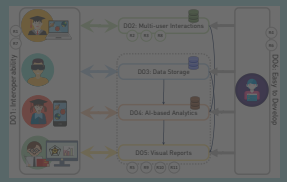

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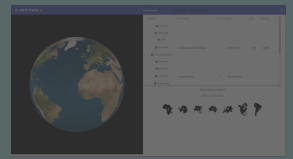

OVERVIEW

- Steady year-to-year increase of publications

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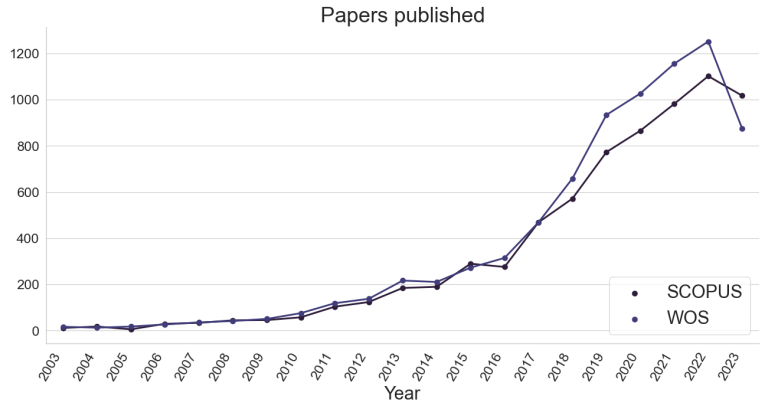

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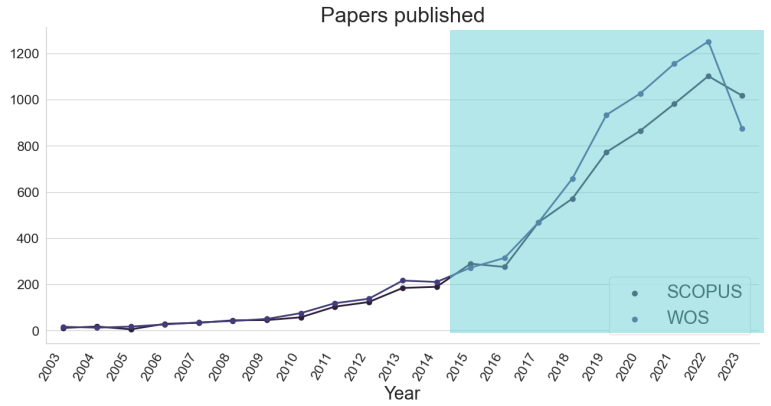
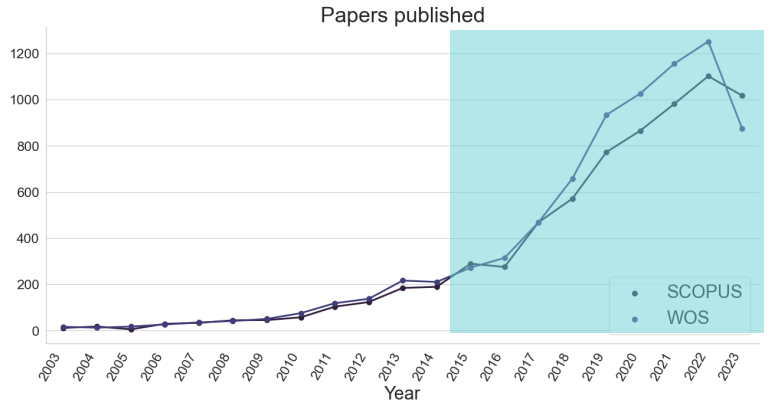


OVERVIEW

- Steady year-to-year increase of publications
- Several systematic reviews covering different aspects of AR in education



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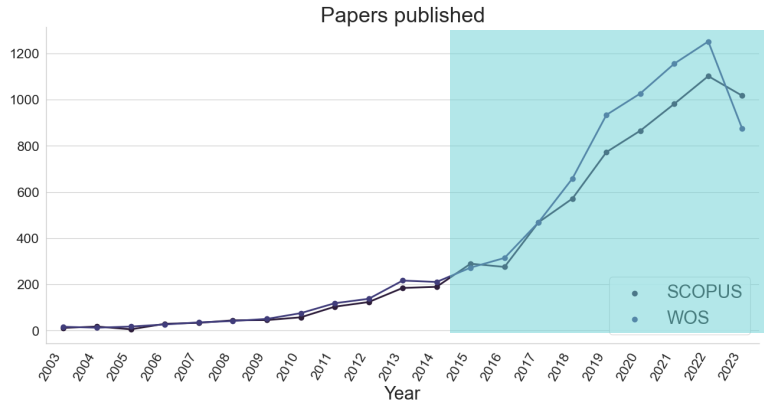

Advantages and drawbacks

Status of the technology

AR for STEM

AR for language learning

Evaluation of usage in schools

OVERVIEW

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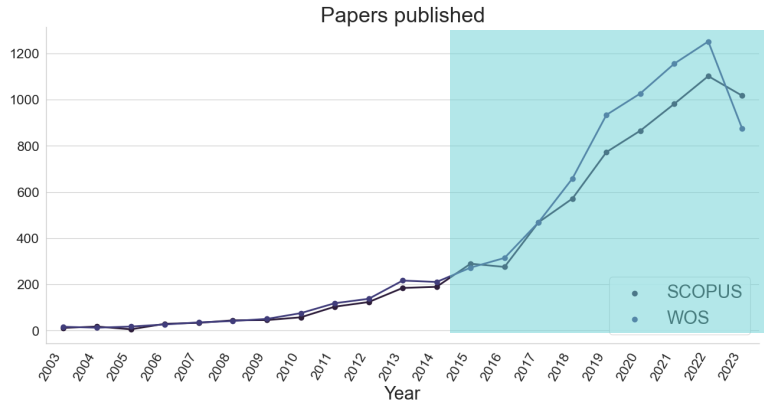
- Several systematic reviews covering different aspects of AR in education



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AR-based serious games

Impact in learning effectiveness

Usability and UX

Bibliometric analysis

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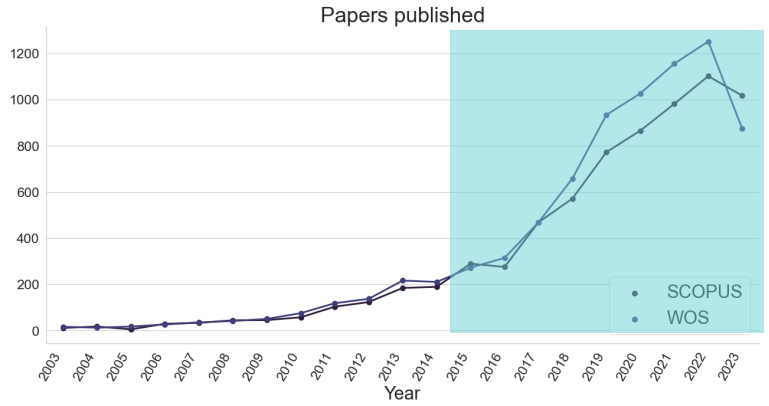

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Bibliometric analysis

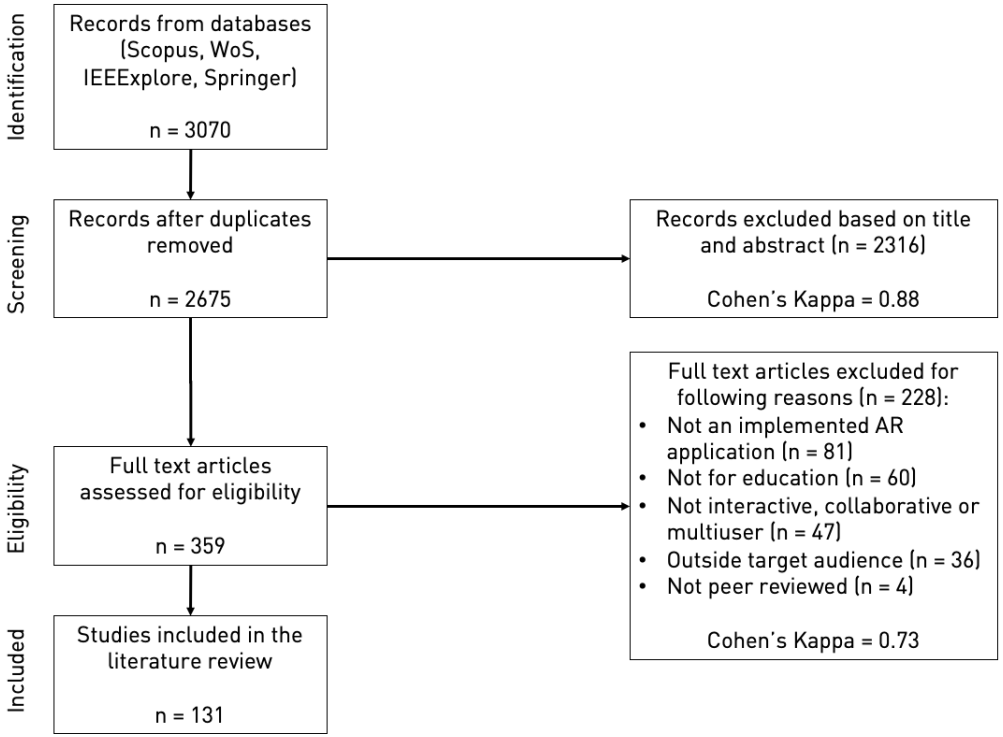
Collaborative AR (2014, 8 papers)

OVERVIEW

- Systematic literature review of AR applications for education

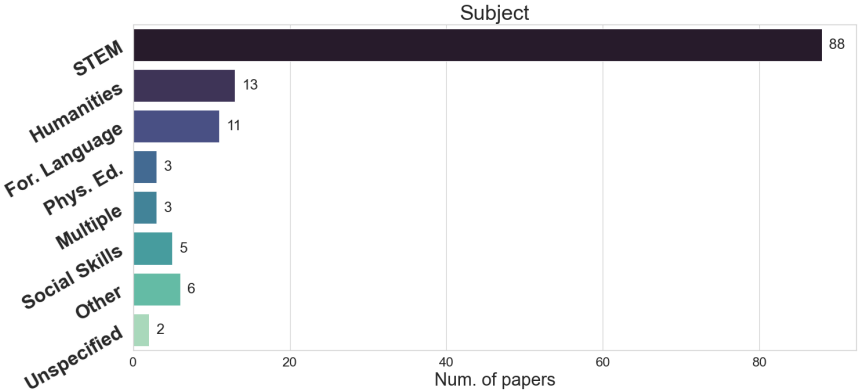
RQ1	What collaborative, multi-user, interactive AR applications in education?
RQ2	What is the motivation for using AR apps as an educational tool?
RQ3	Are AR applications effective at improving the knowledge of the students?

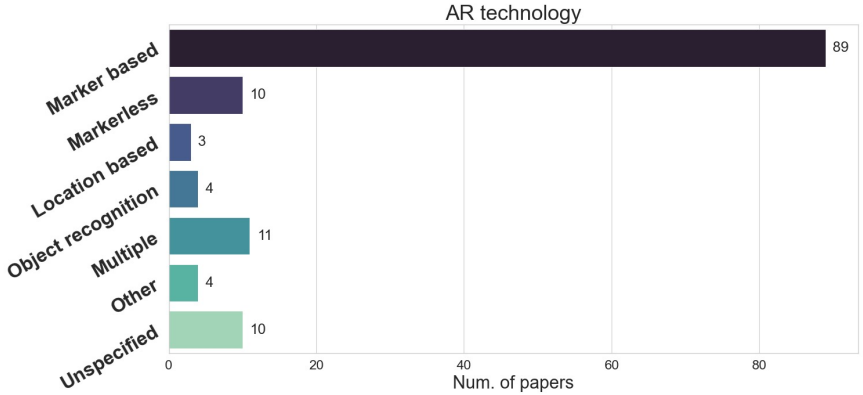
METHODOLOGY

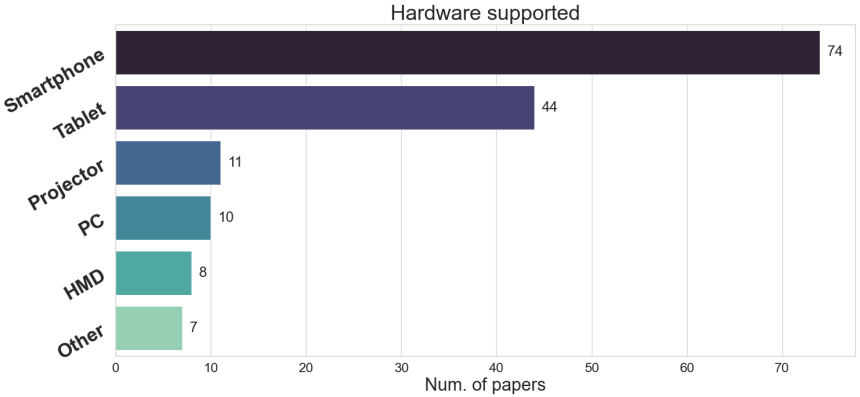


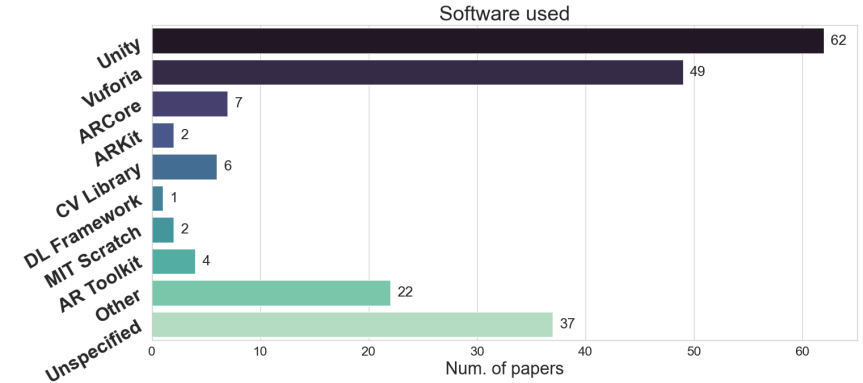
- Inclusion criteria:
  - Studies published between 2015 and 2023
  - New AR application
  - Primary and secondary schools
- Exclusion criteria:
  - Not interactive, collaborative or multi-user
  - Not for education
  - Not peer reviewed

RESULTS









RQ1: Interactive, multi-user, collaborative AR in education

01 Studies were categorized based on their **interactive functionalities:**
Basic interactivity / Object interaction / Quiz / Behaviour tracking / Augmented interactions / **Multi-user** / **Collaborative**

02 Majority of the studies offer **very limited** interactive functionalities

03 Mostly **single-user experiences** (21/131 multi-user, 16/131 collaborative)

04 Behaviour tracking hardly considered (6/131)

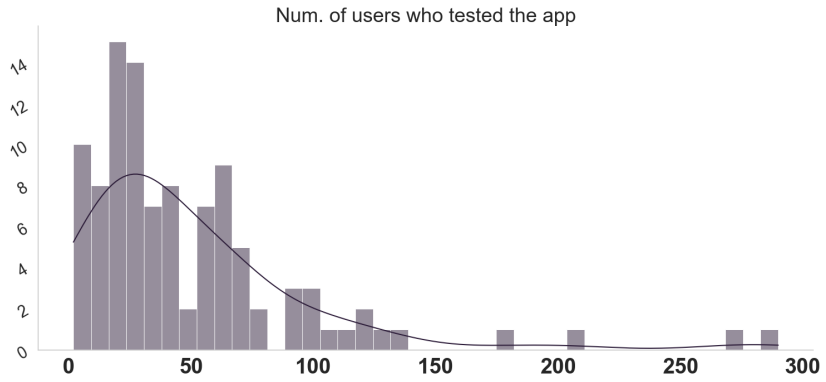
05 Augmented interactions started getting traction in 2019

RQ2: Motivation for AR as educational tool

- Most of the studies **do not motivate** the choice of their application
- They usually present the advantages provided by using AR in the classroom:
  - Interaction with real world
  - Simplifies gamification
  - It can be used as a tool to provide supplementary material
  - Enables 3D visualization and animations
  - Can be especially helpful for children with learning disabilities
  - (Limited) effect on student motivation

RQ3: Effectiveness of AR at improving knowledge

- 103 out of 131 studies provided information on the number of participants



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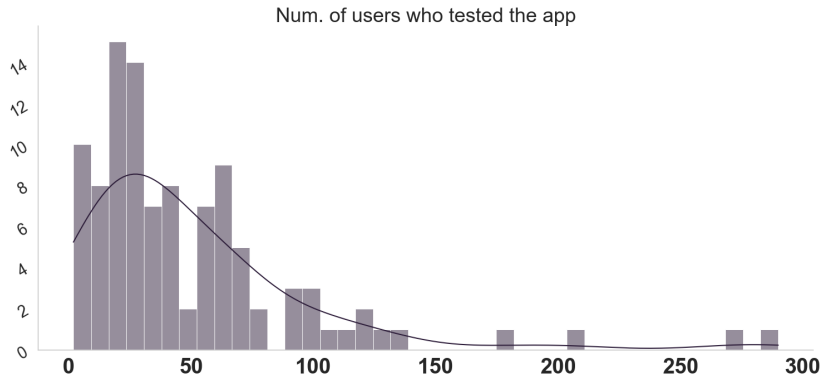
- 103 out of 131 studies provided information on the number of participants
- Evaluation performed in three ways:
  - Comparison with control group
  - Surveys
  - Pre- and post-test



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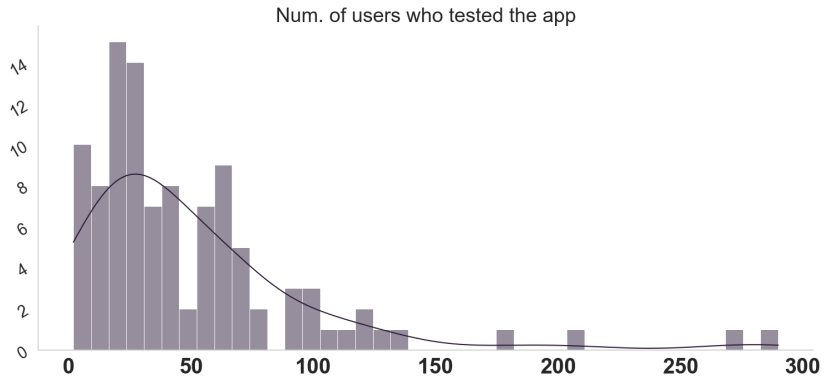

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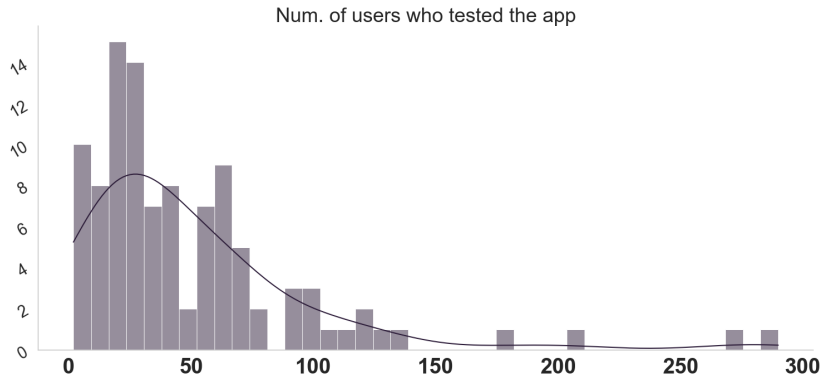

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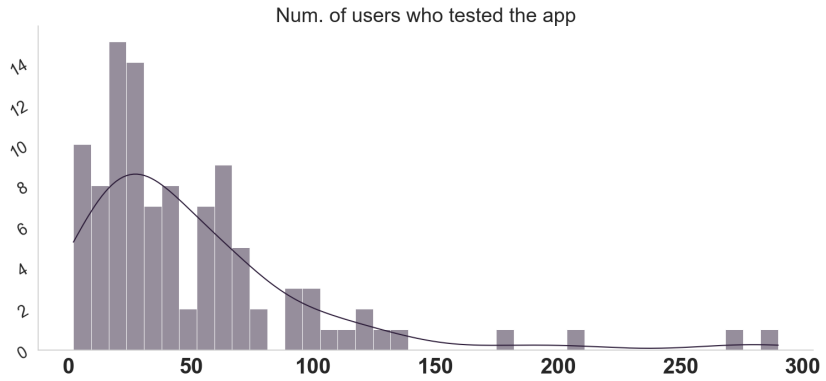

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- No studies showing negative impacts of AR – only 1 showing no effect

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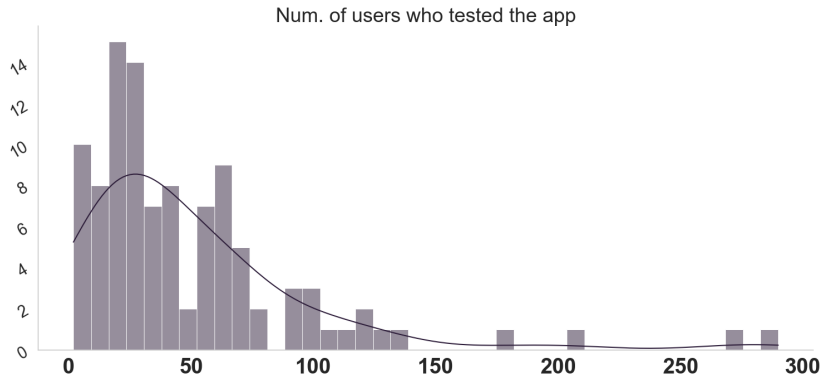

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- Only 2 studies measuring topics retention

DISCUSSION

DISCUSSION

01

Issues
- Lack of authoring tools
- Availability of free-to-use 3D content
- Code publication

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02 Stronger positive impact is related to **inclusion of AR usage in existing school curricula**

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03 Multi-user AR for distance learning is an **unexplored topic**

DISCUSSION

01 Issues
- Lack of authoring tools
- Availability of free-to-use 3D content
- Code publication

02 Stronger positive impact is related to **inclusion of AR usage in existing school curricula**

03 Multi-user AR for distance learning is an **unexplored topic**

04 Latest AR technologies **still not widely used** (mostly vision, QR-based)

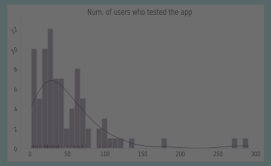
3. RESEARCH RESULTS

Main contributions of the PhD work

Interoperable architecture for collaborative AR in education

C1

In-depth analysis of the state-of-the-art



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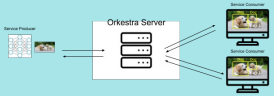

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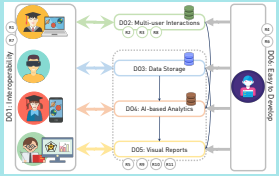

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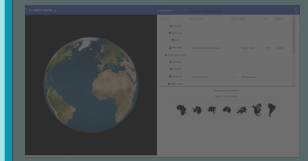


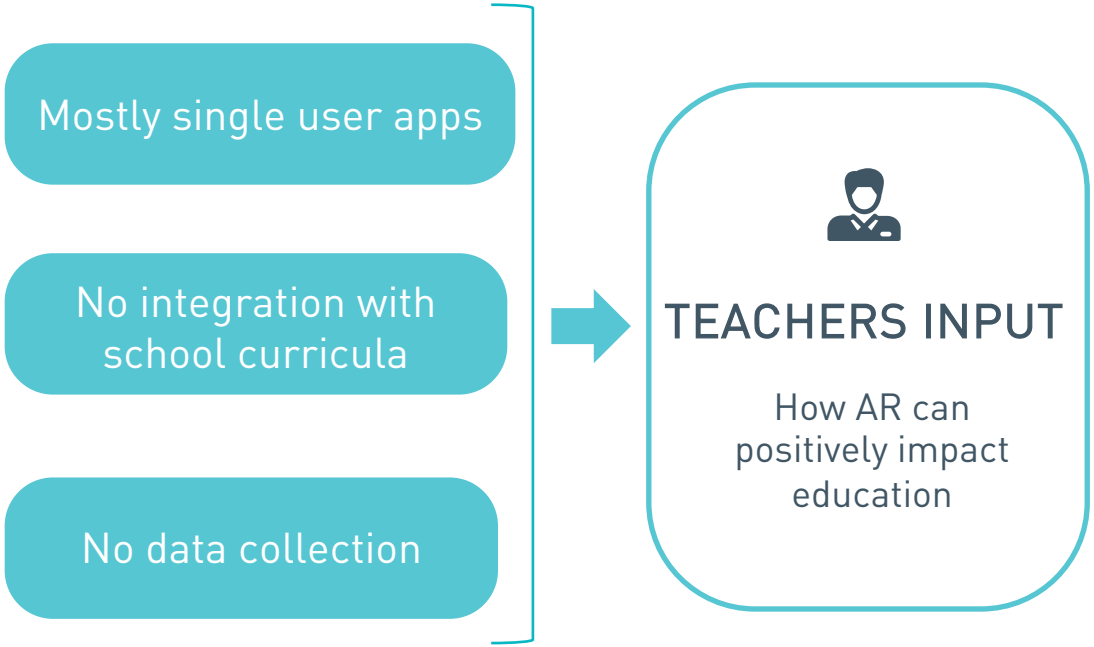
OVERVIEW

Mostly single user apps

No integration with school curricula

No data collection

OVERVIEW



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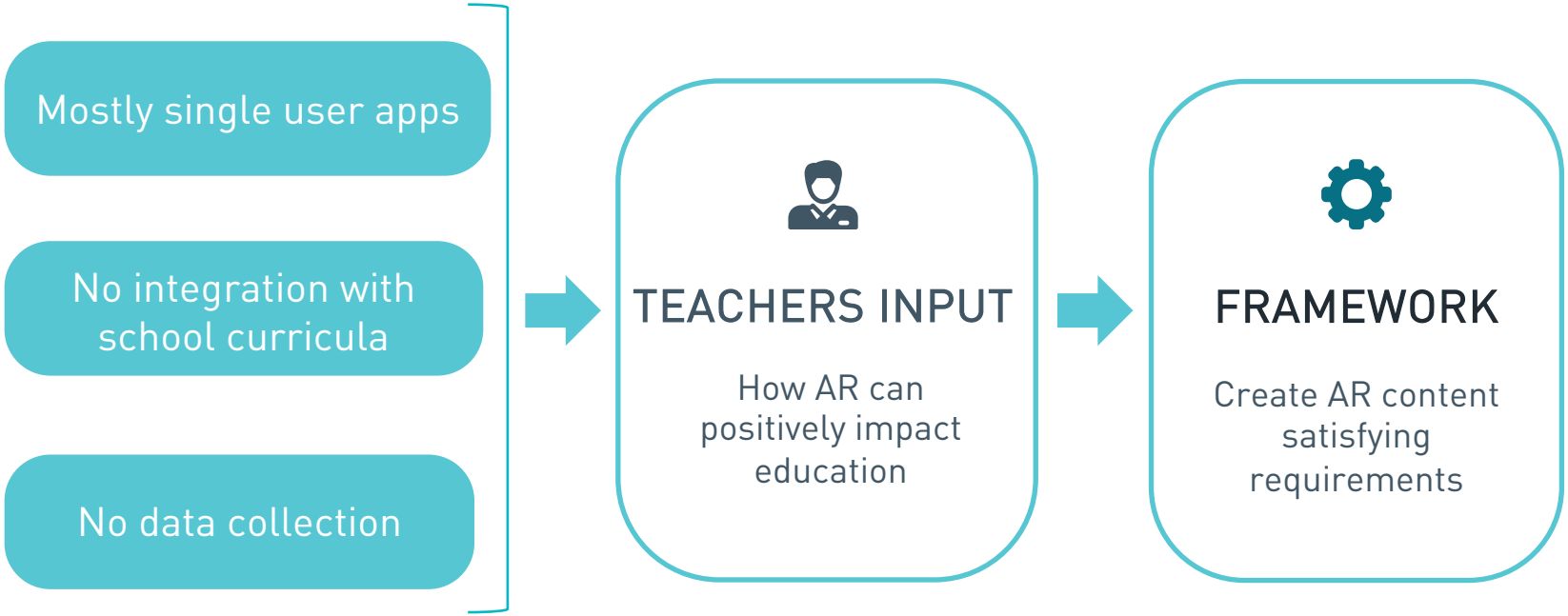
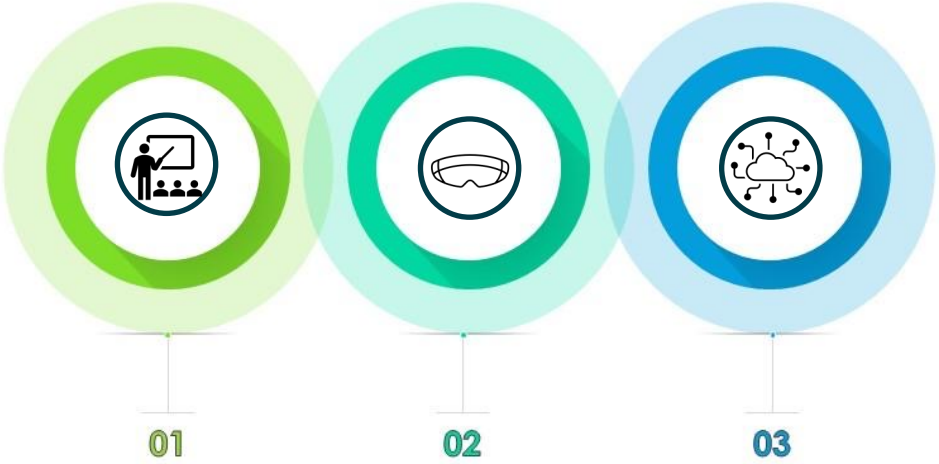


TEACHER SURVEY – In cooperation with Ikastolen Elkartea

- 45 questions split into 3 sections:



Information about the teachers and **usage of TEL** at their school

Usage of AR apps in school and perception of AR as teaching instrument

Which **technological tools** would they like to use at school

TEACHER SURVEY

01 47 teachers participated – mostly **facilitators**

02 High availability of **PCs and laptops**

03 **Widespread adoption** of software tools

04 **Dissatisfaction** with existing AR applications

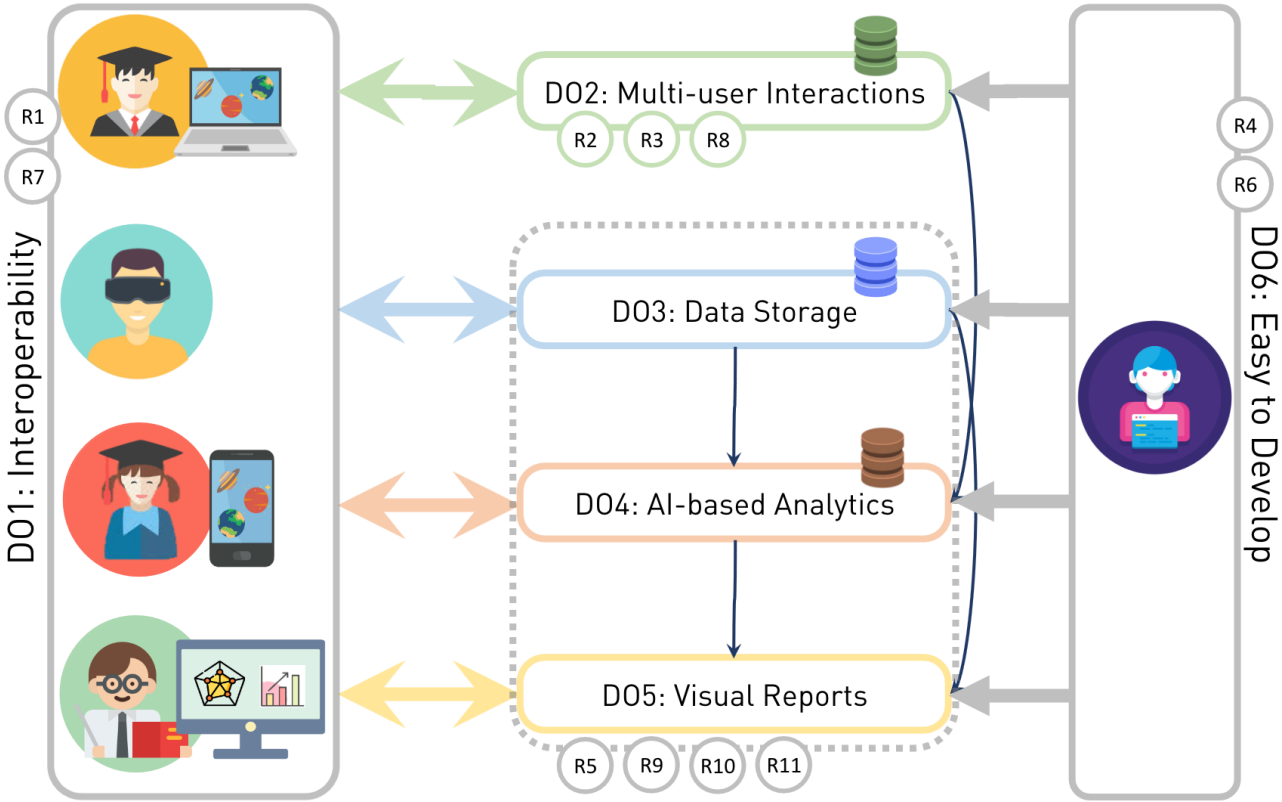
05 AR should provide **interactivity** & **collaboration**

06 Interest in using **Artificial Intelligence** tools

TEACHER REQUIREMENTS

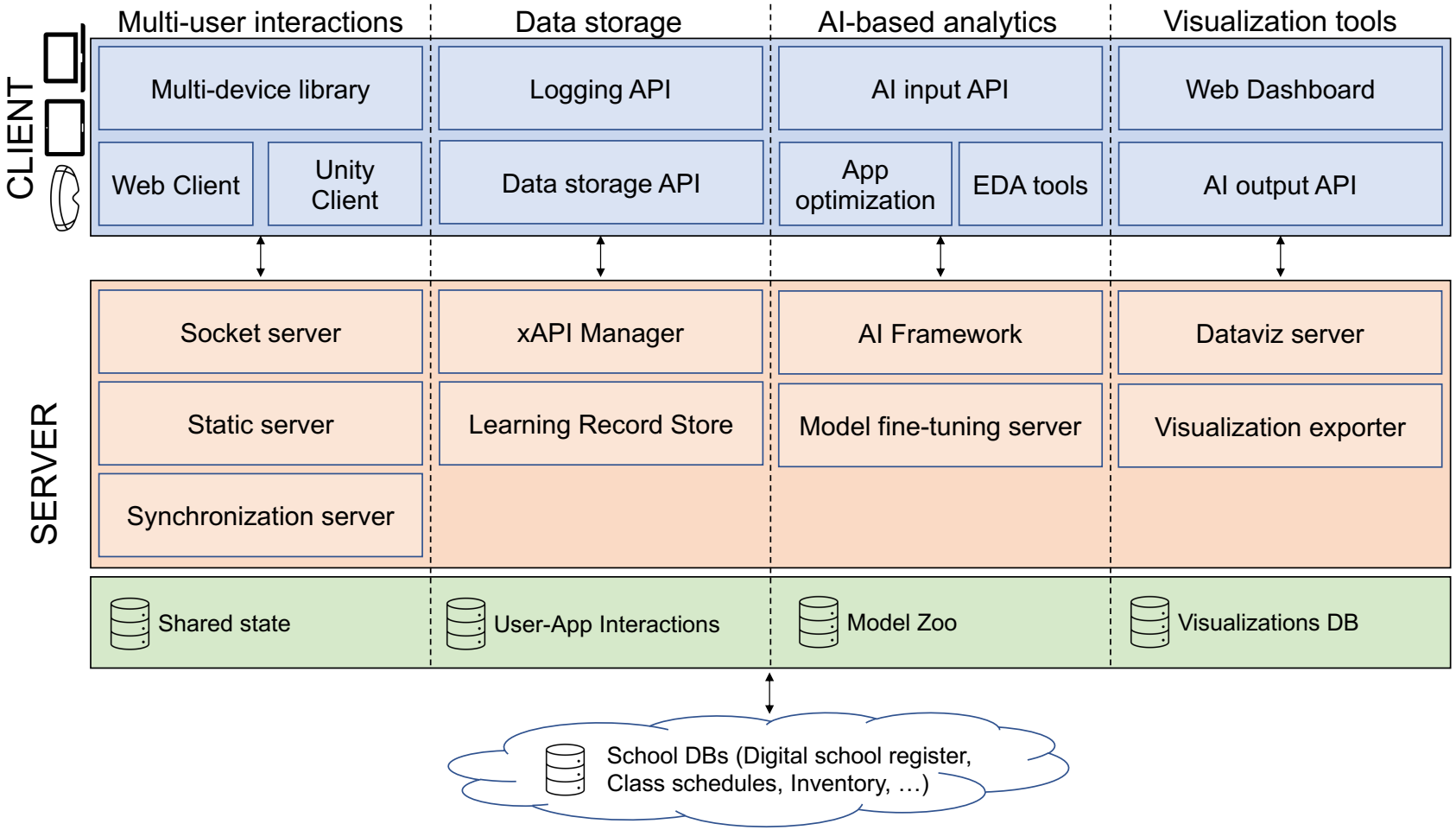
R1	Work on many different platform and devices
R2	Foster teacher-student interactivity
R3	Foster student-student interactivity
R4	Enable several customisation options
R5	Collect data on how the application is used
R6	Enable easy development, as well as installing and updating
R7	Work smoothly on older hardware
R8	Allow collaborative work
R9	Provide tools for analysis of data and usage patterns
R10	Enable automatic analysis of test difficulty
R11	Detect students with learning difficulties

DESIGN OBJECTIVES



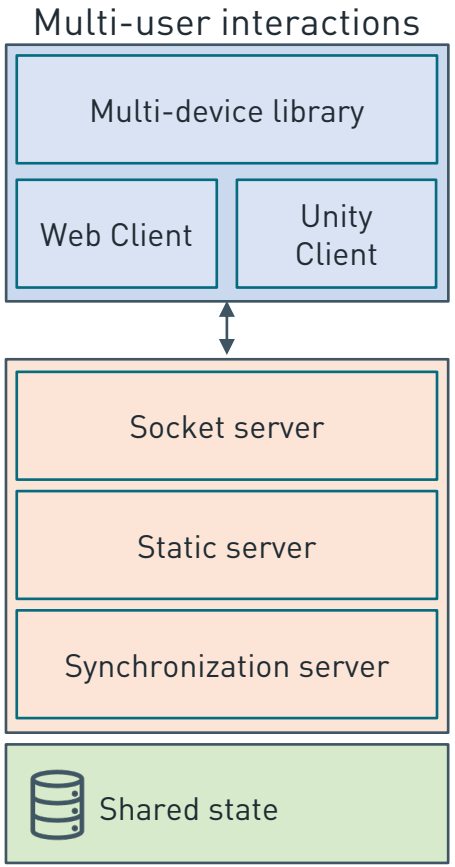
COLLABORATIVE LEARNING ENVIRONMENT FOR AR

- *cleAR* is the architecture defined to fulfil every design objective
- It is a client-server architecture, composed by several modules
- Each module oversees a specific task and satisfies a design objectives
- DO1 (interoperability) and DO6 (ease of development) fulfilled thanks to how the architecture was defined
- Some components rely on existing libraries, developed at Vicomtech or available as open source


Multi-user interactions
Data storage
AI-based analytics
Visualization tools
CLIENT
Multi-device library
Logging API
AI input API
Web Dashboard
Web Client
Unity Client
Data storage API
App optimization
EDA tools
AI output API
SERVER
Socket server
xAPI Manager
AI Framework
Dataviz server
Static server
Learning Record Store
Model fine-tuning server
Visualization exporter
Synchronization server
Shared state
User-App Interactions
Model Zoo
Visualizations DB
School DBs (Digital school register, Class schedules, Inventory, …)

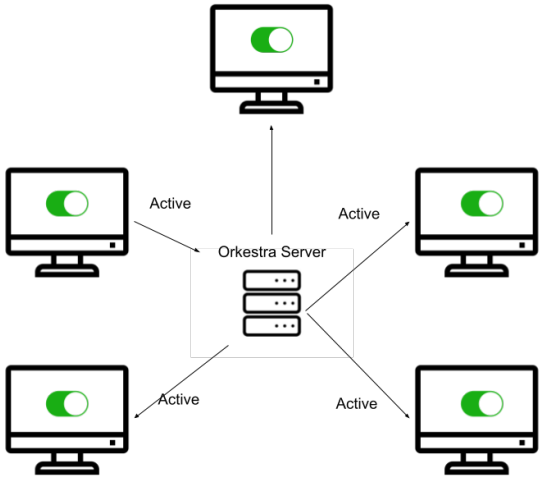
MULTI-USER INTERACTIONS: *ORKESTRA*

- Synchronisation and management of heterogeneous devices in multi-user applications
- Developed for web applications, then extended to other software environments
- Enables context maintenance in multi-device environments
- Main features:
  - State sharing and synchronisation
  - Service publishing from one device to another
  - Video synchronisation from a centralised clock



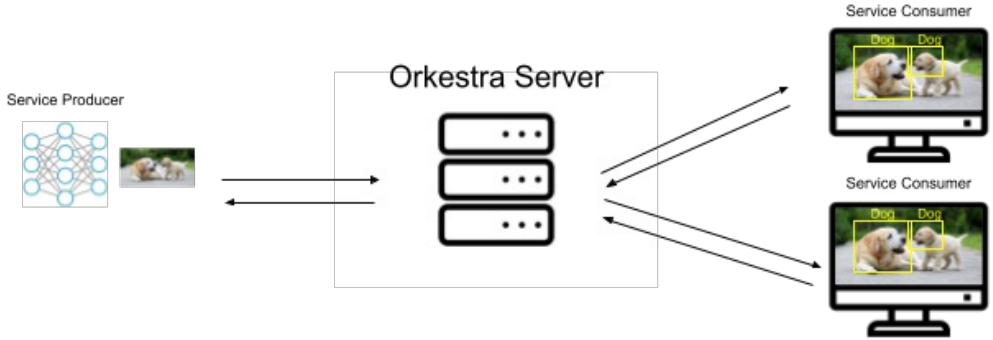
ORKESTRA: state synchronisation

- Applications can store data and share it across devices
- When a device changes its state, this is shared across every connected device
- There are two types of state:
  - Agent
  - Application



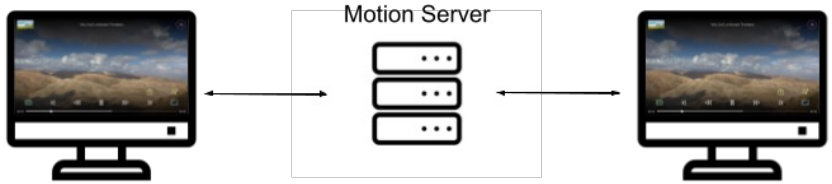
ORKESTRA: services

- Create services on a device which are then consumed by others
- Resource intensive services can be delegated to powerful devices
- Example: computer vision tasks

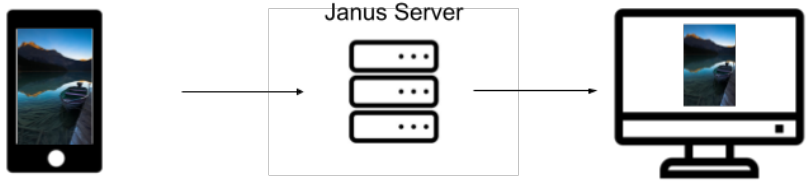


ORKESTRA: video sharing and synchronization

- Multiple user can watch the same video content at the same time

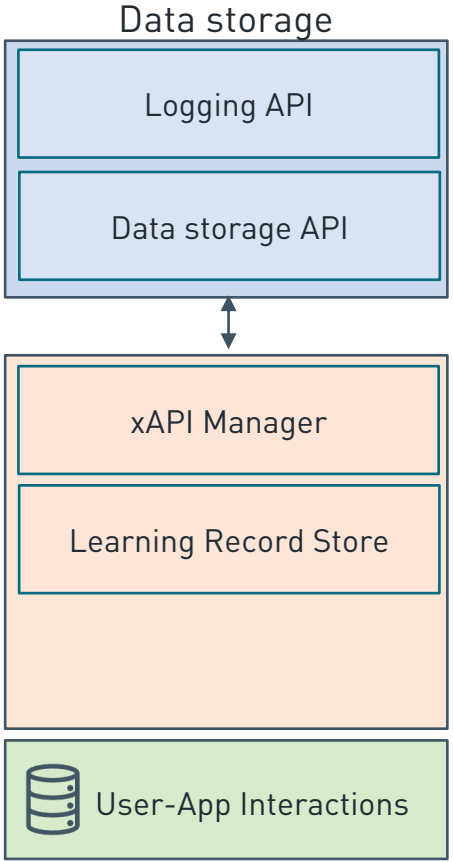


- Multimedia content can also be shared across devices, for example to share the screen or the content grabbed from a camera



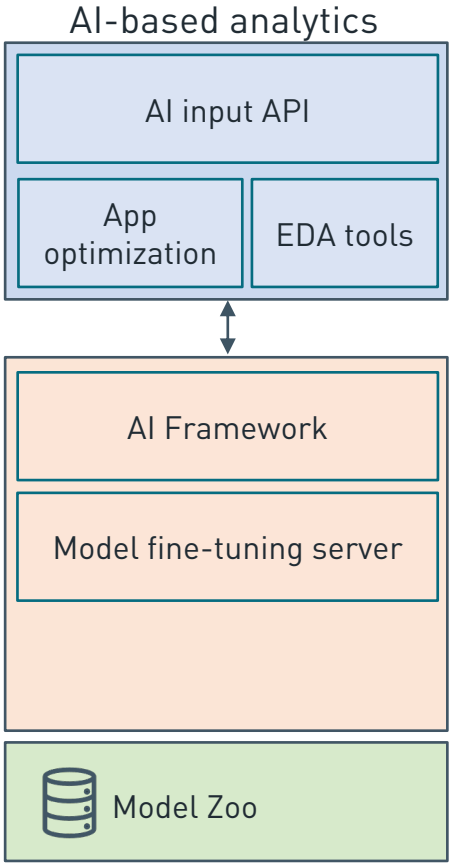
DATA STORAGE

- Data can be serialized and stored on a DB or locally
- An API allows storing and retrieving data through a Learning Record Store
- This enables applications to fetch data from existing LMSs (*e.g.*, a set of questions for a test) and writing data to it (*e.g.*, results of in-app quizzes, students' progress)



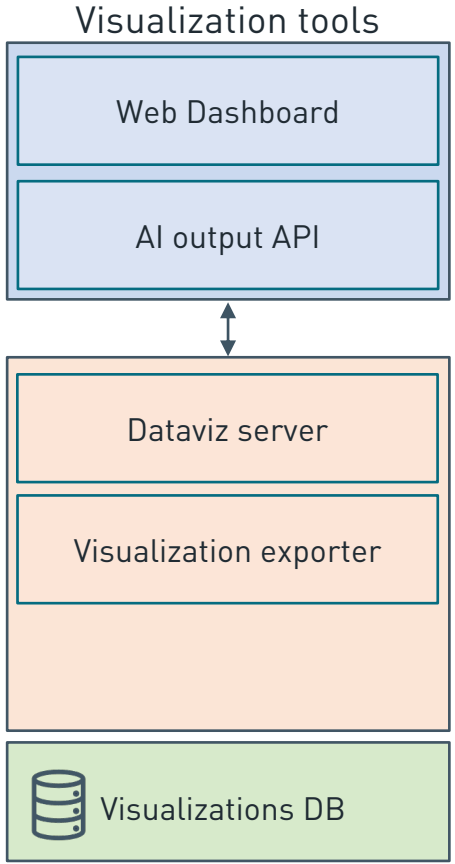
AI-BASED ANALYTICS

- Data collected through the application can be used to train or fine-tune AI models
- Models are trained and stored on the server side
- The API defines an interface for data input, and relies on existing AI frameworks
- Specific algorithms for optimization of app parameters



VISUALIZATION TOOLS

- Provides an interface for visualisation and reporting
- Simplifies the exploration of the data collected
- Low-code creation of plots and charts
- Enables teachers to draw insights



PROOFS OF CONCEPT

- Three PoCs were created to perform a technical validation of the architecture and to verify that different design objectives were satisfied

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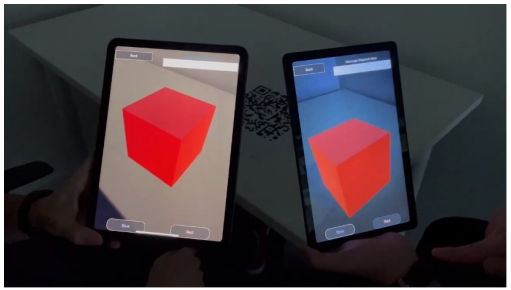
AR Cube



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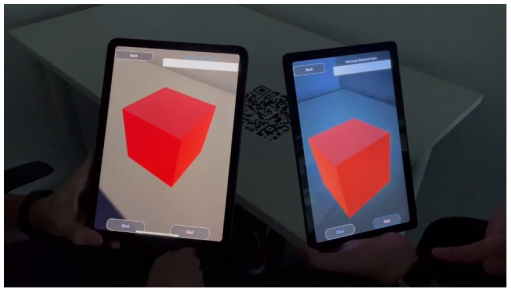
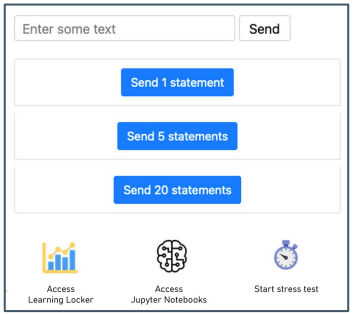


xAPI data analysis



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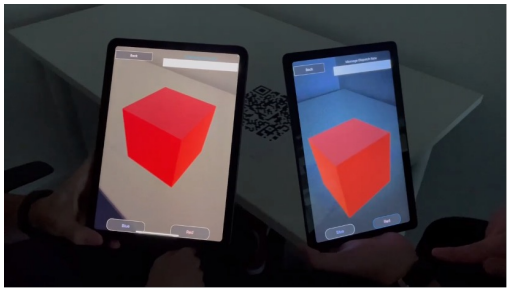

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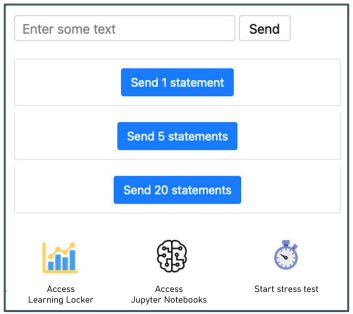
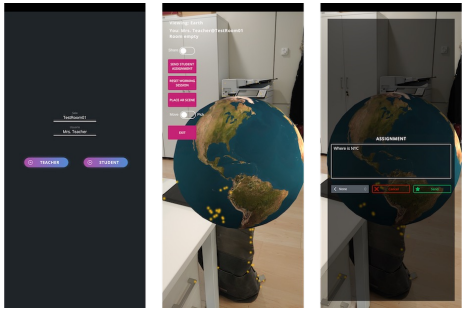


AR Geo Quiz



AR-CUBE

- Interactions with the augmented content are broadcast to all connected users
- Users can rotate the object or change its colour
- Interactions are stored in a queue and sent when the *dispatch time* has elapsed
- *Dispatch time* can also be estimated automatically

AR-CUBE

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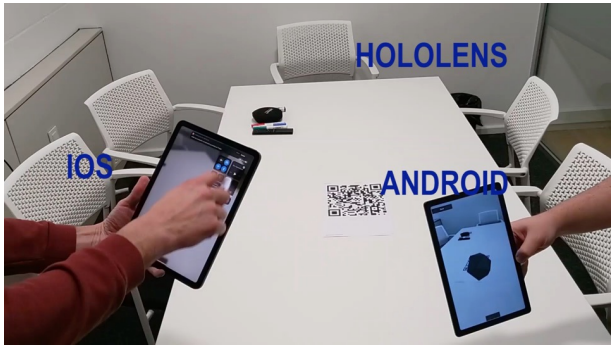
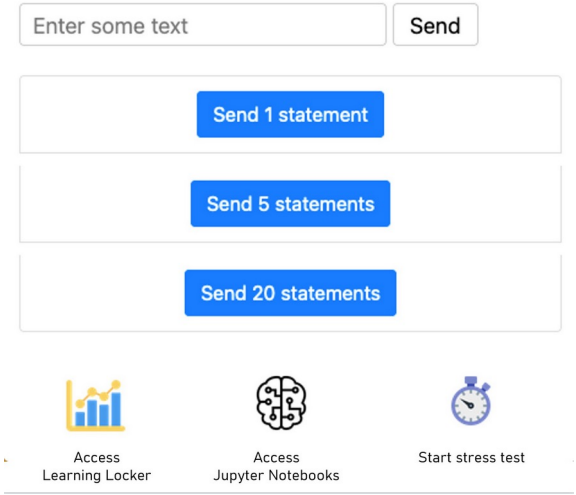


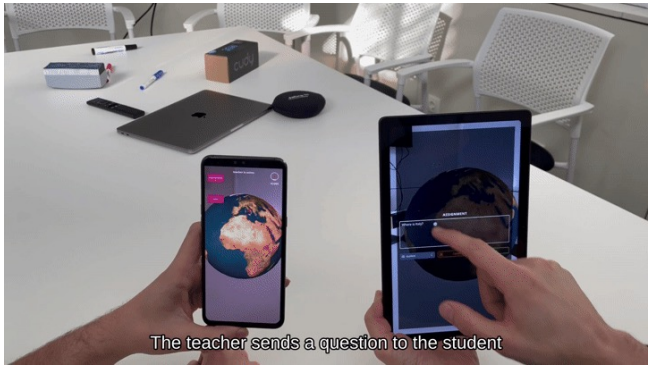
xAPI DATA ANALYSIS

- A Learning Record Store that collects data from users accessing a web page.
- Data collected in the form of xAPI statements
- Demonstrates integration with Learning Locker
- Stress test was performed with 10 clients, sending a total of 80k statements
- The statements were used to train a simple linear classifier



AR GEOGRAPHY QUIZ

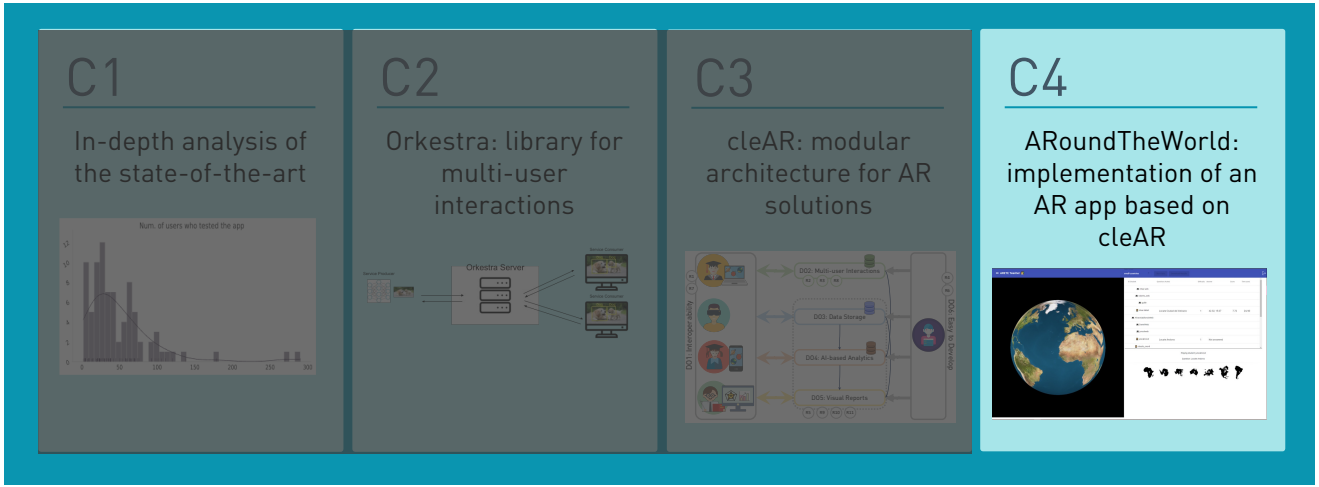
- A more complex example that simulates a geography quiz
- This PoC was then further developed to create *ARoundTheWorld*
- Two modalities:
  - *free exploration*
  - *forced perspective*



PROOFS OF CONCEPT

	Design Objective				
PoC	Interoperable	Multi-user	Data Storage	AI Support	Easy to develop
AR Cube	✓	✓		✓	✓
xAPI Data Analysis		✓	✓	✓	✓
AR Geography Quiz	✓	✓	✓		

Validation of the proposed architecture



OVERVIEW

01 Conceptual validation of cleAR performed through the creation of 3 PoCs

02 A more complex application is required to **validate cleAR in a school environment**

03 The app, *ARoundTheWorld*, was **designed with the help of teachers**

04 Objective: demonstrate potential of *cleAR* in the creation of **collaborative and interoperable applications**

ARoundTheWorld

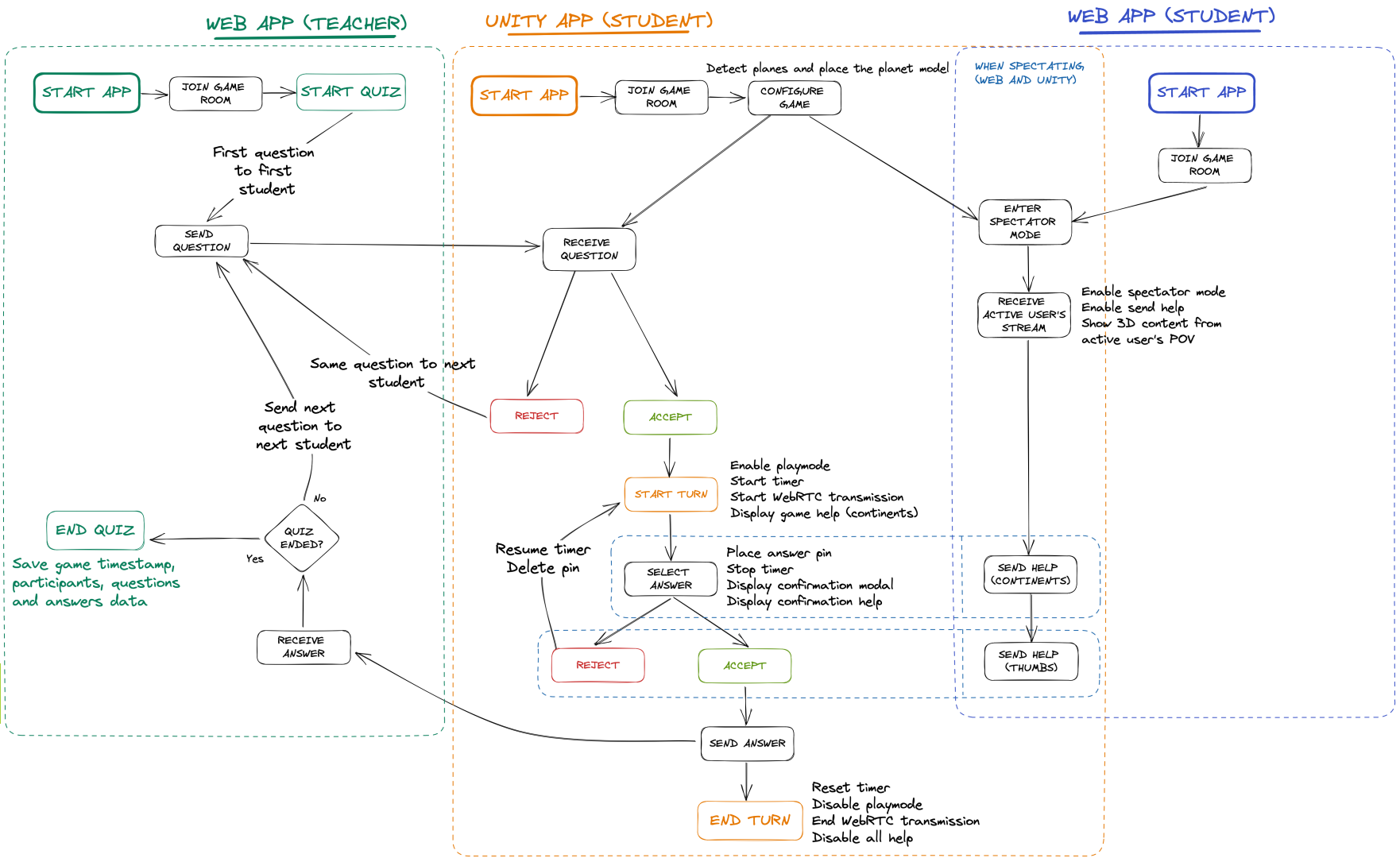
01 **Collaborative geography quiz**

02 App sends a question, student answers by **placing pin on 3D globe**

03 Other students **collaborate by giving hints**

04 Teacher has access to **dashboard**, to **display results** or **create new quiz**

05 App is **gamified** to motivate students


WEB APP (TEACHER)
UNITY APP (STUDENT)
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JOIN GAME ROOM
START QUIZ
First question to first student
SEND QUESTION
Same question to next student
Send next question to next student
No
QUIZ ENDED?
Yes
END QUIZ
Save game timestamp, participants, questions and answers data
RECEIVE ANSWER
START APP
JOIN GAME ROOM
CONFIGURE GAME
Detect planes and place the planet model
RECEIVE QUESTION
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Enable playmode
Start timer
Start WebRTC transmission
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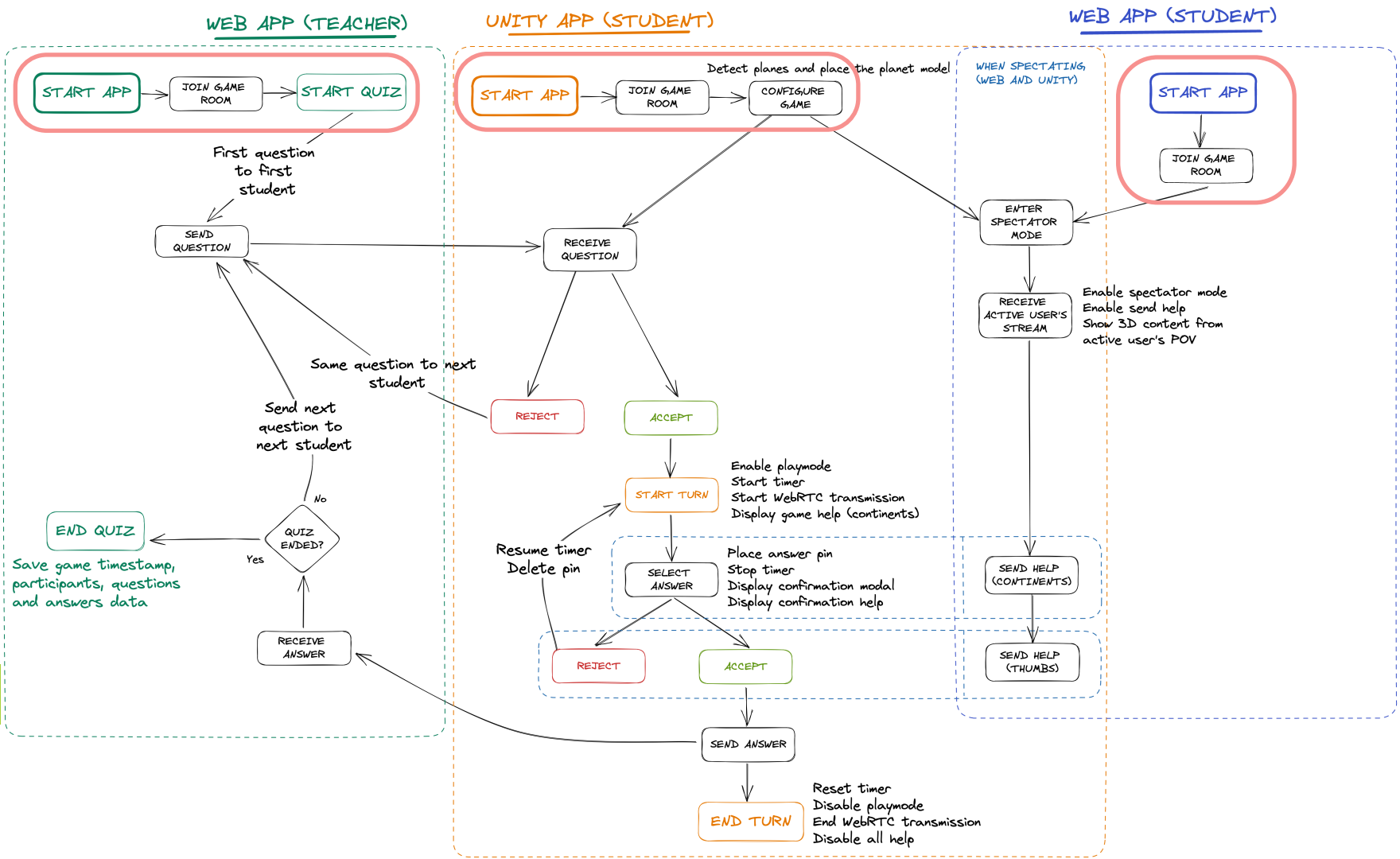
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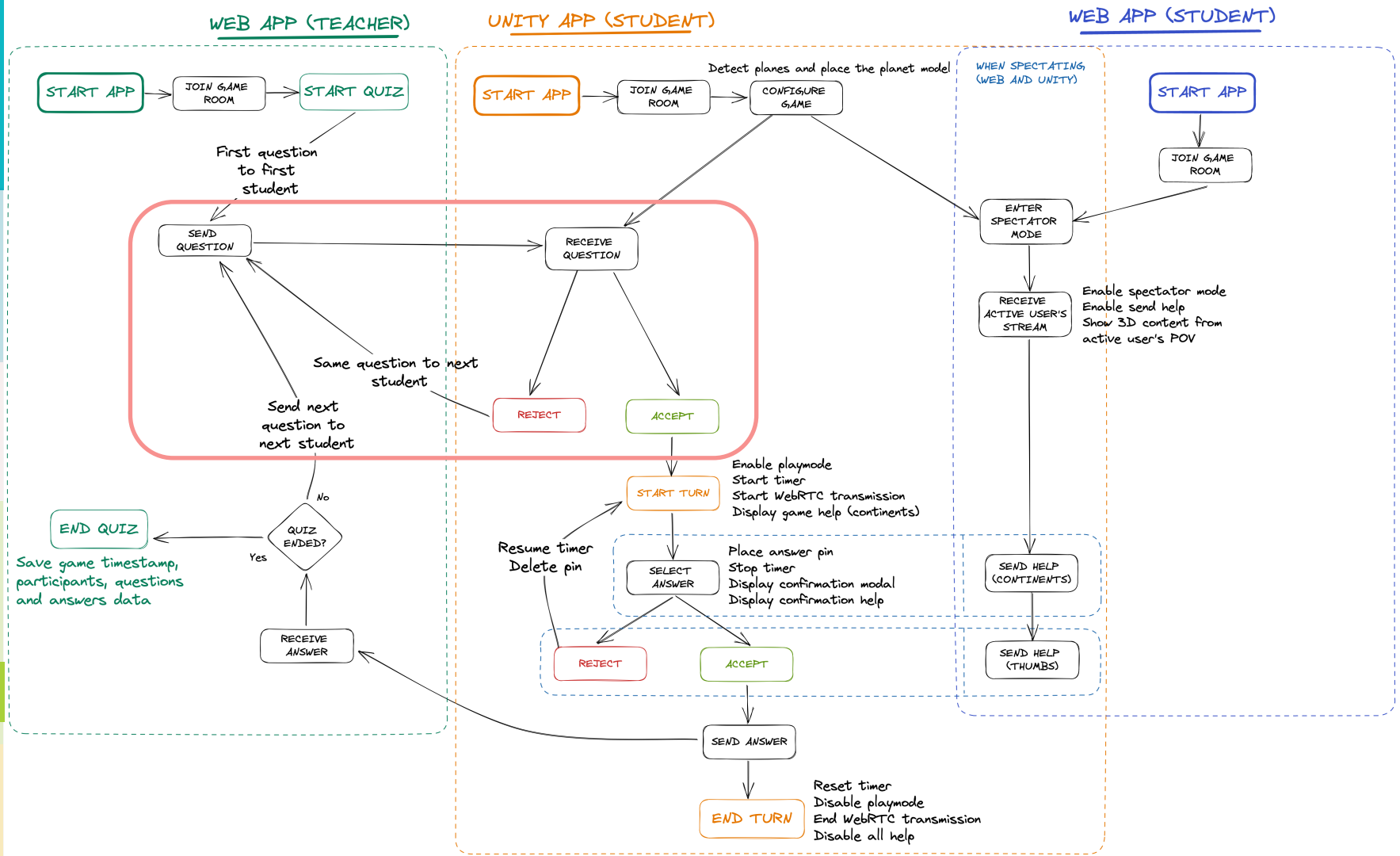
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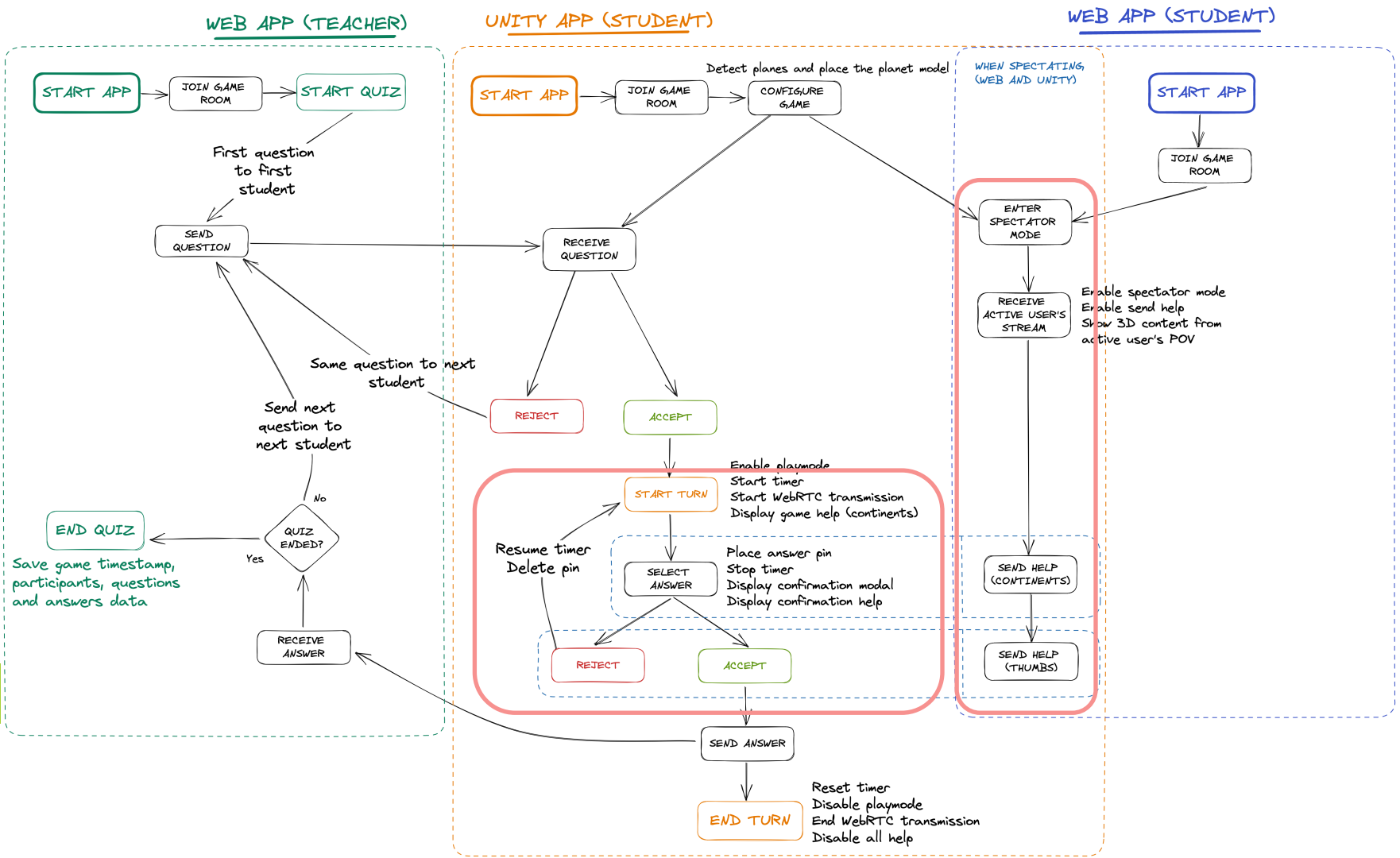
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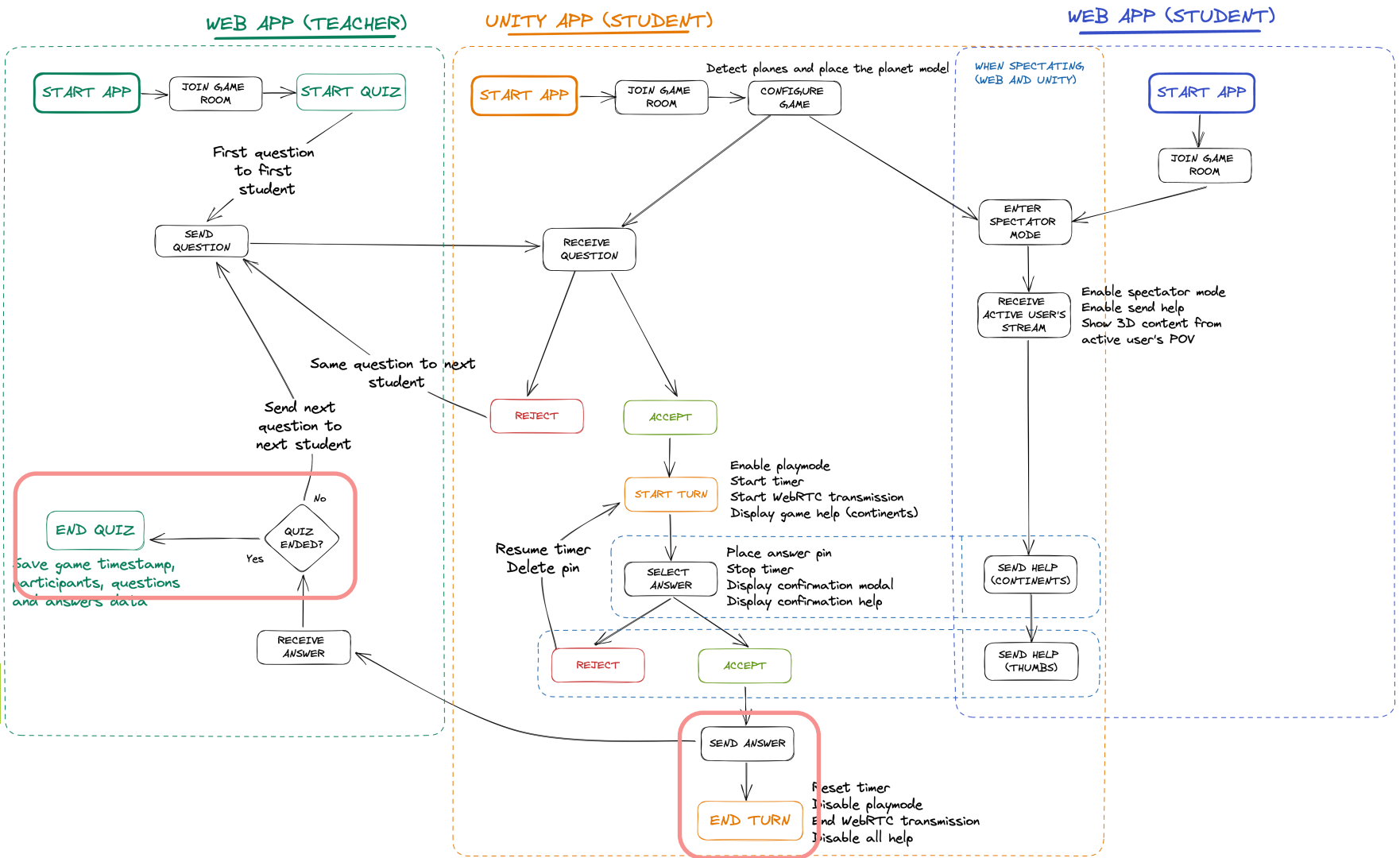
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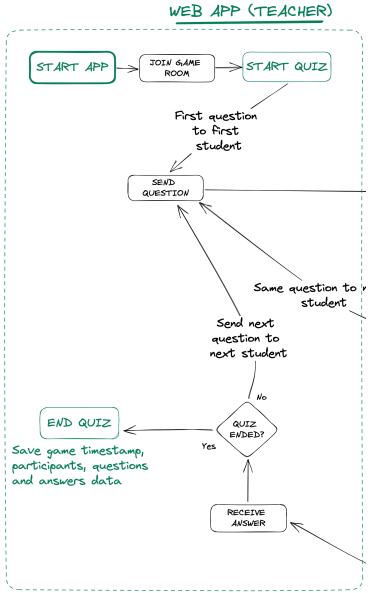
ARoundTheWorld



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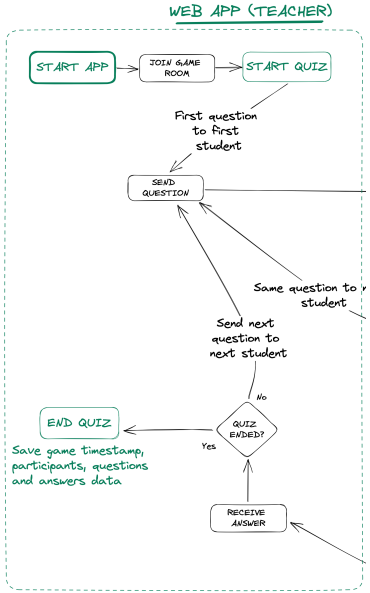

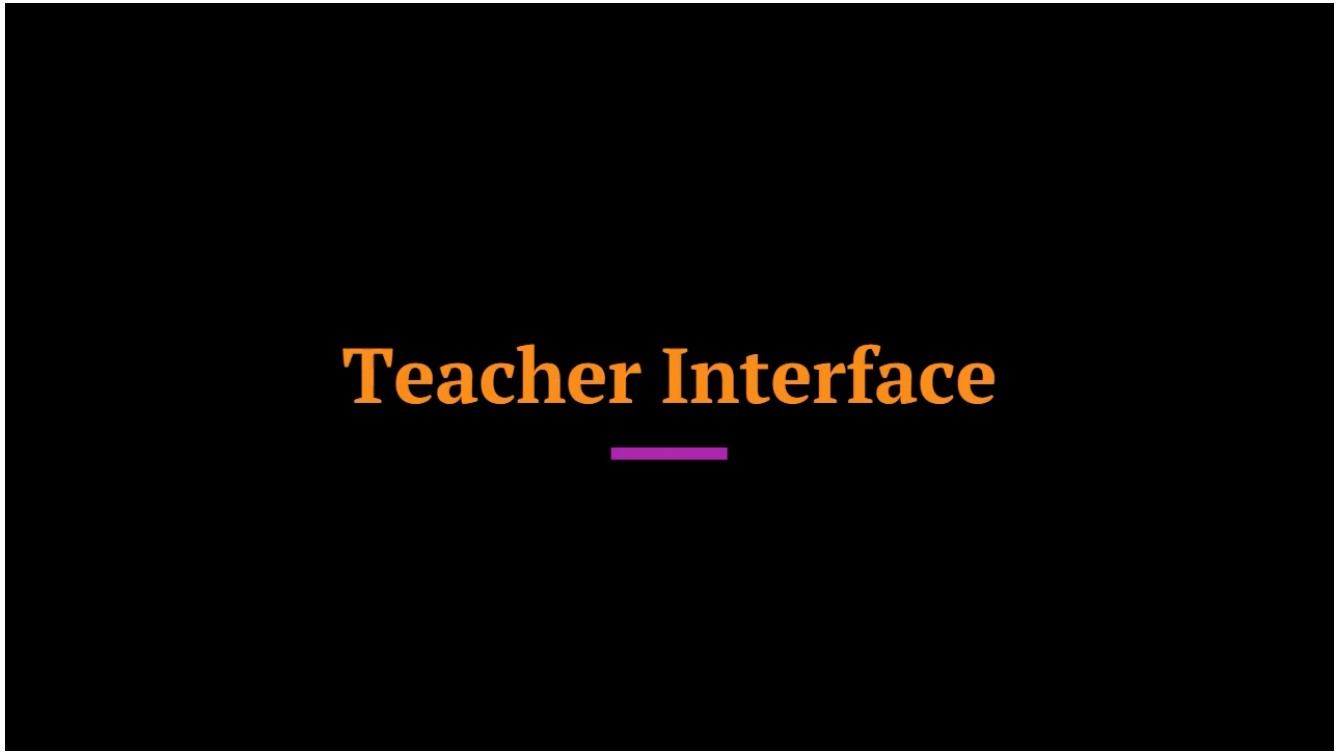

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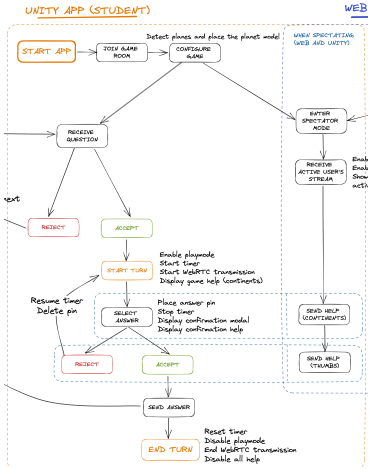

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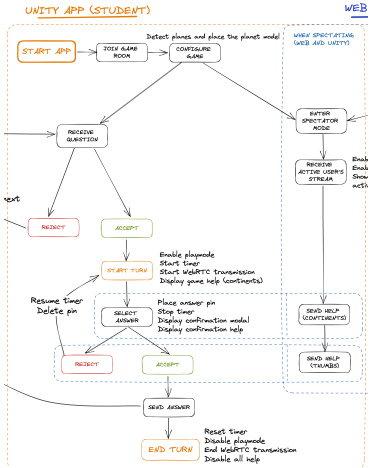
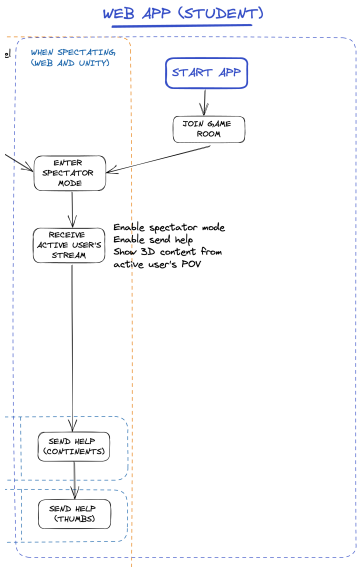


Mobile/Tablet Interface

ARoundTheWorld



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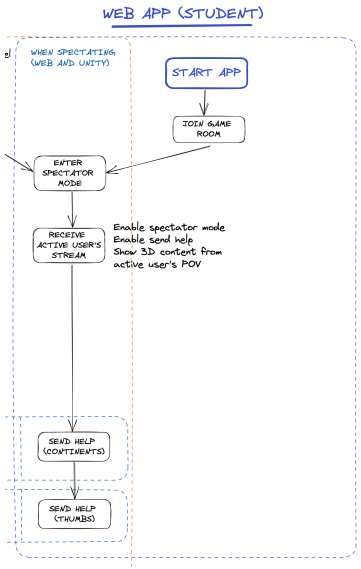
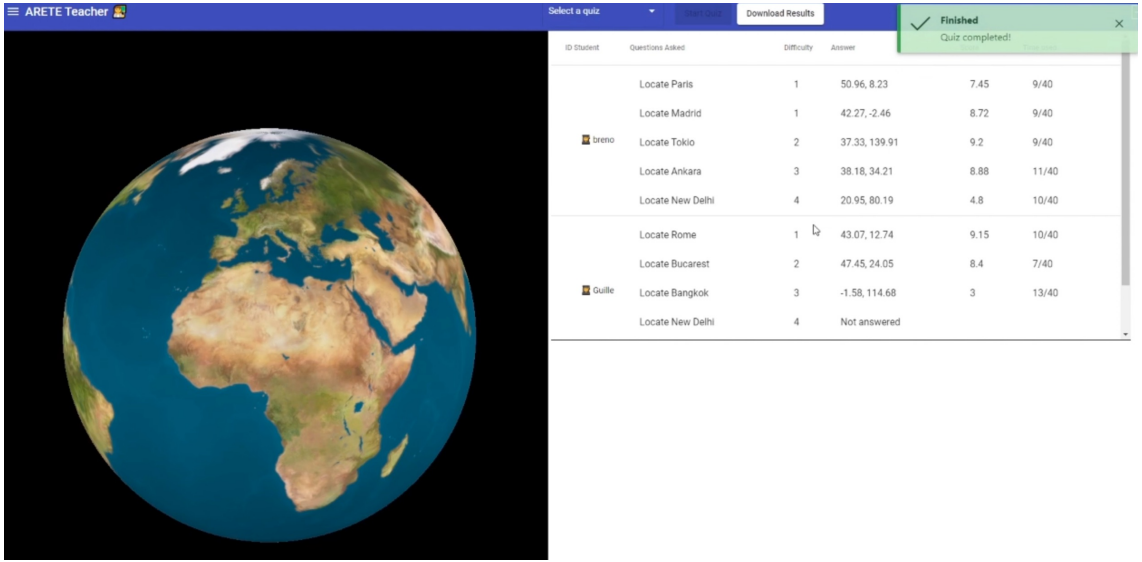


Web Interface

ARoundTheWorld

- At the end of the quiz, the teacher can **check the results**, access a **dashboard with user statistics** or **launch a new quiz**



ARoundTheWorld – fulfilment of Design Objectives

- **Interoperability** (DO1): supports iOS and Android devices, HoloLens HMD and PC
- **Multi-user support** (DO2): *Orkestra* functionalities
- **Data analytics** (DO3, DO4, DO5): xAPI statements on a Learning Locker server
  - Basic data analysis functionalities provided by Learning Locker
  - Advanced EDA, visualisation and IA provided via custom Python package
- **Ease of development** (DO6): interview with developer

ARoundTheWorld – Evaluation

- The evaluation was performed with 44 students from 3 different educational institutions: Salesianos, Zubiri Manteo y Universidad de Deusto

Participants	Gender		Players		Watchers	**Total**
	Males	Females	Tablets	Phones		
14-year-old	9	8	4	5	8	**17**
17-year-old	16	1	3	6	8	**17**
19-year-old	6	4	3	6	1	**10**
Total	**31**	**13**	**10**	**17**	**17**	**44**

ARoundTheWorld – Evaluation protocol

01 Explain purpose and **experiment briefing**

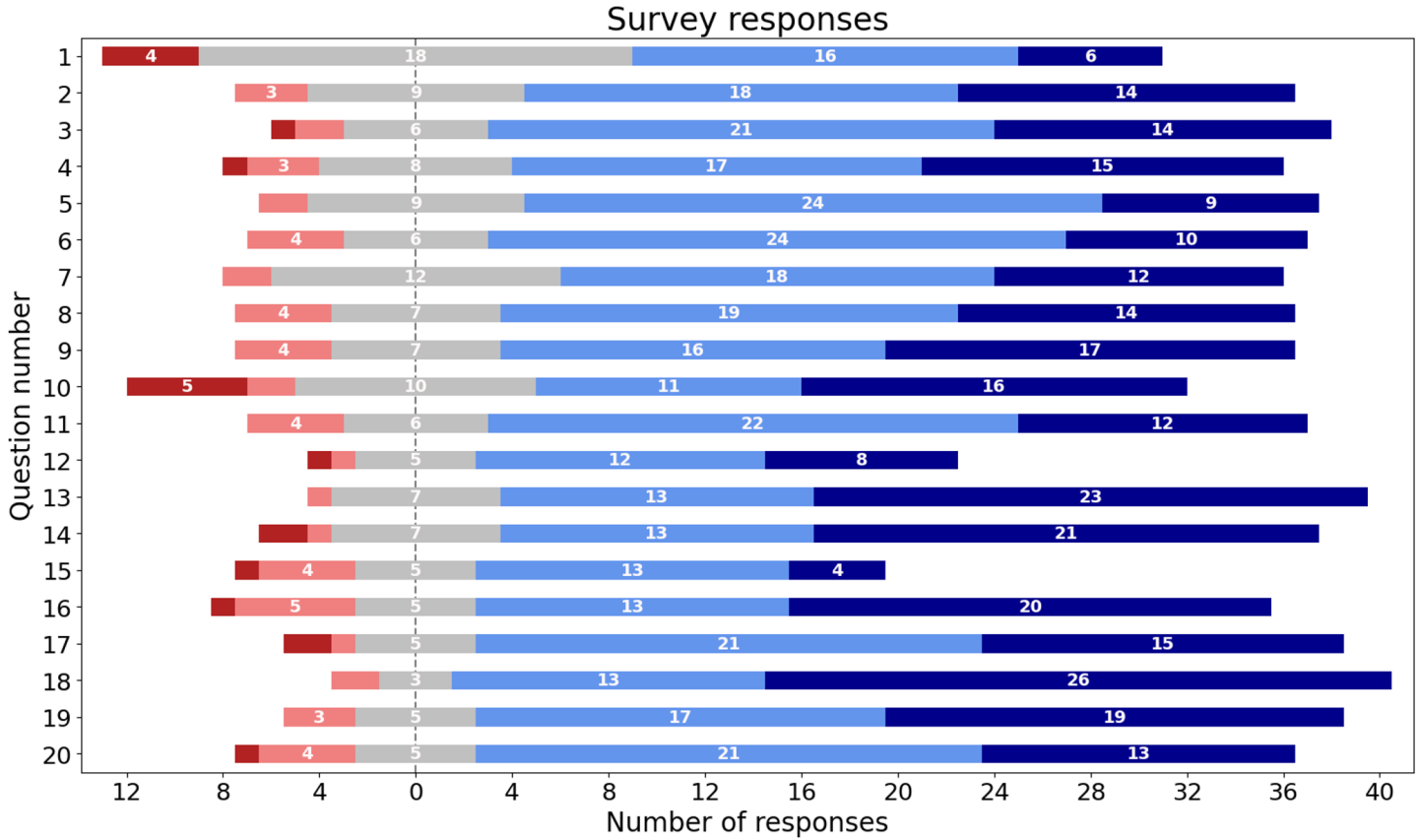
02 **Fill questionnaire** (inspired on P-SUS)

03 Survey ID was the same as the user ID used for **in-app data collection**

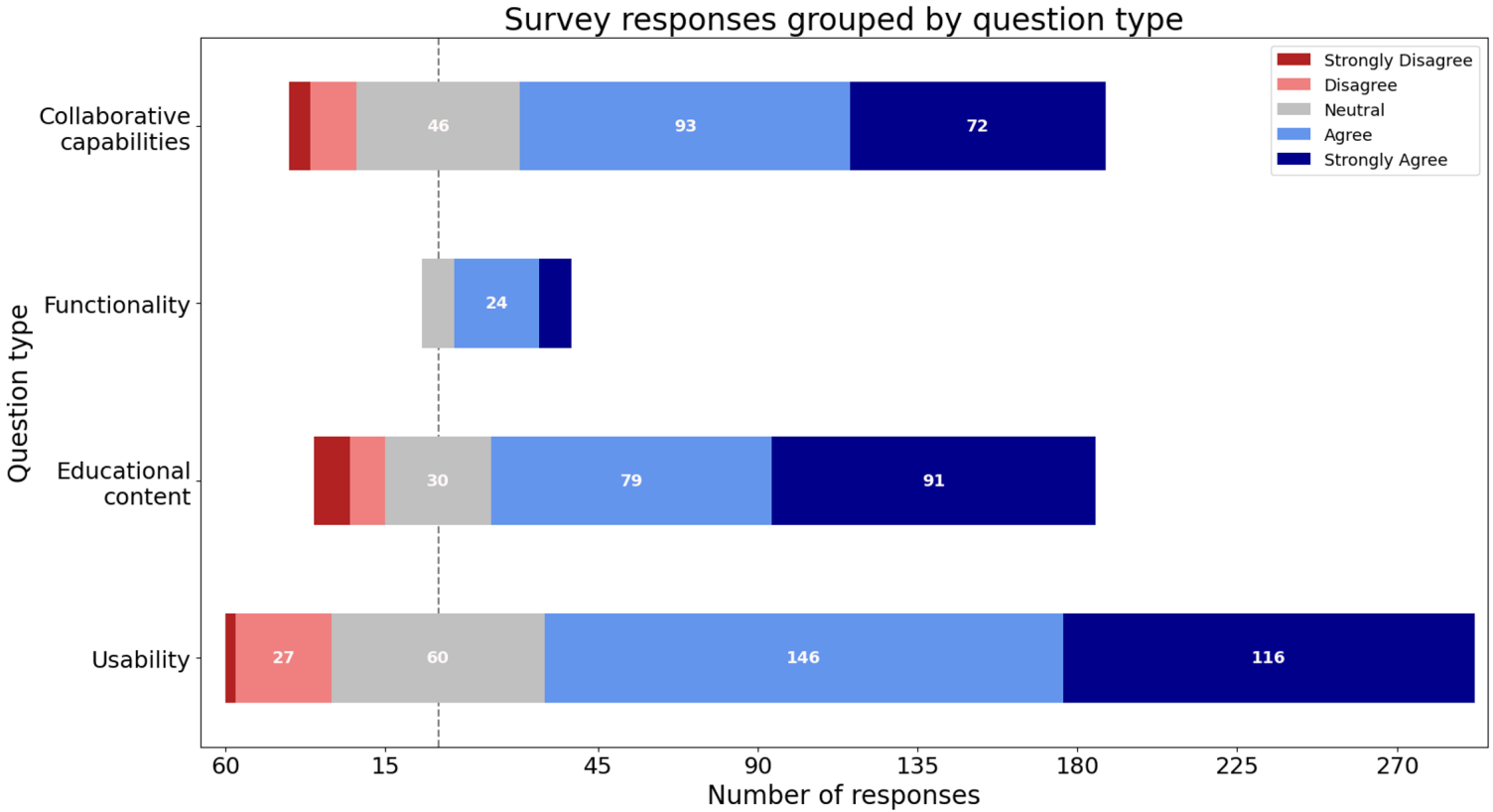
04 **Post-study interview** with teachers

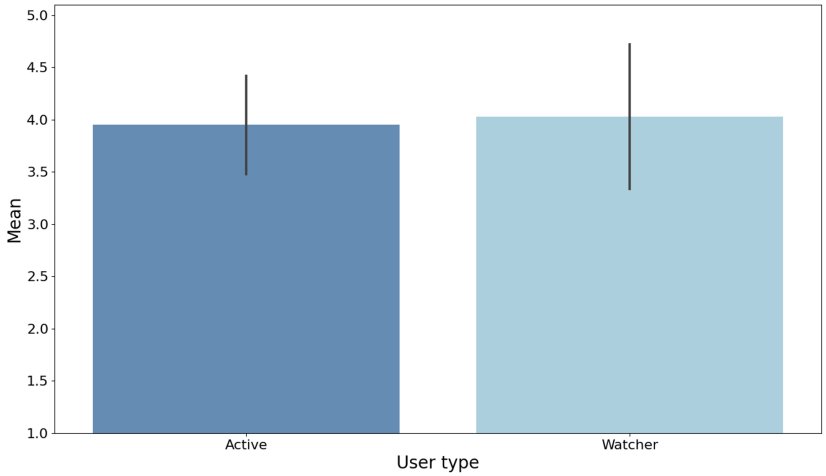
05 Data analysis from xAPI statements collected during experiment

Evaluation results



Evaluation results

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User type
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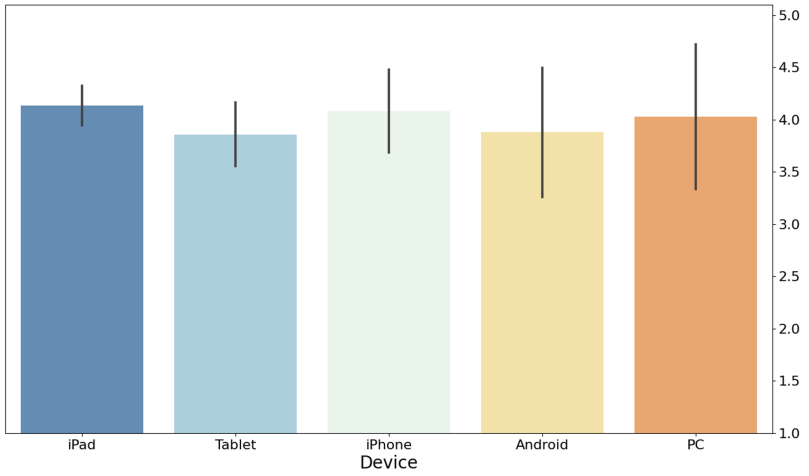
Watcher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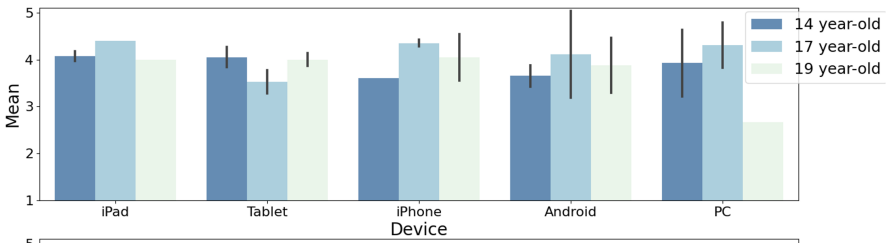
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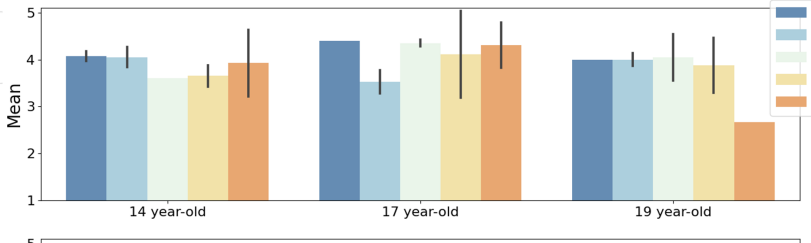
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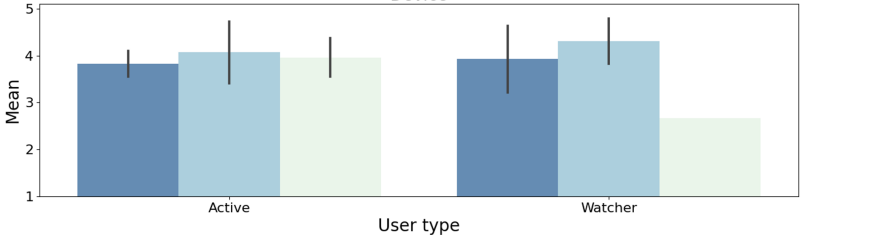
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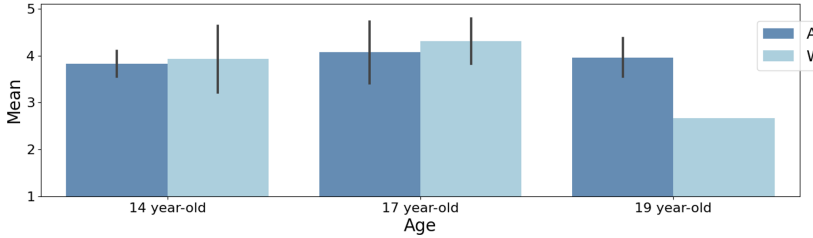
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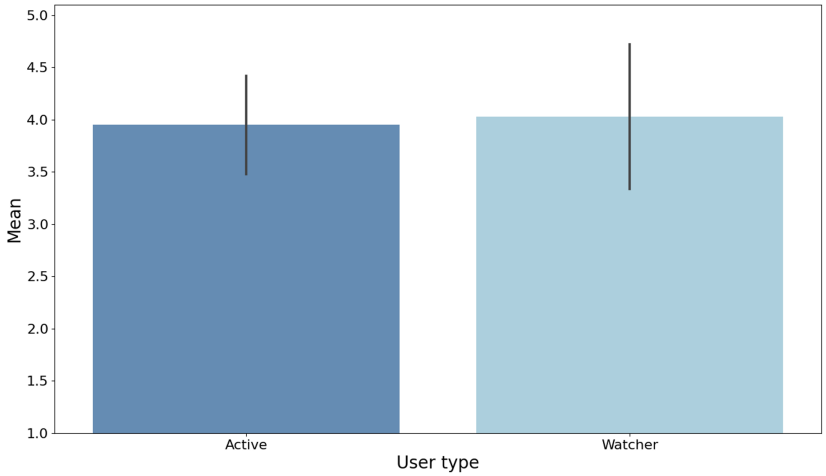
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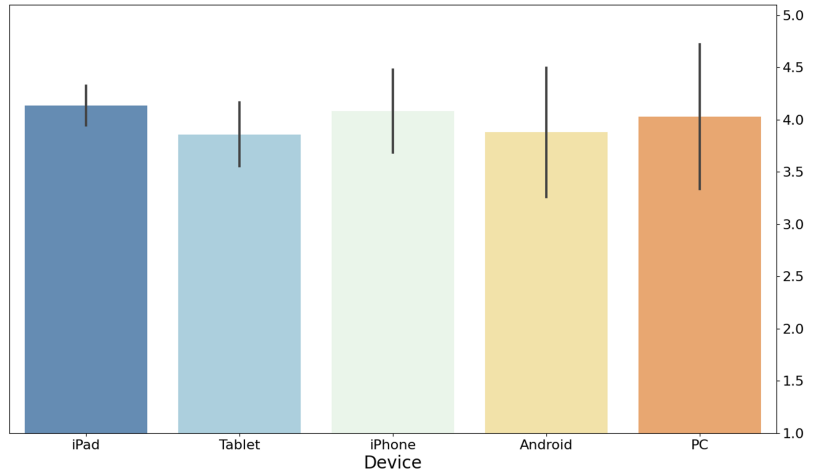
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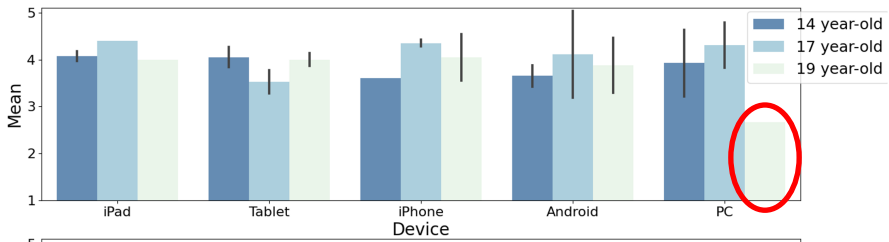
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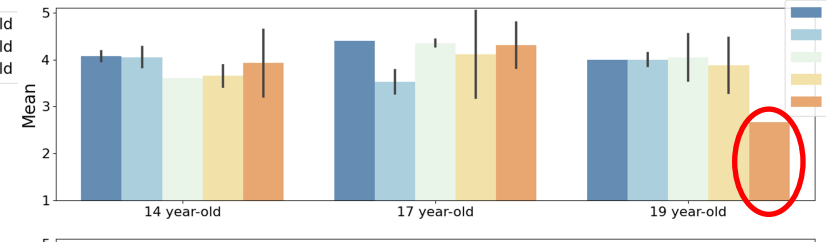
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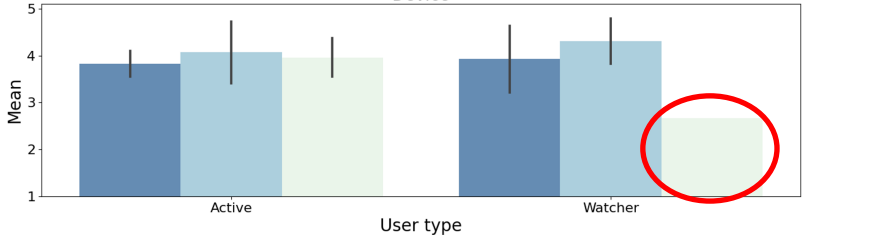
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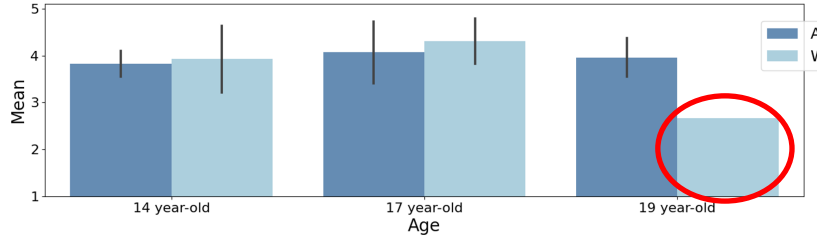
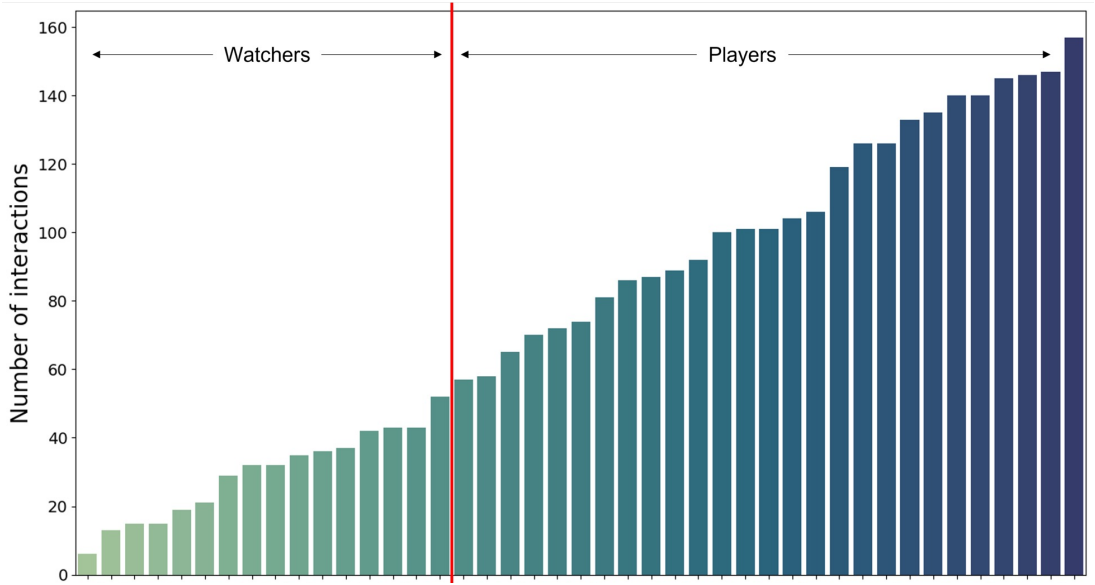

Mean
Age
Active
Watcher

ARoundTheWorld – Data analysis

- Players **interacted much more** than the watchers



ARoundTheWorld – Data analysis

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  - Number of interactions *vs.* survey average punctuation ✗
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  - Survey average punctuation *vs.* number of suggestions ✓

ARoundTheWorld – Data analysis

- Tests to detect correlations in the data and in the survey results
  - Number of interactions *vs.* survey average punctuation ✗
  - Number of interactions *vs.* quiz results ✗
  - Survey average punctuation *vs.* number of suggestions ✓
- Suggests that the **most engaged students** were the ones that gave a **higher score in the survey**

ARoundTheWorld – Teachers' interview

01 **Collaborative features** were especially appreciated

02 **Personalisation options** were also well received

03 Sceptical about the AI functionalities

04 Role of the *watchers* was **too passive**

05 Questions related to **exporting data** and **future updates**

4. CONCLUSIONS

Conclusions and future work

CONCLUSIONS

CONCLUSIONS

01

Gaps

- **Limited** number of works presenting **collaborative AR**
- **Lack of** a framework providing **multi-user, multiplatform** support

CONCLUSIONS

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02 Collaboration with teachers from Ikastolen Elkartea identified **11 requirements for AR applications** to be successfully used in education

CONCLUSIONS

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- **Limited** number of works presenting **collaborative AR**
- **Lack of** a framework providing **multi-user, multiplatform** support

02 Collaboration with teachers from Ikastolen Elkartea identified **11 requirements for AR applications** to be successfully used in education

03 Development of **cleAR, based on 6 design objectives:**

Interoperability / multi-user support / data collection / data viz / analytics / ease of development

CONCLUSIONS

01 Gaps — **Limited** number of works presenting **collaborative AR**; **Lack of** a framework providing **multi-user, multiplatform** support

02 Collaboration with teachers from Ikastolen Elkartea identified **11 requirements for AR applications** to be successfully used in education

03 Development of **cleAR, based on 6 design objectives:**

Interoperability / multi-user support / data collection / data viz / analytics / ease of development

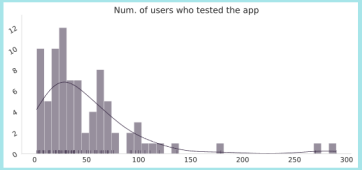
04 **Validated** by testing *ARoundTheWorld* with **44 students** from **3 educational centers**

Post-study interviews and analysis of surveys demonstrate compliance with teacher requirements

PUBLICATIONS

C1

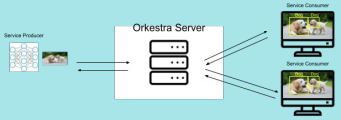
In-depth analysis of the state-of-the-art



- State of research on AR applied to education
- Motivation for using AR
- Effects of AR on motivation and retention

C2

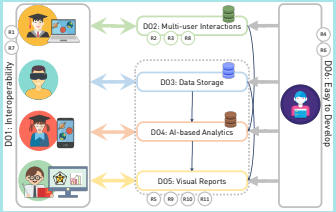
Orkestra: library for multi-user interactions



- Low-latency
- Media synchronization
- Multiplatform

C3

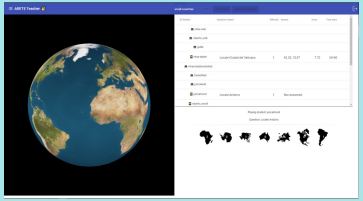
cleAR: modular architecture for AR solutions



- Satisfies teacher requirements
- Simplifies creation of collaborative applications

C4

ARoundTheWorld: implementation of an AR app based on cleAR



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- Validates cleAR design objectives

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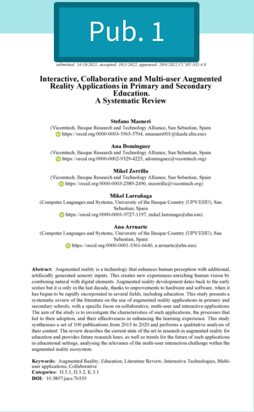

Pub. 1

submitted: 14/10/2021, accepted: 30/3/2022, appeared: 28/6/2022 CC BY-ND 4.0

Interactive, Collaborative and Multi-user Augmented Reality Applications in Primary and Secondary Education. A Systematic Review

Stefano Masneri
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https://orcid.org/0000-0003-1965-5704, smasneri001@ikasle.ehu.eus)

Ana Domínguez
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Abstract: Augmented reality is a technology that enhances human perception with additional, artificially generated sensory inputs. This creates new experiences enriching human vision by combining natural with digital elements. Augmented reality development dates back to the early sixties but it is only in the last decade, thanks to improvements to hardware and software, when it has begun to be rapidly incorporated in several fields, including education. This study presents a systematic review of the literature on the use of augmented reality applications in primary and secondary schools, with a specific focus on collaborative, multi-user and interactive applications. The aim of the study is to investigate the characteristics of such applications, the processes that led to their adoption, and their effectiveness in enhancing the learning experience. This study synthesises a set of 100 publications from 2015 to 2020 and performs a qualitative analysis of their content. The review describes the current state of the art in research in augmented reality for education and provides future research lines, as well as trends for the future of such applications in educational settings, analysing the relevance of the multi-user interaction challenge within the augmented reality ecosystem.

Keywords: Augmented Reality, Education, Literature Review, Interactive Technologies, Multi-user applications, Collaborative
Categories: H.5.1, H.5.2, K.3.1
DOI: 10.3897/jucs.76535

C2

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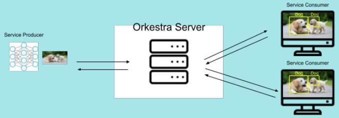

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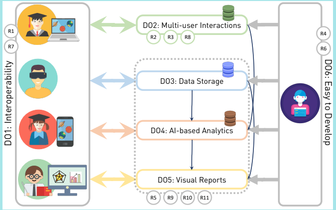

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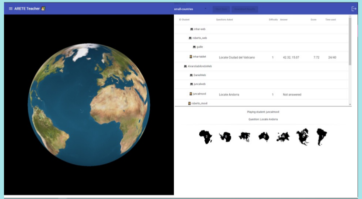

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Journal of Universal Computer Science, vol. 28, no. 6 (2022), 564-590
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C3

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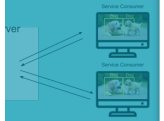

ronization
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C4

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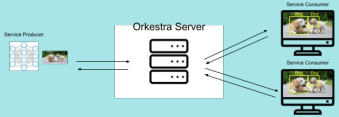

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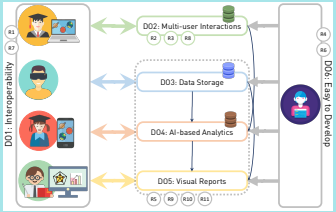

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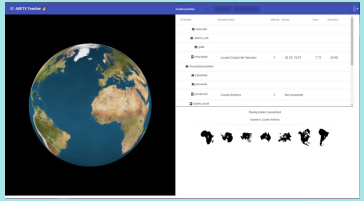

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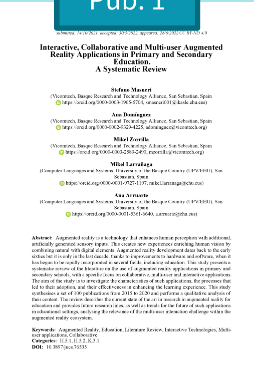

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DOI: 10.3897/jucs.76535

C2

Orkestra: library for multi-user interactions

Pub. 2

Collaborative Multi-user Augmented Reality Solutions in the Classroom

Stefano Masneri[1,2], Ana Domínguez[1] Miguel Sanz[1], Iñigo Tamayo[1], Mikel Zorrilla[1], Mikel Larrañaga[2], and Ana Arruarte[2]

[1] Vicomtech Foundation, Basque Research and Technology Alliance (BRTA), San Sebastián, Spain
smasneri@vicomtech.org
[2] University of the Basque Country (UPV/EHU), San Sebastián, Spain

Abstract. Several educational institutions routinely recommend and use Augmented Reality in learning and teaching, for its potential benefits regarding an increase in the students' motivation and attention as well as their knowledge retention. Most of the time, though, augmented reality applications consist of rather static, single-user experiences which do not fuel collaborative learning. In this paper, we present a novel augmented reality platform whose aim is to facilitate collaboration and interaction between teachers and students by adding synchronisation and multi-user capabilities. We present a case study demonstrating the capabilities of this platform for student-teacher and student-student collaboration.

Keywords: augmented reality, collaborative learning, multi-user applications

1 Introduction

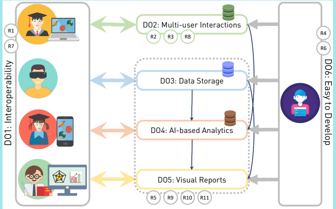
Augmented Reality (AR) is a technology which overlays virtual objects (also called 'augmentations', see [1]) onto the real world, and the virtual objects co-exist in the same space as objects in the real world [2]. Despite AR first being introduced in the early nineties as a performance aid for manufacturing airplanes [3], and with precursors dating back several more decades, it is only in recent years that AR applications are more broadly adopted by both industry and academia. This is due to the availability of libraries supporting AR development and the decreasing costs of the required hardware. Especially in education, high-end equipment such as head-mounted displays (HMD) are still to be missed largely, while tablets and smartphones allow to routinely use AR technology in the classroom, accessible by a broader audience.

In the context of Technology Enhanced Learning (TEL), AR provides a multi-modal learning environment, capable of improving users' experiences and increasing the students' motivation [4]. The most relevant advantages of successfully using AR-based applications in the classroom in comparison with traditional learning are [5]:

– Decrease of students' cognitive load

C3

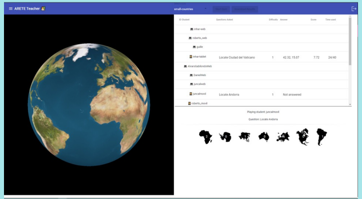
cleAR: modular architecture for AR solutions



- Satisfies teacher requirements
- Simplifies creation of collaborative applications

C4

ARoundTheWorld: implementation of an AR app based on cleAR



- Tested in 3 educational institutions
- Validates cleAR design objectives

Collaborative Multi-user Augmented Reality Solutions in the Classroom

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Abstract. Several educational institutions routinely recommend and use Augmented Reality in learning and teaching, for its potential benefits regarding an increase in the students' motivation and attention as well as their knowledge retention. Most of the time, though, augmented reality applications consist of rather static, single-user experiences which do not fuel collaborative learning. In this paper, we present a novel augmented reality platform whose aim is to facilitate collaboration and interaction between teachers and students by adding synchronisation and multi-user capabilities. We present a case study demonstrating the capabilities of this platform for student-teacher and student-student collaboration.

Keywords: augmented reality, collaborative learning, multi-user applications

1 Introduction

Augmented Reality (AR) is a technology which overlays virtual objects (also called 'augmentations', see [1]) onto the real world, and the virtual objects coexist in the same space as objects in the real world [2]. Despite AR first being introduced in the early nineties as a performance aid for manufacturing airplanes [3], and with precursors dating back several more decades, it is only in recent years that AR applications are more broadly adopted by both industry and academia. This is due to the availability of libraries supporting AR development and the decreasing costs of the required hardware. Especially in education, high-end equipment such as head-mounted displays (HMD) are still to be missed largely, while tablets and smartphones allow to routinely use AR technology in the classroom, accessible by a broader audience.

In the context of Technology Enhanced Learning (TEL), AR provides a multi-modal learning environment, capable of improving users' experiences and increasing the students' motivation [4]. The most relevant advantages of successfully using AR-based applications in the classroom in comparison with traditional learning are [5]:

– Decrease of students' cognitive load

Masneri, S., Domínguez, A., Sanz, M., Tamayo, I., Zorrilla, M., Larrañaga, M., & Arruarte, A. (2022). **Collaborative Multi-user Augmented Reality Solutions in the Classroom**. *In: Auer, M.E., Hortsch, H., Michler, O., Köhler, T. (eds) Mobility for Smart Cities and Regional Development - Challenges for Higher Education. ICL 2021. Lecture Notes in Networks and Systems, vol 390. Springer, Cham. https://doi.org/10.1007/978-3-030-93907-6_106*

- Simplifies creation of collaborative applications
- Validates cleAR design objectives

PUBLICATIONS

C1

In-depth analysis of the state-of-the-art

Pub. 1

submitted: 14/10/2021, accepted: 30/3/2022, appeared: 28/6/2022 CC BY-ND 4.0

Interactive, Collaborative and Multi-user Augmented Reality Applications in Primary and Secondary Education. A Systematic Review

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Abstract: Augmented reality is a technology that enhances human perception with additional, artificially generated sensory inputs. This creates new experiences enriching human vision by combining natural with digital elements. Augmented reality development dates back to the early sixties but it is only in the last decade, thanks to improvements to hardware and software, when it has begun to be rapidly incorporated in several fields, including education. This study presents a systematic review of the literature on the use of augmented reality applications in primary and secondary schools, with a specific focus on collaborative, multi-user and interactive applications. The aim of the study is to investigate the characteristics of such applications, the processes that led to their adoption, and their effectiveness in enhancing the learning experience. This study synthesises a set of 100 publications from 2015 to 2020 and performs a qualitative analysis of their content. The review describes the current state of the art in research in augmented reality for education and provides future research lines, as well as trends for the future of such applications in educational settings, analysing the relevance of the multi-user interaction challenge within the augmented reality ecosystem.

Keywords: Augmented Reality, Education, Literature Review, Interactive Technologies, Multi-user applications, Collaborative
Categories: H.5.1, H.5.2, K.3.1
DOI: 10.3897/jucs.76535

C2

Orkestra: library for multi-user interactions

Pub. 2

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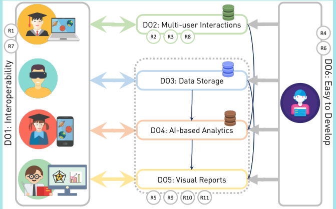
C3

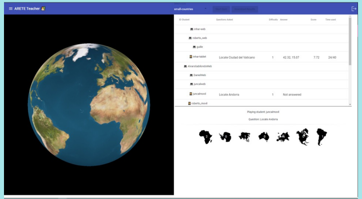
cleAR: modular architecture for AR solutions



- Satisfies teacher requirements
- Simplifies creation of collaborative applications

C4

ARoundTheWorld: implementation of an AR app based on cleAR



- Tested in 3 educational institutions
- Validates cleAR design objectives

PUBLICATIONS

C1

In-depth analysis of the state-of-the-art

Pub. 1

Interactive, Collaborative and Multi-user Augmented Reality Applications in Primary and Secondary Education. A Systematic Review

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C2

Orkestra: library for multi-user interactions

Pub. 2

Collaborative Multi-user Augmented Reality Solutions in the Classroom

C3

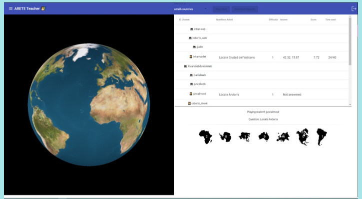
cleAR: modular architecture for AR solutions

Pub. 3

cleAR: an interoperable architecture for multi-user AR-based school curricula

C4

ARoundTheWorld: implementation of an AR app based on cleAR



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Virtual Reality (2023) 27:1813–1825
https://doi.org/10.1007/s10055-023-00764-5

ORIGINAL ARTICLE

cleAR: an interoperable architecture for multi-user AR-based school curricula

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Abstract
Although there are some experiences that demonstrate the validity of the use of augmented reality in schools to help students understand and retain complex concepts, augmented reality has not been widely adopted in the education sector yet. This is in part because it is hard to use augmented reality applications in collaborative learning scenarios and to integrate them in the existing school curricula. In this work, we present an interoperable architecture that simplifies the creation of augmented reality applications, enables multi-user student collaboration and provides advanced mechanisms for data analysis and visualization. A review of the literature together with a survey answered by 47 primary and secondary school teachers allowed us to identify the design objectives of cleAR, an architecture for augmented reality-based collaborative educational applications. cleAR has been validated through the development of three proofs of concept. cleAR provides a more mature technological ecosystem that will foster the emergence of augmented reality applications for education and their inclusion in existing school programs.

Keywords Augmented reality · Multi-user interactions · Collaborative learning · Visual learning analytics · Artificial intelligence

1 Introduction

The usage of technology in the last decade has transformed the education sector, empowering teachers and students by creating more engaging environments, facilitating collaboration and enabling different learning styles. During the COVID-19 pandemic and its associated lockdowns, most teaching activities have moved online and all stakeholders relied on different technologies to keep school activities ongoing (Azorín 2020).

In recent years, augmented reality (AR) technology is being used more and more, thanks to an ever-increasing number of devices supporting it, as well as a more mature software ecosystem that allows developers to speedup the creation of AR-based applications. With their ability to attach virtual content to any physical surface, either through the usage of markers or by using plane detection or geographical information, AR applications have found a valuable role in training and education. Several companies offer educational AR apps and many scientific publications have shown that AR can enhance and improve the learning experience (Akçayır and Akçayır 2017).

Unfortunately though, AR has not yet seen widespread usage in education, and most of the experiences carried out so far are based on small experiments. This is due to several causes (presented in Sect. 3.2) which can be summarized with the difficulty for developers and educators to create content that can be used by every student and that integrates well with the existing school curricula. One of the

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C3

cleAR: modular

C4

ARoundTheWorld:

Masneri, S., Domínguez, A. , Sanz, M. , Zorrilla, M., Larrañaga, M., & Arruarte, A. (2023). **cleAR: an interoperable architecture for multi-user AR-based school curricula.** *Virtual Reality 27, 1813–1825 (2023). https://doi.org/10.1007/s10055-023-00764-5*

- Tested in 3 educational institutions
- Validates cleAR design objectives

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C4

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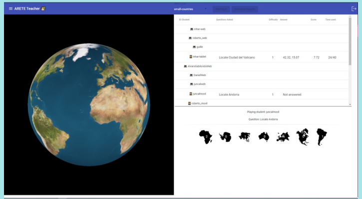

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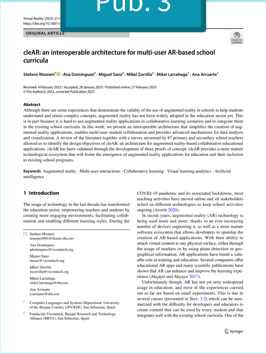
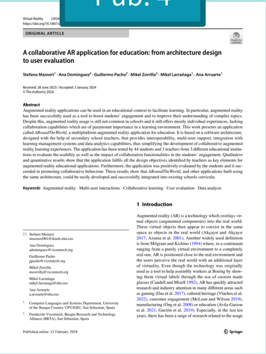


cleAR: an interoperable architecture for multi-user AR-based school curricula

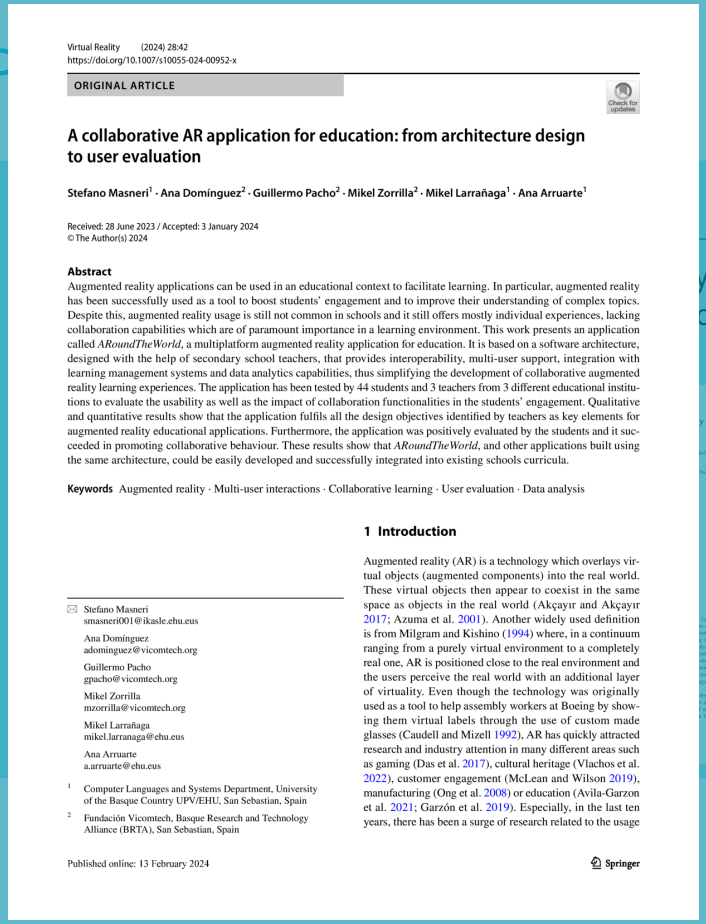
C4

ARoundTheWorld: implementation of an AR app based on cleAR

Pub. 4



A collaborative AR application for education: from architecture design to user evaluation



Virtual Reality (2024) 28:42
https://doi.org/10.1007/s10055-024-00952-x

ORIGINAL ARTICLE

A collaborative AR application for education: from architecture design to user evaluation

Stefano Masneri[1] · Ana Domínguez[2] · Guillermo Pacho[2] · Mikel Zorrilla[2] · Mikel Larrañaga[1] · Ana Arruarte[1]

Received: 28 June 2023 / Accepted: 3 January 2024

Abstract
Augmented reality applications can be used in an educational context to facilitate learning. In particular, augmented reality has been successfully used as a tool to boost students' engagement and to improve their understanding of complex topics. Despite this, augmented reality usage is still not common in schools and it still offers mostly individual experiences, lacking collaboration capabilities which are of paramount importance in a learning environment. This work presents an application called *ARoundTheWorld*, a multiplatform augmented reality application for education. It is based on a software architecture, designed with the help of secondary school teachers, that provides interoperability, multi-user support, integration with learning management systems and data analytics capabilities, thus simplifying the development of collaborative augmented reality learning experiences. The application has been tested by 44 students and 3 teachers from 3 different educational institutions to evaluate the usability as well as the impact of collaboration functionalities in the students' engagement. Qualitative and quantitative results show that the application fulfils all the design objectives identified by teachers as key elements for augmented reality educational applications. Furthermore, the application was positively evaluated by the students and it succeeded in promoting collaborative behaviour. These results show that *ARoundTheWorld*, and other applications built using the same architecture, could be easily developed and successfully integrated into existing schools curricula.

Keywords Augmented reality · Multi-user interactions · Collaborative learning · User evaluation · Data analysis

1 Introduction

Augmented reality (AR) is a technology which overlays virtual objects (augmented components) into the real world. These virtual objects then appear to coexist in the same space as objects in the real world (Akçayır and Akçayır 2017; Azuma et al. 2001). Another widely used definition is from Milgram and Kishino (1994) where, in a continuum ranging from a purely virtual environment to a completely real one, AR is positioned close to the real environment and the users perceive the real world with an additional layer of virtuality. Even though the technology was originally used as a tool to help assembly workers at Boeing by showing them virtual labels through the use of custom made glasses (Caudell and Mizell 1992), AR has quickly attracted research and industry attention in many different areas such as gaming (Das et al. 2017), cultural heritage (Vlachos et al. 2022), customer engagement (McLean and Wilson 2019), manufacturing (Ong et al. 2008) or education (Avila-Garzon et al. 2021; Garzón et al. 2019). Especially, in the last ten years, there has been a surge of research related to the usage

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Published online: 13 February 2024

C3

cleAR: modular

C4

ARoundTheWorld:

Masneri, S., Domínguez, A., Pacho, G., Zorrilla, M., Larrañaga, M., Arruarte, A. **A collaborative AR application for education: from architecture design to user evaluation**. *Virtual Reality* ***28***, *42 (2024). https://doi.org/10.1007/s10055-024-00952-x*

PUBLICATIONS

INTRODUCTION
Motivation
Objectives
Methodology
Contributions

STATE OF THE ART
Overview
Methodology
Results
Discussion

RESEARCH RESULTS
Interoperable architecture for collaborative AR in education
Validation of the proposed architecture

CONCLUSIONS
Conclusions
Publications
Future work

C1

In-depth analysis of the state-of-the-art

Pub. 1

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cleAR: an interoperable architecture for multi-user AR-based school curricula

C4

ARoundTheWorld: implementation of an AR app based on cleAR

Pub. 4

A collaborative AR application for education: from architecture design to user evaluation

PUBLICATIONS

Publications related to ARETE project

PUBLICATIONS

Publications related to ARETE project

Pub. 5

Work-in-progress—ARETE - An Interactive Educational System using Augmented Reality

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***Abstract*—ARETE (Augmented Reality Interactive Educational System) is a European project, which aims to develop an interactive toolkit for Augmented Reality (AR) content. In this work in progress paper, we describe the system which is currently being developed. The ARETE system follows human-centered interaction design practices and has a strong focus in interactive, multi-user and multi-lingual technologies. On completion, the system will be evaluated across three pilot studies. The three pilots will involve more than 3000 students across ten European countries and they will assess the impact of usage of the ARETE system and the educational value of AR for English literacy skills, STEM (Science, Technology, Engineering and Math) skills and in the implementation of Positive Behaviour Support in Schools (PBIS). ARETE will also be involved in the implementation of new standards for the creation of cross platform content and services as well as the creation of learning experience data repositories.**

***Index Terms*—augmented reality, digital education, interactive systems, standardization**

I. Introduction

Augmented Reality (AR) refers to the real-time digital overlay of information over physical elements [1]. Research on AR related technology as well as its industrial applications are flourishing all over the world and especially across Europe, in various domains. These application areas range from healthcare to biomedical, from agriculture to transportation, from training and education to gaming and entertainment purposes. AR has been described as a single-user tool with provision for collaborative spaces [2]. The ARETE project [3] aims to build a collaborative AR ecosystem with multi-user interaction to add value to education.

With the ongoing spread of Covid19 pandemic [4] affecting working and learning models around the globe, the importance and need of digital education becomes more relevant than it was ever before. By targeting high technology readiness level, ARETE will strengthen the European canvas of research, industrial capacities and market acceptance for positioning it as a leader across the globe.

The ARETE project aims to develop, integrate and disseminate interactive technologies via AR methods and tools. The creation of new technologies and the inter-connection of existing digital systems will build a pan-European sustainable competitive ecosystem. Thus, the ARETE ecosystem will support fast dissemination of augmented learning content to a wide audience, while strengthening the research and industrial capacities in Europe to develop future interactive devices for education, taking into account accessibility to a broader community.

In this paper we present the work under progress since the start of the ARETE project in November 2019 as well its impact that is envisioned for the betterment of society, economy and communities from research and industry.

II. Project Objectives

The overall scope of the ARETE project is defined around four main objectives as listed below:

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6th International Conference of the Immersive Learning Research Network (iLRN 2020)
Online, June 21-25, 2020.

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PUBLICATIONS

Publications related to ARETE project

Pub. 5

Work-in-progress—ARETE - An Interactive Educational System using Augmented Reality

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***Abstract*—ARETE (Augmented Reality Interactive Educational System) is a European project, which aims to develop an interactive toolkit for Augmented Reality (AR) content. In this work in progress paper, we describe the system which is currently being developed. The ARETE system follows human-centered interaction design practices and has a strong focus in interactive, multi-user and multi-lingual technologies. On completion, the system will be evaluated across three pilot studies. The three pilots will involve more than 3000 students across ten European countries and they will assess the impact of usage of the ARETE system and the educational value of AR for English literacy skills, STEM (Science, Technology, Engineering and Math) skills and in the implementation of Positive Behaviour Support in Schools (PBIS). ARETE will also be involved in the implementation of new standards for the creation of cross platform content and services as well as the creation of learning experience data repositories.**

***Index Terms*—augmented reality, digital education, interactive systems, standardization**

I. INTRODUCTION

Augmented Reality (AR) refers to the real-time digital overlay of information over physical elements [1]. Research on AR related technology as well as its industrial applications are flourishing all over the world and especially across Europe, in various domains. These application areas range from healthcare to biomedical, from agriculture to transportation, from training and education to gaming and entertainment purposes. AR has been described as a single-user tool with provision for collaborative spaces [2]. The ARETE project [3] aims to build a collaborative AR ecosystem with multi-user interaction to add value to education.

With the ongoing spread of Covid19 pandemic [4] affecting working and learning models around the globe, the importance and need of digital education becomes more relevant than it was ever before. By targeting high technology readiness level, ARETE will strengthen the European canvas of research, industrial capacities and market acceptance for positioning it as a leader across the globe.

The ARETE project aims to develop, integrate and disseminate interactive technologies via AR methods and tools. The creation of new technologies and the inter-connection of existing digital systems will build a pan-European sustainable competitive ecosystem. Thus, the ARETE ecosystem will support fast dissemination of augmented learning content to a wide audience, while strengthening the research and industrial capacities in Europe to develop future interactive devices for education, taking into account accessibility to a broader community.

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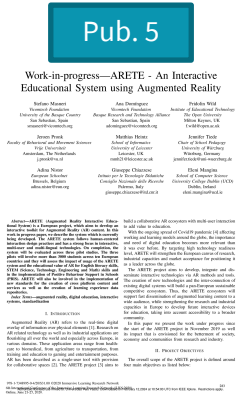

Work-in-progress—ARETE - An Interactive Educational System using Augmented Reality

Stefano Masneri, Ana Domínguez, Frédéric Wild, Jeroen Pronk, Mathias Heinz, Jennifer Tiefe, Adina Nonne, Giuseppe Chiazzese, Eleni Mangina

Pub. 6

Collaborative Augmented Reality Tools for Behavioral Lessons

Ana Domínguez, Álvaro Calvero, Bruno Simões, Giuseppe Chiazzese, Mariella Farella, Mario Arrigo, Luciana Seta, Antonella Chifari, Crispino Tosto, Sui Lin Goei, Eleni Mangina, and Stefano Masneri

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Ana Domínguez[1(✉)], Álvaro Cabrero[1], Bruno Simões[1], Giuseppe Chiazzese[2], Mariella Farella[2], Marco Arrigo[2], Luciano Seta[2], Antonella Chifari[2], Crispino Tosto[2], Sui Lin Goei[3], Eleni Mangina[4], and Stefano Masneri[5]

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Abstract. Multi-user Augmented Reality experiences have proven useful in increasing user engagement and facilitating the learning of new concepts. Thanks to the new generation of Augmented Reality frameworks for smartphones and tablets, their daily use in the classroom is becoming more common. In this paper, we present the work done towards the implementation of classroom-based behavioural lessons based on collaborative Augmented Reality environments. We have developed a library that enables multi-user Augmented Reality applications and have used it to implement some scenarios developed in the context Positive Behaviour Intervention and Support framework.

Keywords: Augmented Reality · Collaborative learning · Multi-user applications · Education · Behavioural lessons · PBIS

1 Introduction

Augmented Reality (AR) experiences are thriving and becoming increasingly important in the educational landscape to increase student motivation, engagement and knowledge retention. In fact, AR can be a breakthrough in education by transforming the entire learning experience. AR makes it possible to visualise computer-generated objects on a device while viewing the real world with a camera in real time. This allows students to learn in an immersive environment where 3D augmentations and rich visual animations complement textbooks with interactive content. AR makes learning more engaging and effortless by simplifying concepts. All this makes students' attitudes more positive and increases their willingness to collaborate with other students and the teacher.

Given the above benefits and its increasing popularity, AR has become an active research topic. However, the possibilities for interaction and collaboration

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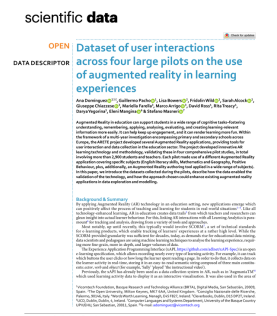

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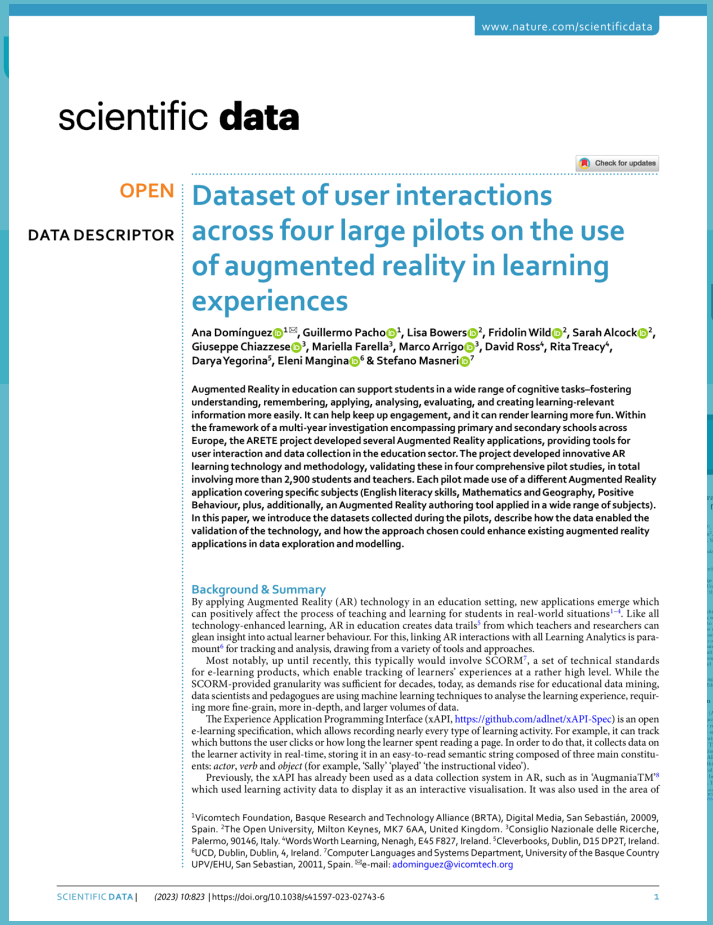
DATA DESCRIPTOR

Dataset of user interactions across four large pilots on the use of augmented reality in learning experiences



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Dataset of user interactions across four large pilots on the use of augmented reality in learning experiences

Ana Domínguez[1✉], Guillermo Pacho[1], Lisa Bowers[2], Fridolin Wild[2], Sarah Alcock[2], Giuseppe Chiazzese[3], Mariella Farella[3], Marco Arrigo[3], David Ross[4], Rita Treacy[4], Darya Yegorina[5], Eleni Mangina[6] & Stefano Masneri[7]

Augmented Reality in education can support students in a wide range of cognitive tasks–fostering understanding, remembering, applying, analysing, evaluating, and creating learning-relevant information more easily. It can help keep up engagement, and it can render learning more fun. Within the framework of a multi-year investigation encompassing primary and secondary schools across Europe, the ARETE project developed several Augmented Reality applications, providing tools for user interaction and data collection in the education sector. The project developed innovative AR learning technology and methodology, validating these in four comprehensive pilot studies, in total involving more than 2,900 students and teachers. Each pilot made use of a different Augmented Reality application covering specific subjects (English literacy skills, Mathematics and Geography, Positive Behaviour, plus, additionally, an Augmented Reality authoring tool applied in a wide range of subjects). In this paper, we introduce the datasets collected during the pilots, describe how the data enabled the validation of the technology, and how the approach chosen could enhance existing augmented reality applications in data exploration and modelling.

Background & Summary

By applying Augmented Reality (AR) technology in an education setting, new applications emerge which can positively affect the process of teaching and learning for students in real-world situations[1–4]. Like all technology-enhanced learning, AR in education creates data trails[5] from which teachers and researchers can glean insight into actual learner behaviour. For this, linking AR interactions with all Learning Analytics is paramount[6] for tracking and analysis, drawing from a variety of tools and approaches.

Most notably, up until recently, this typically would involve SCORM[7], a set of technical standards for *e*-learning products, which enable tracking of learners' experiences at a rather high level. While the SCORM-provided granularity was sufficient for decades, today, as demands rise for educational data mining, data scientists and pedagogues are using machine learning techniques to analyse the learning experience, requiring more fine-grain, more in-depth, and larger volumes of data.

The Experience Application Programming Interface (xAPI, https://github.com/adlnet/xAPI-Spec) is an open e-learning specification, which allows recording nearly every type of learning activity. For example, it can track which buttons the user clicks or how long the learner spent reading a page. In order to do that, it collects data on the learner activity in real-time, storing it in an easy-to-read semantic string composed of three main constituents: *actor*, *verb* and *object* (for example, 'Sally' 'played' 'the instructional video').

Previously, the xAPI has already been used as a data collection system in AR, such as in 'AugmaniaTM'[8] which used learning activity data to display it as an interactive visualisation. It was also used in the area of

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CODE PUBLICATION

01 SLR data analysis: https://github.com/Stocastico/AR_SLR_Paper

02 Orkestra
- Client: https://github.com/tv-vicomtech/orkestraClient
- Server: https://github.com/tv-vicomtech/orkestraServer
- Unity: https://github.com/tv-vicomtech/orkestraLibUnity

03 cleAR
- Definition & PoC: https://github.com/Stocastico/ARchitecture_paper
- xAPI: https://github.com/Stocastico/xapi_analysis

04 Validation
- ARoundTheWorld: https://github.com/tv-vicomtech/ARoundtheworld
- Data analysis: https://github.com/Stocastico/Evaluation_paper

FUTURE WORK

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Simplify and speed-up the development work

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Integration of **more advanced AI tools** in *cleAR*

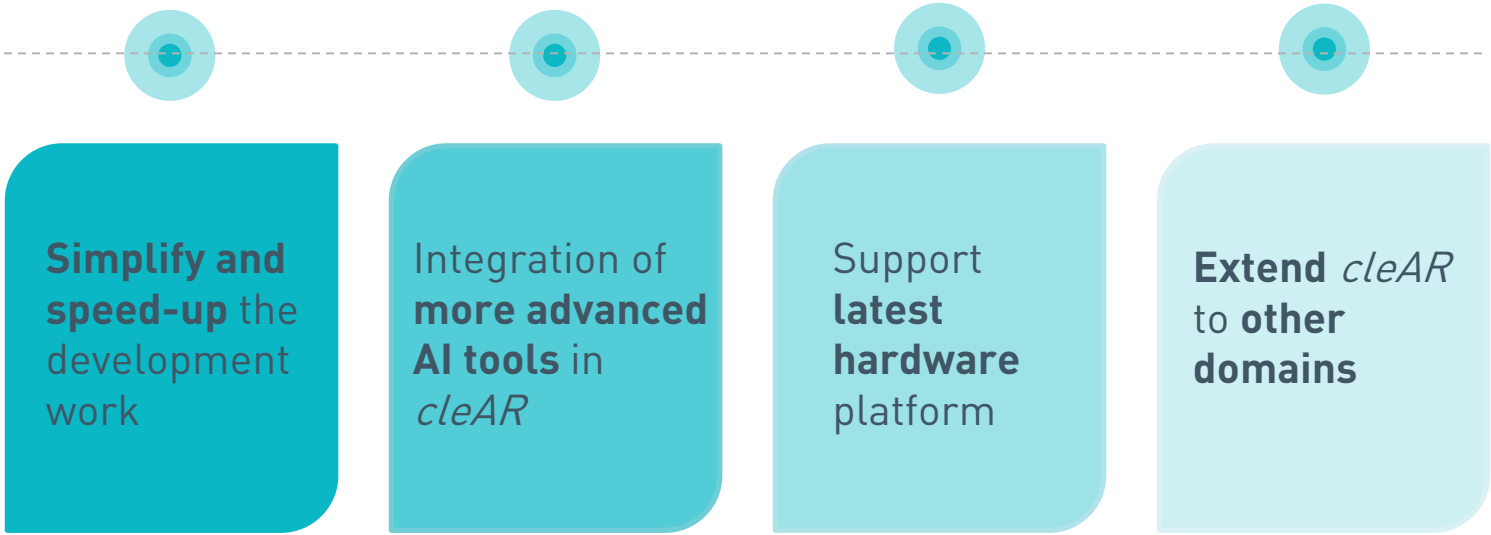
FUTURE WORK

Simplify and speed-up the development work

Integration of **more advanced AI tools** in *cleAR*

Support **latest hardware** platform

FUTURE WORK



A Novel Architecture for Collaborative Augmented Reality Experiences for Education

By Stefano Masneri
Supervised by Dr. Ana Arruarte Lasa and Dr. Mikel Zorrilla Berasategi

Donostia – San Sebastián
Friday, 8 March 2024

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Universidad del País Vasco
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